Original Article

A new approach for estimating stock status from length frequency data

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This study presents a new method (LBB) for the analysis of length frequency data from commercial catches. LBB works for species that grow throughout their lives, such as most commercially-important fish and invertebrates, and requires no input in addition to length frequency data. It estimates asymptotic length, length at first capture, relative natural mortality, and relative fishing mortality. Standard fisheries equations can then be used to approximate current exploited biomass relative to unexploited biomass. In addition, these parameters allow the estimation of length at first capture that would maximize catch and biomass for a given fishing effort, and estimation of a proxy for the relative biomass capable of producing maximum sustainable yields. Relative biomass estimates of LBB were not significantly different from the "true" values in simulated data and were similar to independent estimates from full stock assessments. LBB also presents a new indicator for assessing whether an observed size structure is indicative of a healthy stock. LBB results will obviously be misleading if the length frequency data do not represent the size composition of the exploited size range of the stock or if length frequencies resulting from the interplay of growth and mortality are masked by strong recruitment pulses.

Keywords: biomass depletion, data-poor stocks, healthy size structure, length frequency analysis, M/K, MSFD, proxies for MSY.
Introduction
National and regional fisheries regulations have changed in recent years to require science-based management of not only the most valuable, but of all exploited fish stocks (MSA, 2007; CFP, 2013). This has renewed interest in simple stock-reduction analysis (SRA, Kimura and Tagart, 1982) that uses available catch trends and life history data to provide estimates of exploitation and sustainable catch limits (e.g. Dick and MacCall, 2011; Costello et al., 2012; Martell and Froese, 2013; Thorson et al., 2013; Thorson and Cope, 2015; Froese et al., 2016a; Free et al., 2017; Zhou et al., 2017a, b). Most of these methods require, as input, an independent estimate of biomass relative to unfished biomass in the final year and perform poorly if that estimate is wrong (Wetzel and Punt, 2011; Thorson and Cope, 2015). Using expert advice as prior for recent stock status is problematic, because it can be criticized as being subjective or a circular exercise, given the strong influence of this prior on the outcome of the analysis (see similar criticism of best-guess estimates for natural mortality and steepness in full stock assessments in Mangel et al., 2013).

The size composition of exploited populations has long been used in fisheries management to estimate stock status and exploitation (Beverton and Holt, 1957; Munro, 1982; Pauly and Morgan, 1987; Gulland and Rosenberg, 1992), relative abundance of spawners and spawning potential ratio (SPR) (Goodyear, 1993; Hordyk et al., 2015b), and more recently to determine whether size and age structure are comparable to that of a healthy stock (MSFD, 2008; Froese et al., 2015). Size composition data have also been used directly in the assessment of data-poor fisheries (e.g. Dick and MacCall, 2011; Costello et al., 2012; Martell and Froese, 2013; Thorson et al., 2013; Thorson and Cope, 2015; Froese et al., 2016c; Free et al., 2017; Zhou et al., 2017a, b), where they can provide a preliminary estimate or objective prior of current relative stock size. A recent overview of the pros and cons of length-based methods is given in Rudd and Thorson (2017).

This study presents a length-based Bayesian biomass estimation method (LBB) for the analysis of size composition, such as length frequency (LF) data from commercial catches, where all relevant parameters are estimated simultaneously with a Bayesian Monte Carlo Markov Chain (MCMC) approach. The purpose of this study is to explore the reliability of parameter estimates obtained by LBB and of derived fisheries reference points (B/B0 or B/Bref) when compared with simulated length frequencies, where the “true” parameter values are known, and with real-world length frequencies, where independent estimates of fisheries reference points were available from other assessment methods for comparison.

Material and methods
Methods
For the following conceptual development of LBB, growth in body length is assumed to follow the von Bertalanffy (1938) growth equation, in the form given by Beverton and Holt (1957), i.e.

\[ L(t) = L_{\text{inf}} \left[ 1 - e^{-K(t-t_0)} \right] \]

where \( L(t) \) is the length at time \( t \), \( L_{\text{inf}} \) is the asymptotic length, \( K \) is the rate by which \( L_{\text{inf}} \) is approached, and \( t_0 \) is the theoretical age at zero length. The growth parameters \( L_{\text{inf}} \) and \( K \) are used in several equations in this study.

To minimize the parameter requirements for LBB, the analytic framework is not based on absolute rates of growth and mortality, but rather on natural mortality rate (\( M \)) relative to somatic growth rate (\( M/K \)) and fishing mortality rate (\( F \)) relative to somatic growth rate (\( F/K \)), with the goal of estimating mean relative fishing mortality (\( F/M \)) and current biomass relative to unfished biomass (\( B/B_0 \)). In other words, in organisms that grow throughout their lives, the increase in length can be used as a proxy for elapsed time, and by using ratios instead of absolute values the units of time and biomass cancel out.

LBB first estimates the asymptotic length \( L_{\text{inf}} \), the length at first capture \( L_c \), where 50% of the individuals are retained by the gear, and mean \( M/K \) and \( F/K \) over the past years. If a good estimate of \( L_{\text{inf}} \) is available from an independent study, this value can be introduced by the user, thus decreasing uncertainty in LBB results. With these parameters, the current relative stock size in the form of biomass depletion \( B/B_0 \) can be calculated from standard fisheries equations.

The LBB analytical framework is shown in Figure 1 for a “synthetic” cohort (Thorson and Cope, 2015) under equilibrium conditions. Initial cohort numbers decline near linearly with length (upper curve in Figure 1) as a function of natural mortality and somatic growth with an \( M/K \) ratio of about 1.5, which is a typical value for adults of species that grow throughout their life, reaching maximum size at maximum age (Taylor, 1958; Jensen, 1996; Hordyk et al., 2015b; Froese et al., 2016c). The cohort is fished with a gear with length-dependent selectivity (\( S(L) \)) described by an ogive function (Sparre and Venema, 1998). Total mortality increases with the onset of fishing; therefore, the number of exploited individuals (curve descending from \( L_c \) in Figure 1) declines more steeply with length than the upper curve representing no exploitation. Vulnerability to the gear increases from 0 to 1 over a certain length range until all individuals would be retained by the gear if they encounter it (S-shaped curve in Figure 1). The actual catch (lower curve in Figure 1) is determined by the amount of fishing and is a function of fishing mortality \( F \) and natural mortality \( M \) relative to somatic growth \( K \) and of gear selectivity \( S(L) \).

The decline in numbers over length as shown in Figure 1 for a cohort can also be interpreted as a snapshot of a population consisting of several year classes, with constant recruitment and life history traits (Quinn and Deriso, 1999, pp. 10 and 382; Thorson and Cope, 2015) over the time-span about equivalent to the oldest fish in the sample minus the age at first capture. Relative catch in numbers can then be observed as LF distribution in the commercial catch. The challenge is to estimate key parameters of selectivity, growth, and mortality \( (L_c, L_{\text{inf}}, M/K, F/K) \) from the catch curve in numbers. Once these parameters are known, current stock size \( B \) relative to unexploited stock size \( B_0 \) and thus current stock status \( B/B_0 \) can be estimated from a combination of standard fisheries equations (Beverton and Holt, 1957, 1966). Also, the length \( L_{\text{c opt}} \) can be calculated, which determines the \( L_c \) value that would result in \( L_{\text{opt}} \) becoming the mean length in the catch, with the highest catch and biomass for the respective fishing mortality and a minimized impact on size structure (Froese et al., 2016c). Finally, assuming \( L_c = L_{\text{c opt}} \) and \( F/M = 1 \), a proxy for the relative biomass that
can produce maximum sustainable yield (MSY) can be calculated from the same standard fisheries equations.

If the gear operates with full selectivity (dashed section of red curve in Figure 2), the curvature of the catch in numbers-at-length curve is a function of total mortality rate ($Z = M + F$) relative to $K$, the curve is described by the equation (Quinn and Deriso, 1999, p. 369):

$$N_L = N_{L_{start}} \left( \frac{L_{inf} - L}{L_{inf} - L_{start}} \right)^{Z/K} \text{ for } L_{start} < L < L_{inf}$$

(2)

where $N_L$ is the number of survivors to length $L$, $N_{L_{start}}$ is the number at length $L_{start}$ with full selection, from which all individuals entering the gear are retained by the gear, and $Z/K$ is the ratio of the total mortality rate $Z$ to the somatic growth rate. Because

Figure 1. Conceptual framework for the analysis of length frequency data from the commercial fishery, here modelled with life history traits of Atlantic cod (*Gadus morhua*). The upper curve shows the decline in cohort numbers without fishing, with a question mark indicating that mortality and thus numbers of individuals not yet vulnerable to the gear are unknown and not relevant for the method. The curve descending from $L_x$ shows the decline with fishing, the upper humped curve shows the fish vulnerable to the gear, and the lower humped curve is the catch in numbers resulting from a given fishing effort. The vertical dashed lines indicate the length ($L_x$) where fish become vulnerable to the gear, the length ($L_c$) where 50% of the individuals are retained by the gear, the length ($L_{opt}$) where the unexploited cohort would have maximum biomass, and the asymptotic length ($L_{inf}$).

Figure 2. Schematic representation of the length frequency distribution in commercial catch, with indication of the sections that are subject to no gear selection (dotted curve), partial gear selection (solid curve), and full gear selection (dashed curve). Note the difference between the length at half of the peak of the catch curve and the slightly larger true $L_c$ used in the model.
New approach for estimating stock status from LF data

LF data do not hold any information about absolute abundance, there is no loss of information when both sides of Equation (2) are divided by their respective sums. This allows extracting the constant $N_{\text{start}}$ out of the sum in the right-side denominator. It then cancels out against $N_{\text{start}}$ in the numerator, and the remaining two parameters to be determined are $Z/K$ and $L_{\text{inf}}$.

$$
\frac{N_i}{\sum N_i} = \left( \frac{L_{\text{inf}}-L_i}{L_{\text{inf}}-L_{\text{start}}} \right)^{Z/K} \sum \left( \frac{L_{\text{inf}}-L_{i-1}}{L_{\text{inf}}-L_{\text{start}}} \right)^{Z/K}
$$

Equation (3)

Note that in the unfished state, $Z/K$ becomes $M/K$, $L_{\text{start}}$ is zero, and $N_{\text{start}}$ can be set to 1. Equation (2) then simplifies to

$$
P_{L/l_{\text{inf}}} = \left( 1 - \frac{L}{L_{\text{inf}}} \right)^{M/K} \tag{4}
$$

where $P_{L/l_{\text{inf}}}$ is the probability to survive to length $L/l_{\text{inf}}$ which is solely a function of the $M/K$ ratio. In other words, all populations with the same $M/K$ ratio, whether small or large size, short or long-lived, herbivore or carnivore, occurring in warm or cold waters, will have the same probability of reaching a given fraction of their asymptotic length, independently of the absolute values of $M$, $K$, and $L_{\text{inf}}$. The same is true for the fully exploited part of the population, where the probability of reaching a length beyond the fully selected length $L_{\text{start}}$ is a function of $Z/K$.

The catch in numbers that is subject to partial selection is, in addition to the parameters in Equation (3), a function of the selectivity of the gear (here assumed trawl-like) for the respective species, given by the ogive function in Equation (5).

$$
S_l = \frac{1}{1 + e^{-\alpha (L-L_a)}} \tag{5}
$$

where $S_l$ is the fraction of individuals that are retained by the gear at length $L$, $L_a$ is as defined above, and $\alpha$ describes the steepness of the ogive (Sparre and Venema, 1998; Quinn and Deriso, 1999).

The length corresponding to a certain probability $P$ of being retained by the gear can be obtained from Equation (6).

$$
L_P = \frac{\alpha L_a - \log\left( \frac{P}{\alpha} - 1 \right)}{\alpha} \tag{6}
$$

where $L_P$ is the length with probability $P$ of being retained by the gear and $L_a$ and $\alpha$ are as defined above. If $L_a$ and $L_a$ are known, Equation (6) allows calculation of the lengths where $L_a = 1\%$, $L_a = 50\%$, and $L_{\text{start}} = 95\%$ of the individuals are retained by the gear by setting $P$ equal to 0.01, 0.5, or 0.95, respectively.

Because the number of survivors continues to decline as the selection ogive gradually approaches its maximum, the length at the peak catch in numbers underestimates the length of full selectivity, and consequently the length at half the peak underestimates $L_a$ (see length at half of peak length of true ogive as indicated in Figure 2). Therefore, the parameters of the true selection ogive cannot be estimated correctly by fitting Equation (5) to the ascending part of the catch-in-numbers curve. Rather, Equation (3) has to be replaced by a difference equation fitted to the whole catch-in-numbers curve to estimate $L_{\text{inf}}$, $L_a$, $\alpha$, $M/K$, and $F/K$ simultaneously:

$$
N_i = N_{i-1} \left( \frac{L_{\text{inf}}-L_i}{L_{\text{inf}}-L_{i-1}} \right)^{\alpha} \quad \text{and} \quad C_i = N_i \cdot S_l
$$

where $L_i$ is the number of individuals at length $i$, $L_{i-1}$ is the number at the previous length, $C$ refers to the number of individuals vulnerable to the gear and proportionally represented in the catch, and all other parameters are as described above. By dividing both sides of the $C_i$ equation by their respective sums, the numbers are standardized and made compatible across years.

$$
\frac{C_i}{\sum C_i} = \frac{N_i \cdot S_l}{\sum N_i \cdot S_l} \tag{8}
$$

Fitting Equation (8) to LF data gives estimates of $M/K$ and $F/K$, which can be combined to give $F/M = (F/K)/(M/K)$.

Simulated data
For the purpose of verification, simulated data were created with Equation (8) so that the parameter values underlying the simulated frequencies were known and could be compared with the results of a subsequent LBB analysis. The deterministic frequency calculated for every length class was randomized by taking its value as the mean of a lognormal distribution with a coefficient of variation of 0.1 and selecting randomly a value from that distribution. Parameter values were chosen to represent lightly to heavily fished, commercially-important species ranging from shrimp, sprat, and plaice to cod and swordfish, for a total of nine hypothetical stocks. One additional cod stock simulated higher $F$ in specimens above 40-cm length and another additional cod stock simulated a recruitment pulse of 2-year-old fish where expected frequencies were doubled.

Equation (5) represents a selection ogive that is typical of trawls, purse-seines, and longlines (Sparre and Venema, 1998; Clarke et al., 2005). As proof of concept that different types of selection functions can be accommodated by LBB, a Gaussian selection which may approximate the selection of a gillnet (Sparre and Venema, 1998) was tested for three additional simulated stocks. The spreadsheet used for creating the simulated data, the corresponding input file for the R-code, and the R-code used for adding the random noise and for the analysis are included in the Supplementary Material.

Empirical data
The data required for the analysis proposed in this study are length frequencies representative of commercial catches and collected, e.g. by on-board observers or by measuring and counting all individuals of the target species at a main landing site or in a fish market (Probst et al., 2011; Pauly and Greenberg, 2013). Suitable LF samples with trawl-like selection should show an asymmetric pattern similar to Figure 2. Stocks or years which strongly deviated from the expected pattern were excluded from the analysis. For comparison with Figure 2, length frequencies for the first and last year of available data are shown for every included stock in the Supplementary Material, together with the sources for the LF data and for the independent assessments.
Length-based Bayesian estimation method

The LBB estimation was implemented within the Bayesian Gibbs sampler software JAGS (Plummer, 2003) and executed using the statistical language R (R Core Team, 2013) to fit observed proportions-at-length \( \hat{p}_{L_i} \) to their expected values \( \hat{p}_{L_i} \). Based on Equation (8), the model predicted length distribution \( \hat{p}_{L_i} \) is given by:

\[
\hat{p}_{L_i} = \frac{\hat{N}_i}{\sum \hat{N}_i} \quad (9)
\]

where \( \hat{N}_i \) is a function of the estimable population dynamic determents \( L_{\text{inf}}, M/K, \) and \( F/K \) [Equation (8)] and the selectivity parameters \( L_c \) and \( \alpha \) [Equation (5)].

The observed and predicted length distributions were then fitted by assuming Dirichlet-multinomial distribution, which was proposed for fitting size and age composition in Bayesian stock assessment models because of its property of accounting for overdispersion (i.e. additional unexplained variance) compared with the standard multinomial (Mántyniemi et al., 2015; Thorson et al., 2017a). Proportions-at-length assume Dirichlet-multinomial distribution with an effective sample size of \( n_{\text{obs}} = 1000 \), which was chosen based on desirable performance across various simulation-testing trial scenarios and on sample sizes of 800–3000 in LFs obtained from the EU Data Collection Framework.

Priors for \( L_{\text{inf}} \) and \( Z/K \) were derived by pooling available LF data across years and fitting equation 2 to the fully selected part of the catch-in-numbers curve with the nonlinear least squares estimator function \( \text{nlst}() \) in R (Bates and Debroy, 2016). The method requires start values and ranges for the parameters and these were obtained as described in Supplementary Table S2.

The following equations describe the framework of approximating the stock status from the estimated quantities \( L_{\text{inf}}, M/K, \) and \( L_c \) (Froese et al., 2016c). First, with estimates of \( L_{\text{inf}} \) and \( M/K, \) the length \( L_{\text{opt}} \) where unexploited cohort biomass is maximum is obtained from Equation (10) (Holt, 1958):

\[
L_{\text{opt}} = L_{\text{inf}} \left( \frac{3}{3 + \frac{K}{M}} \right) \quad (10)
\]

The length at first capture \( L_{c,\text{opt}} \) that maximizes catch and biomass for a given fishing pressure and leads to \( L_{\text{opt}} \) as mean length in the catch (Froese et al., 2016c) can be obtained from:

\[
L_{c,\text{opt}} = \frac{L_{\text{inf}}(2 + \frac{3}{M})}{\left(1 + \frac{3}{M}\right)(3 + \frac{K}{M})} \quad (11)
\]

\( L_{c,\text{opt}} \) is used below to calculate a proxy for the relative biomass that can produce MSY.

An index of yield-per-recruit (Beverton and Holt, 1966) can be expressed as a function of \( L_c/L_{\text{inf}}, F/K, M/K, \) and relative fishing mortality \( F/M: \)

\[
\frac{Y'}{R} = \frac{F/M}{1 + F/M} \left(1 - L_{c}/L_{\text{inf}}\right)^{M/K} \left(\frac{1 - 3\left(1 - L_{c}/L_{\text{inf}}\right)}{1 + M/K + F/K} + \frac{3\left(1 - L_{c}/L_{\text{inf}}\right)^2}{1 + M/K + F/K} \right) \quad (12)
\]

An index of catch per unit of effort (CPUE/R) is obtained by dividing Equation (12) by the fishing intensity \( F/M, \) assuming that fishing mortality \( F \) is directly proportional to fishing effort. Since CPUE is proportional to biomass in the exploited phase of the stock, Equation (13) represents relative CPUE/R as well as an index of exploited biomass per recruit \( B'/R \) (Beverton and Holt, 1966):

\[
\frac{\text{CPUE}'}{R} = \frac{\text{CPUE}}{R} = \frac{1}{1 + \frac{3}{M/K + F/K}} \left(1 - \frac{3\left(1 - L_{c}/L_{\text{inf}}\right)}{1 + M/K + F/K} + \frac{3\left(1 - L_{c}/L_{\text{inf}}\right)^2}{1 + M/K + F/K} \right) \quad (13)
\]

The relative biomass in the exploited phase of the population if no fishing takes place is given by:

\[
\frac{B'_{\text{opt}}}{R} = \frac{\text{CPUE}'}{R} \left(1 - L_{c}/L_{\text{inf}}\right)^{3/2} \quad (14)
\]

where \( B'_{\text{opt}} > L_c \) denotes the exploitable fraction (> \( L_c \)) of the unfished biomass \( B_0 \). An index of relative biomass depletion for the exploited part of the population \( B/B_0 \) is then obtained from (Beverton and Holt, 1966):

\[
\frac{B}{B_0} = \frac{\text{CPUE}'}{R} \left(1 - L_{c}/L_{\text{inf}}\right)^{3/2} \quad (15)
\]

A proxy for the relative biomass that can produce MSY \( (B_{\text{MSY}}/B_0) \) was obtained by re-running Equations (12–15) with \( F/M = 1 \) and \( L_c = L_{c,\text{opt}} \).

Pauly and Soriano (1986) and Pauly and Greenberg (2013) point out that the assumption of knife-edge selection leads to overestimation of yield per recruit when the selection ogive overlaps with most of the life span of short-lived species. They, therefore, propose using instead the alternative approach of Beverton and Holt (1966) for yield assessment when \( F \) varies to obtain unbiased estimates of yield per recruit. This approach basically consists of calculating \( Y'/R_1 \) and \( Y'/R_2 \) for the lower \( L_1 \) and upper \( L_2 \) border of a length class with the mean fishing mortality \( F/K \) applicable for that size range, obtained by multiplying the \( F/K \) of full selection with the mean selectivity for that length class. \( Y'/R_2 \) is then adjusted for the decrease in number of fish due to \( F_1/K \) as they grow from \( L_1 \) to \( L_2 \). The “reduction factor” \( r_{1,2} \) (Beverton and Holt, 1966) for this decrease is obtained from:

\[
r_{1,2} = \frac{\left(1 - \frac{L_1}{L_{c,\text{opt}}}ight)^{3/2}}{\left(1 - \frac{L_1}{L_{c,\text{opt}}}ight)^{3/2}} \quad (16)
\]

The relative yield per recruit contributed by the first length interval \( L_1 \) to \( L_2 \) is then obtained from:

\[
\frac{Y'/R_1}{Y'/R_2} = \frac{Y'/R_1 - Y'/R_2}{Y'/R_2} \quad (17)
\]

The relative yield contributed by subsequent length classes, here \( L_3 \) to \( L_4 \), is obtained from:

\[
\frac{Y'/R_3}{Y'/R_4} = \frac{Y'/R_3 (r_{1,2} r_{2,3}) - Y'/R_4 (r_{1,2} r_{2,3} r_{3,4})}{Y'/R_4} \quad (18)
\]

where the parentheses contain the product of all previous reduction factors.
For the final length class from \( L_n \) to \( L_{\text{inf}} \), relative yield is obtained from:

\[
Y' / R_{n, \text{inf}} = Y / R_{n, \text{inf}}(r_{1,2} r_{2,3} \ldots r_{n-1,n})
\]

(19)

Summing up the yield of all length classes leads to an estimate of relative yield per recruit that incorporates the effect of partial gear selection. The implementation in LBB of this procedure thus deals with the bias associated with the assumption of knife-edge selection in Equations (12–14).

Dividing yield per recruit in every length class by the respective \( F / M \) ratio (as an index of fishing effort) gives an index of cpue or abundance [same as in Equation (13)] for that length class. Summing up gives an index of cpue or abundance for the exploited length range.

Equation (14) is applied to the lower and upper bounds of each length class, and their difference is then the unexploited biomass contributed by this length class. Multiplying by selectivity and summing up gives an index of abundance in the exploited length range without fishing. Dividing exploited by unexploited abundance gives the biomass ratio \( B / B_0 \) in the exploited length range (Beverton and Holt, 1966).

Note that length classes with different \( F \) need not have the same width, i.e. subsequent length ranges with the same \( F \) can be treated as one class. This continuous estimation of relative yield and biomass per recruit can be applied for any trajectory of \( F / M \) as a function of length, such as selectivity of trawls or gillnets, or increasing trawl avoidance of fish as they get larger.

Uncertainty in the estimate of \( B / B_0 \) was assumed to be determined by the respective uncertainties in the estimates of \( F / M \), \( M / K \), \( F / K \), and \( L_{\text{inf}} \). The error propagation method for multiplication or division was applied, deriving the relative uncertainty of \( B / B_0 \) as the square root of the sum of the squared relative uncertainties in these four parameters.

Results
Simulation results
Fitting Equation (8) to simulated data for six hypothetical stocks with ogive selection and regular exploitation (\( F / M = 1–1.5 \)) gave parameter estimates that were close to the “true” values used in the simulations (Table 1). Of 36 comparisons of parameter estimates with “true” values, 25 (69%) included the “true” value within their credible intervals (~95% confidence limits) of the estimates. In the other cases, marked bold in Table 1, the central value estimated by LBB did diverge from the “true” value by 2.3–3.3% in three cases of \( L_{\text{opt}} \), 0.8–1.6% in four cases of \( L_{\text{inf}} \), 6.7–7.1% in three cases of \( \alpha \), and 16.5% in one case of \( M / K \). As for the predicted biomass ratio \( B / B_0 \) in the final year, the “true” value was within the confidence limits of the LBB estimate in all cases.

Simulations were also used for very preliminary exploration of LBB bias in cases of very light or heavy exploitation, variable \( F \), or a strong recruitment pulse. This led to more cases where the “true” values were not included in the estimated confidence limits of \( L_{\text{inf}} \), \( L_{\text{opt}} \), \( \alpha \), and \( F / K \) (see Table 1); however, “true” relative biomass was within the confidence limits of the \( B / B_0 \) estimate in all cases.

As a proof of concept, namely that LBB can also accommodate other selection functions, three stocks with simulated data for Gaussian selectivity were included. Eight (67%) of 12 parameter estimates included the “true” value within their approximate 95% confidence limits. The other cases are marked bold in Table 1. The “true” biomass ratio \( B / B_0 \) in the final year was within the predicted confidence limits in all cases.

Results based on empirical data
LBB predictions of relative biomass in the final year were evaluated against independent estimates of regular stock assessments (Supplementary Table S4). A total of 34 stocks were analysed, with a geographical range from Nova Scotia to South Africa, with a taxonomic range including cuttlefish, shrimps, anchovies, sprat, herring, flatfish, roundfish, skates, and sharks, and with a maximum length range of 7–123 cm. LBB estimates of relative fishing mortality \( F / M \) had overlapping confidence limits with and thus were similar to \( F / F_{\text{msy}} \) estimates in 16 (50%) of 32 stocks. LBB estimates of relative biomass had overlapping 95% confidence limits and thus were similar in 16 (76%) of 21 stocks with available data.

The ratios \( L_{\text{mean}} / L_{\text{opt}} \) and \( L_{\text{inf}} / L_{\text{opt}} \) were below unity (\(<0.9\)) in 20 (61%) of the 33 stocks, suggesting truncated length structure and fishing of too small individuals. The ratio of the 95th percentile length to asymptotic length \( L_{\text{inf}} / L_{\text{opt}} \) was close to unity (\(>0.9\)) in 18 (55%) of 33 stocks, suggesting that at least some large fish were still present. The proportion of mature individuals in the catch was <50% in 14 (42%) of 33 stocks, suggesting that catch in these fisheries consists mostly of juveniles.

Discussion
LBB is a new Bayesian method for the analysis of fisheries-dependent LF data, which are widely available from port sampling and fisheries observers programmes. LBB is designed to require minimum data input to approximate depletion or current exploited biomass relative to unexploited biomass (\( B / B_0 \)) as one of its key outputs. The assumptions, verification, caveats, and scope for application of LBB are discussed in the context of other existing methods in the following sections.

How realistic is the prior \( M / K \approx 1.5 \)?
The \( M / K \) ratio of 1.5 proposed as a life history invariant by Jensen (1996) and Hordyk et al. (2015b) implies that species that reach their maximum age at about 95% of \( L_{\text{inf}} \) have an adult \( M / K \) ratio of 1.5; also, Taylor (1958) suggests that the age at 95% of \( L_{\text{inf}} \) is a realistic proxy for maximum age in many commercially-important fish. These insights can be combined into the following rule of thumb: in LF distributions where only few species survive beyond age 3, 4, or 5, the maximum length range of 7–123 cm.

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In summary, theoretical considerations as well as empirical observations suggest that $M/K \approx 1.5$ is a reasonable default prior for species where maximum length and maximum age coincide. The applicability of LBB to species that continue living after having approached $L_{\text{int}}$ is discussed below.

**Verification**

To verify the ability of LBB to correctly predict the parameters of Equations (5) and (8) from suitable LF data, the method was applied to simulated data where the "true" parameter values were known. Estimates were regarded as not significantly different if the "true" parameter values fell inside their expected 95% confidence limits. Except for $L_{\text{int}}$ and $M/K$, which are the median across years, all other estimates refer to the last year of simulations.

In the scenario with fishing pressure increasing in larger fish, the $F/K$ ratios estimated by LBB fell about in the middle of the simulated range (see CodLightSim and CodVeryLightSim in Table 1). Simulations were also used for preliminary tests of extreme scenarios, such as very light (CodVeryLightSim, $F/M = 0.005$) to heavy (CodHeavySim, $F/M = 4$) exploitation, doubling of $F$ in larger size classes (CodFSSim), or a recruitment pulse doubling the expected frequencies in 2-year-old specimens (CodRecSim). As for differences between heavy and light exploitation, the uncertainty in $B/B_0$ was considerably higher in lightly or very lightly exploited stocks, but the estimated central values were nearly identical with the true values (see CodLightSim and CodVeryLightSim in Table 1).

In summary, if the assumptions of constant growth, mortality, and recruitment schedules during the period reflected by the LF selection ogive were off, but the other parameters and especially the biomass estimate were close to the "true" values.

### Table 1: Median estimated parameter values (est) with indication of the range that contains 95% of the Monte Carlo estimates in parentheses in comparison with "true" values used in the simulation of the data.

<table>
<thead>
<tr>
<th>Simulated stock</th>
<th>$L_{\text{int}}$ true</th>
<th>$L_{\text{int}}$ est</th>
<th>$L_1$ true</th>
<th>$L_1$ est</th>
<th>alpha true</th>
<th>alpha est</th>
<th>$F/K$ true</th>
<th>$F/K$ est</th>
<th>$M/K$ true</th>
<th>$M/K$ est</th>
<th>$B/B_0$ true</th>
<th>$B/B_0$ est</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regular exploitation over a wide range of life history traits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CodSim</td>
<td>120</td>
<td>122</td>
<td>35</td>
<td>34.7</td>
<td>60</td>
<td>64.0</td>
<td>1.54</td>
<td>1.60</td>
<td>1.54</td>
<td>1.58</td>
<td>0.26</td>
<td>0.25</td>
</tr>
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<td>HerringSim</td>
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<td>35.8</td>
<td>18</td>
<td>18.1</td>
<td>42</td>
<td>39.0</td>
<td>2.40</td>
<td>2.50</td>
<td>2.50</td>
<td>1.60</td>
<td>1.69</td>
<td>0.25</td>
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<tr>
<td>PlaiceSim</td>
<td>48</td>
<td>47.7</td>
<td>26</td>
<td>25.8</td>
<td>48</td>
<td>47.9</td>
<td>1.33</td>
<td>1.10</td>
<td>1.33</td>
<td>1.55</td>
<td>0.36</td>
<td>0.42</td>
</tr>
<tr>
<td>ShrimpSim</td>
<td>7.0</td>
<td>6.83</td>
<td>2.5</td>
<td>2.54</td>
<td>28</td>
<td>28.4</td>
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<td>2.20</td>
<td>1.78</td>
<td>1.57</td>
<td>0.23</td>
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<tr>
<td>SpratSim</td>
<td>15</td>
<td>15.0</td>
<td>7.0</td>
<td>6.99</td>
<td>30</td>
<td>30.7</td>
<td>1.50</td>
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<td>1.60</td>
<td>1.75</td>
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<tr>
<td>SwordSim</td>
<td>299</td>
<td>309</td>
<td>90</td>
<td>89.2</td>
<td>60</td>
<td>61.7</td>
<td>1.82</td>
<td>1.90</td>
<td>1.90</td>
<td>1.36</td>
<td>1.59</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Different exploitation, variable $F$, and recruitment pulse</strong></td>
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<td></td>
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<tr>
<td>CodLightSim</td>
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<td>121</td>
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<td>34.9</td>
<td>60</td>
<td>61.7</td>
<td>1.82</td>
<td>1.90</td>
<td>1.90</td>
<td>1.36</td>
<td>1.59</td>
<td>0.20</td>
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<tr>
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<td>5.1</td>
<td>5.1</td>
<td>1.35</td>
<td>1.59</td>
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<td>CodRecSim</td>
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<td>32.8</td>
<td>60</td>
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<tr>
<td>SeabreamGillSim</td>
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<td>8.0</td>
<td>7.88</td>
<td>2.0</td>
<td>1.95</td>
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<td>2.30</td>
<td>1.25</td>
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<td>0.37</td>
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<td>45.9</td>
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<td>10.3</td>
<td>4.62</td>
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<td>1.54</td>
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<td>0.42</td>
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<tr>
<td>CodGillVeryLightSim</td>
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<td>120</td>
<td>45</td>
<td>45.6</td>
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<td>10.2</td>
<td>0.08</td>
<td>0.85</td>
<td>0.85</td>
<td>1.51</td>
<td>0.99</td>
<td>0.84</td>
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</tbody>
</table>

Parameter estimates that do not include the "true" value within their ~95% confidence limits are marked bold and the percentage of the deviation is given under the true value. Except for $L_{\text{int}}$ and $M/K$, which are the median across years, all other estimates refer to the last year of simulations.
sample are met, LBB is capable of reliably estimating the biomass ratio \( B/B_0 \) that is compatible with the LF pattern. Because of the tendency of MCMC to underestimate uncertainty, confidence limits of other parameter estimates may not include the “true” value, but still remain close to the “true” values.

To make the case that LBB can also be used with other than trawl-like selection functions, three cases of Gaussian gillnet-like selection were included among the simulations. Sixty-seven percent of the parameter estimates and all estimates of \( B/B_0 \) included the “true” values in their \( \sim 95\% \) confidence limits, which may serve as a preliminary proof of concept.

**Evaluation**

LBB provides estimates of relative fishing mortality \( F/M \), which can be understood as a proxy for \( F/F_{\text{msy}} \) estimates such as typically present in full stock assessments (ICES, 2017a). However, LBB estimates represent the average \( F/M \) over the past years, back to when the fish now in the largest length class became vulnerable to fishing. This average \( F/M \) may be very different from \( F/F_{\text{msy}} \) in the final year. If fishing pressure has decreased in recent years, as is the case in several of the examined stocks, then average \( F/M \) will be higher than \( F/F_{\text{msy}} \) in the final year. Also, if \( F_{\text{msy}} \) is larger than \( M \), as is the case in many ICES stocks (Froese et al., 2016a; ICES, 2017b; see e.g. European plaice (Pleuronectes platessa), saithe (Pollachius virens), and common sole (Solea solea) in Supplementary Table S4), then \( F/M \) will be higher than \( F/F_{\text{msy}} \). These differences may explain that the 50% of LBB \( F/M \) estimates with non-overlapping confidence limits were higher than the independent \( F/F_{\text{msy}} \) estimates (Supplementary Table S4).

However, average \( F/M \) across all fully exploited length classes and over the past years is a required input for yield-per-recruit equations. If recruitment and somatic growth have been reasonably stable, current biomass is a function of the cumulative fishing pressures that the stock has experienced over the exploited age range. Consequently, the LBB estimates of relative biomass agreed much better with the independent assessments, with LBB estimates having overlapping 95% confidence limits and thus being similar in 16 (76%) of 21 stocks with available data. Notably, with one exception in winter skate (Leucoraja ocellata) (where \( B/B_{\text{msy}} \) estimated by LBB was 1.0 (95% CL 0.6–1.6) whereas the independent estimate was 0.35), LBB estimates of depletion were typically more precautionary than the estimates from full assessments, never proposing that a stock was well above the MSY level when instead it was well below.

Note that most independent assessments did not provide estimates of \( B/B_0 \) but rather of \( B/B_{\text{msy}} \) or \( B/B_{\text{pa}} \) where in the latter case \( B/(2 \times B_{\text{pa}}) \) was used as a proxy for \( B/B_{\text{msy}} \) (same as in ICES, 2017c). In LBB, relative biomass predicted for \( F/M, M/K = 1.5 \) and \( L_c = L_{c,\text{opt}} \) is used as a proxy for \( B_{\text{msy}}/B_0 \) with typical values near 0.4 (see Supplementary Material). Several of the assessments used instead Schaefer models with \( B_{\text{msy}}/B_0 = 0.5 \). Also, LBB estimates \( B/B_0 \) for the exploited length range, whereas some of the independent assessments used total biomass or spawning-stock...
biomass. For example, if $L_c$ is significantly larger than mean length at first maturity, the depletion of biomass in the exploited length range may be much stronger than the depletion of spawning biomass or total biomass reported in assessments. These differences may explain some of the observed discrepancies. In summary, $F/M$ estimates of LBB tended to be above independent estimates of $F/F_{msy}$ and are not recommended as reliable proxies for current fishing pressure. In contrast, LBB estimates of depletion were similar to independent estimates in about 75% of the comparisons and thus appear suitable for use as priors or as preliminary guidance in the management of data-poor stocks.

**Applicability of LBB to populations that continue living after approaching $L_{inf}$**

Tropical small reef fish typically grow rapidly towards their maximum size, which coincides with their maximum age. However, in some species, populations have been found whose adults continue to live for several decades after approaching $L_{inf}$ (e.g., Choat and Axe, 1996; Choat et al., 2003; Robertson et al., 2005; Trip et al., 2008). Close examination of these studies and the data they refer to (see the pertinent section in the Supplementary Material) suggest that extended survival without growth indeed occurs. In these populations, fast early growth is followed by extended longevity around maximum size when large individuals permanently relocate from warm shallow water to deep, colder water. But this life history strategy does not occur in all populations of the respective species, presumably because not all populations have access to suitable nearby deep, colder waters.

With regard to the applicability of LBB to such long-lived populations, this should be possible for the warm-water phase with typical growth and mortality patterns, but not for the cold-water phase with a wide span of ages clustering around $L_{inf}$ because without growth, length cannot be used as a proxy for age and, therefore, $Z/K$ does not describe length-dependent mortality. True cases of high longevity without growth should be recognizable from the LF pattern, which should show an unusual normal distribution of high frequencies around reasonable estimates of $L_{inf}$. LBB analysis should not be performed on such populations.

**Comparison of LBB with similar approaches**

A similar method to LBB is the SPR approach, which basically uses the section of the length-frequency curve above the length $L_{m50}$ where 50% of the individuals are mature, calculates the corresponding egg production by converting lengths into fecundity using a length–fecundity relationship, and then compares egg production with the one that would be present without fishing. Hordyk et al. (2015a, b; 2016) present a length-based implementation of SPR (LB-SPR) and demonstrate that, under the assumptions of knife-edge selectivity at length $L_c$ and knife-edge maturation at $L_{mp}$, SPR is determined by the ratios of $M/K$, $F/M$, $L_{mp}/L_{inf}$, and $L_c/L_{inf}$. Required input to the model is $M/K$, $L_{m50}$, $L_{mp}$, $L_{inf}$, and $CV_{Linf}$. Similar as in LBB, fishing pressure $F/M$ will be the average over the age range in the analyzed length-frequency sample (Hordyk et al., 2015a, b). In contrast to LB-SPR, LBB does not need maturation schedules or length–fecundity parameters to be known. It accounts for the problem of knife-edge assumption and estimates $M/K$, $L_{inf}$ and $CV_{Linf}$ from the available data.

In another method similar to LBB, the CC-SRA method of Thorson and Cope (2015) uses age composition data to construct catch curves and estimates mean fishing mortality for fully selected age classes as input into a modified SRA model such that prior $F/M$ replaces the need for a prior on depletion. The main difference between LBB and CC-SRA is the need for age-structured data, which are often lacking in data-poor stocks. The length-based integrated mixed effects (LIMEs) method (Rudd and Thorson 2017) was developed as a length-based extension to CC-SRA. LIME uses LF data in place of the more resource-intensive samples of age and thus is closer to the data needs of LBB, but still needs life history data such as approximations of natural mortality, growth, and maturation.

**Caveats of LBB**

Similar to other length-based methods, LBB will perform poorly if LF are not representative of the length composition of the exploited phase of the stock. This may be caused by gears that have a different selectivity or catchability than the main commercial gears (e.g., survey gears), or by length samples taken in areas where a non-representative subset of the exploited stock is present, such as in nursery or spawning areas. Also the availability of representative LF data can be an issue. Combining different LF samples poses an extra challenge, because the frequencies have to be weighted according to their contribution to the total catch and should stem from the same season for species with seasonal growth. For example, if landings and discards are sampled separately, incorrect weighting before adding up frequencies may lead to distributions with two distinct but unrealistic peaks. This may be one reason for the strong deviations between the LBB estimates and the independent assessment results for European plaice ($P. platessa$) in Supplementary Table S4.

LBB assumes fluctuations of mortality, growth, and recruitment around mean values over the range of ages in the LF sample and should not be used if this assumption is violated. For example, high interannual recruitment variability may lead to multiple peaks and poor analytical results (Quinn and Deriso, 1999; Hordyk et al., 2015a; Thorson and Cope, 2015), because without additional information, length-based methods cannot determine whether the observed difference in the frequency of many small and few large individuals is caused by an unusually strong cohort of recruits or by strong removal of large fish (Rudd and Thorson, 2017).

In general, it is dangerous to rely too heavily on results from a fancy method that are ultimately based on limited observations combined with bold assumptions. But the same and similar problems also apply to data-rich assessment methods; as Thorson and Cope (2015, p. 40) point out, “data-poor methods such as presented here should not be held to a higher standard than their richer cousins”.

**Use of LBB in management of data-poor stocks**

LBB may be directly useful for management of data-poor stocks with unreliable or missing catch data. Representative LF samples from the main gear used in the fishery or from the main landing site may suffice to get a preliminary impression of stock size relative to levels that can produce MSY. LBB also gives a comparison of current length at first capture $L_c$ relative to the one ($L_{c, opt}$) that would maximize catch and biomass for the given fishing pressure (Froese et al., 2016c). Based on this information, management can propose changes in lengths at first capture and in
fishing effort until relative biomass predicted by LF data exceeds the approximate MSY level.

Note, however, that the assumption of $F_{\text{min}} = M$ used in the estimation of the proxy for $B_{\text{peak}} / B$ is not precautionary, because $M$ is the upper bound rather than a surrogate of $F_{\text{min}}$ (Quinn and Deriso, 1999, p. 461). Consequently, the $B / B_{\text{peak}}$ estimate of LBB should not be used as a target, but rather as a lower bound of desirable stock sizes.

Figure 3 shows an example of graphical LBB output for turbot ($Scophthalmus maximus$) in the North Sea, based on observer data from 2010 to 2014 from the German fleet (see full analysis in the Supplementary Material). Despite considerable noise in the data, the LBB assessment agrees with the full assessment (ICES, 2017c) with regard to high fishing pressure during that period and biomass fluctuating between proxies for half and full MSY level, with some recovery in recent years (see Supplementary Table S4). Throughout the time-series, $L_c$ was well below $L_{c,\text{opt}}$, resulting in annual length structures with peaks well below $L_{\text{opt}}$.

### Use of LBB in evaluating the size structure of stocks

The Marine Strategy Framework Directive (MSFD) of the EU asks for the age and size distributions of commercially exploited species to be indicative of a healthy population (MSFD, 2008, Descriptor D3.3). The corresponding implementation instructions (COM, 2017) prescribe two indicators for Descriptor D3.3: the proportion of mature individuals and the 95th percentile of length composition. The LBB estimates of these official D3.3 indicators are shown in Supplementary Table S4.

COM (2017) encourages further scientific and technical development of suitable indicators for Descriptor D3.3. In this regard, LBB estimates the mean length in the exploited population ($L_{\text{mean}}$) as well as the length in the unexploited population ($L_{\text{opt}}$) where cohort biomass is maximum and, if fecundity is proportional to body weight, related reproductive potential is also maximum. The age at $L_{\text{opt}}$ is then the mean age of parents and thus, by definition, equivalent to generation time (Pianka, 2000). An exploited population with a mean length that is close to $L_{\text{opt}}$ has a size and age distribution similar to an unexploited healthy population. In other words, the ratio $L_{\text{mean}} / L_{\text{opt}}$ is a theoretically sound and easy-to-estimate indicator for a healthy size and age composition of exploited stocks.

A size and age composition close to $L_{\text{opt}}$ can be achieved by starting fishing at the length $L_{\text{opt}}$, which has the additional advantage of maximizing catch (Beverton and Holt, 1957) and biomass (Froese et al., 2016c) for the applied fishing pressure ($F/M$).

Of 33 analysed real stocks, 13 (39%) had mean lengths close to $L_{\text{opt}}$ with $L_{\text{mean}} / L_{\text{opt}} > 0.9$ and thus a size and age structure indicative of a healthy stock (Supplementary Table S4). Interestingly, all of these stocks also had lengths at first capture close to the optimum selectivity length with $L / L_{c,\text{opt}} > 0.9$. A linear regression of $L_{\text{mean}} / L_{\text{opt}}$ as a function of $L / L_{c,\text{opt}}$ accounts for 97% of the variability in the data ($y = 0.243 + 0.74x$, $n = 32$, $r^2 = 0.97$), thus providing a first empirical confirmation of the $L_{c,\text{opt}}$ concept, which was derived in Froese et al. (2016c) from basic population dynamics equations in Beverton and Holt (1957).

A very preliminary regression analysis of the size structure indicators in Table S4 shows a weak correlation for $L / L_{\text{opt}}$ over $L_{\text{mean}} / L_{\text{opt}}$ ($r^2 = 0.26$), and a very weak correlation of Mat (%) over $L_{\text{mean}} / L_{\text{opt}}$ ($r^2 = 0.10$), suggesting that these indicators may reflect different properties of the analysed size distributions. In summary, the ratio $L_{\text{mean}} / L_{\text{opt}}$ may be a suitable new indicator for MSFD Descriptor D3.3.

### Conclusions

LBB is a simple and fast method for estimating relative stock size. In contrast to similar methods, it requires no information on age, maturity, recruitment, growth, effort, or mortality, just representative LF data from the commercial fishery. LBB derives priors for $L_{\text{inf}}$ and selectivity from aggregated annual LF samples and assumes a prior $M / K$ ratio around 1.5 (95% CI 1.2–1.8). It then performs Bayesian analyses of the annual LF data to simultaneously estimate $L_{\text{inf}}$, $L_{\text{c}}$, $M / K$, and $F / K$. With these inputs, a combination of standard fisheries equations (Beverton and Holt, 1957, 1966) provides an estimate of relative biomass ($B / B_{\text{peak}}$) or for the exploited size range.

LBB estimates appear especially useful as objective relative biomass priors for use in other assessment models. But the LBB estimates of length at first capture and relative biomass in comparison with their respective reference points can also be used directly in management. We thus recommend LBB as a new addition to the assessment tool box, especially for data-poor stocks.

The mean length in exploited populations relative to the length at maximum biomass in the unfished population ($L_{\text{mean}} / L_{\text{opt}}$) is a theoretically sound and easy-to-estimate indicator for a size and age composition indicative of a healthy stock. It should be considered as potential new indicator in the evaluation of size and age structure. Additional supplementary material is available at http://oceanrep.geomar.de/43182/.

### Supplementary data

**Supplementary material** is available at the ICESJMS online version of the manuscript.

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A new approach for estimating stock status from length frequency data

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Additional supplementary material is available at http://oceanrep.geomar.de/43182/: the R-code to run LBB and files with the settings and the data for the analysis of the various stocks. LBB is also available as a function in the TropFishR package (Mildenberger et al. 2018) available from https://cran.r-project.org/package=TropFishR.

Data sources

Length composition data for spiny dogfish (Squalus acanthias), winter skate (Leucoraja ocellata), and thorny skate (Amblyraja radiata) in the Northwest Atlantic were obtained from The Historic Pelagic Shark Commercial Fishery Length Frequency Data provided by Fisheries and Oceans Canada (DFO) (Stone, 2017). Data came from directed fisheries for these species and were collected at landing ports. All individuals were measured in cm total length to the nearest integer.

LF data for six North Sea stocks were obtained from the annual sampling programme according to the EU German Data Collection Framework measuring the catch composition of the main commercial German fishing fleets with the highest catches, values, or effort. Length frequency data were obtained by observers-at-sea mainly covering demersal shrimp and flatfish beam trawlers and otter board trawls on demersal and pelagic fish (Ulleweit et al., 2010).

LF data for 14 stocks from the Mediterranean were obtained from commercial catches, which were collected mostly in the context of the European Data Collection Framework programme (https://stecf.jrc.ec.europa.eu/dd/medbs) and in some cases in the framework of FAO regional projects (e.g. FAO-AdriaMed). In particular, length composition data for blue and red shrimp (Aristeus antennatus) from geographical subareas GSA 1 and GSA 5, giant red shrimp (Aristaeomorpha foliacea) from GSAs 18–19, European anchovy (Engraulis encrasicolus) from GSA06 and GSAs 17–18, European hake (Merluccius merluccius) from GSA 9, red mullet (Mul-lus barbatus) from GSA 6 and 25, deep-water rose shrimp (Parapenaeus longirostris) from GSA 10, and common cuttlefish (Sepia officinalis) from GSA 17 were obtained from the JRC data dissemination tool (https://stecf.jrc.ec.europa.eu/c/document_library/get_file?uuid=e38bf490-ced2-4213-b71e-3902aba6e0a1&groupId=43805) and from the reports and stock assessment forms respectively available from STECF (https://stecf.jrc.europa.eu/reports/medbs) and from FAO-GFCM (http://www.fao.org/gfcm/data/safs/en/). Such datasets included landings from various gears (bottom trawls, nets, longlines) as well as discards.

Data for European pilchard (Sardina pilchardus) and European anchovy (Engraulis encrasicolus) from the Ionian and Aegean seas came from the catch of purse-seines and were col-
lected onboard and at landing ports (no discards were included because they are considered neg-
ligible). Data for red mullet (*Mullus barbatus*) and European hake (*Merluccius merluccius*) from
the same areas were also collected onboard and at landing ports, but came from various gears
(bottom trawls, nets, longlines) and included discards.

Length composition data for European sprat (*Sprattus sprattus*) from the Black Sea were
obtained from STEFC report (2017). Whiting (*Merlangius merlangus*) and Mediterranean horse
mackerel (*Trachurus mediterraneus*) from the Black Sea were collected at several landing ports
and were caught via different gears such as purse-seines and bottom trawls.

Length composition data for the South African “linefish” stocks carpenter (*Argyrozona
argyrozoa*; *n* = 2), silver kob (*Argyrosomus inodorus*; *n* = 2), slinger (*Chrysoblephus puniceus*;
*n* = 1), caught by the boat-based coastal handline fishery, were sourced from the National Ma-
rine Linefish System (NMLS) hosted by the South African Department of Agriculture, Forestry
and Fishery (DAFF). Fisheries-dependent length data were sampled as part of a large national
landing site observer programme during 2008–2010. Length composition data for carpenter and
silver kob were separated into two regions along the South African south coast to match previous
formal age-structured stock assessments for these species, whereas a single assessment model
has been used for slinger in the South African coast (Winker *et al*., 2012).

### Start values for the nonlinear least squares estimator function

LBB requires priors for *L*<sub>inf</sub> and *Z*/K, which were derived by pooling available LF data across
years and fitting equation 2 in the main text to the fully selected part of the catch-in-numbers
curve with the nonlinear least squares estimator function nls() in R (Bates and DebRoy, 2016).
The method requires start values and ranges for the parameters and these were obtained as de-
scribed in Table S1.

### Derivation of priors

The equations for how the LBB priors for *L*<sub>inf</sub>, *L*<sub>c</sub>, *a*, *M*/K, and *F*/K were derived are given in R-
notation in Table S2.

### Sources of independent stock assessments

The sources (mostly URLs) of independent stock assessments used for comparing the results of
LBB are given for every stock in Table S3.

### Results based on empirical data

LBB predictions of relative biomass in the final year evaluated against independent estimates of
regular stock assessments for a total of 34 stocks are given in Table S4.
Table S1. Start values (Linf.st and ZK.st) and their ranges used for nonlinear least squares estimation, in R-notation, where Length are the observed length classes and Freq are the observed frequencies. L.start is the length class from which onward full selection was assumed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Range</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf.st</td>
<td>max(Length)</td>
<td>0.9<em>Linf.st – 1.2</em>Linf.st</td>
<td>Length of largest observed specimen in the dataset</td>
</tr>
<tr>
<td>max.Freq</td>
<td>max(Freq)</td>
<td></td>
<td>Highest observed frequency</td>
</tr>
<tr>
<td>L10</td>
<td>Length[which(Freq&gt;(0.1*max.Freq))[1]]</td>
<td></td>
<td>Length at 10% selection</td>
</tr>
<tr>
<td>L90</td>
<td>Length[which(Freq&gt;(0.9*max.Freq))[1]]</td>
<td></td>
<td>Length at 90% selection</td>
</tr>
<tr>
<td>Lc.st</td>
<td>(L10 + L90)/2</td>
<td>(Lc.st-L10)/2</td>
<td>Length at half of peak frequency</td>
</tr>
<tr>
<td>alpha.st</td>
<td>-log(max.Freq/Freq[which(Freq&gt;(0.1*max.Freq))[1]]/(L10-Lc.st))</td>
<td>0.2*alpha.st</td>
<td>From main text equation 2 with $L = L_{10}$ and $S_L = 0.1$, solved for $\alpha$</td>
</tr>
<tr>
<td>L.start</td>
<td>Lc.st + 6.9 / alpha.st</td>
<td></td>
<td>Length where $S_L = 0.999$</td>
</tr>
<tr>
<td>L.mean</td>
<td>sum(Length[Length&gt;=Lc.st]*Freq[Length&gt;=Lc.st]) / sum(Freq[Length&gt;=Lc.st])</td>
<td>0.1*(Linf.st-Lmean.st)/(Lmean.st-Lc.st)</td>
<td>Needed to get a prior for Z/K</td>
</tr>
<tr>
<td>ZK.st</td>
<td>(Linf.st-Lmean.st)/(Lmean.st-Lc.st)</td>
<td></td>
<td>After Beverton and Holt (1956). Used for fitting main text Equation 1</td>
</tr>
</tbody>
</table>

Table S2. Derivation of priors for the Bayesian estimation of parameters in equations 4 and 7 in the main text. Equations are given in R-notation.

<table>
<thead>
<tr>
<th>Prior</th>
<th>Distribution</th>
<th>Mean</th>
<th>SD or tau</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf.pr</td>
<td>Gaussian</td>
<td>Linf.nls</td>
<td>Linf.sd.pr = ifelse(Linf.nls.sd/Linf.nls&lt;0.01, Linf.nls.sd,0.01*Linf.nls)</td>
<td>Where Linf.nls and Linf.nls.sd were obtained by fitting equation 1 in the main text to the fully selected length classes, aggregated over all years. S.d. is restricted to $CV &lt; 0.01$ to limit interannual variability thought to stem mostly from sampling error.</td>
</tr>
<tr>
<td>Lc.pr</td>
<td>Gaussian</td>
<td>1.02*Lc.st</td>
<td>Lc.sd.pr = 0.1*Lc.pr</td>
<td>Where Lc.st is determined as stated in Table S1 and the multiplier accounts for small bias.</td>
</tr>
<tr>
<td>r.alpha.st</td>
<td>-log(r.max.Freq/r.Freq.y[which(r.Freq.y &gt; (0.1*r.max.Freq))[1]])/(L10/Linf.pr-Lc.pr/Linf.pr)</td>
<td></td>
<td>Similar to derivation of alpha.st in Table S1, but here applied to annual standardized data.</td>
<td></td>
</tr>
<tr>
<td>r.alpha.pr</td>
<td>Gaussian</td>
<td>r.alpha.st</td>
<td>0.025*r.alpha.st</td>
<td></td>
</tr>
<tr>
<td>MK.pr</td>
<td>Gaussian</td>
<td>1.5</td>
<td>0.15</td>
<td>Evolutionary M/K ratio proposed by various authors, see Jensen (1996), Froese et al. (2016a).</td>
</tr>
<tr>
<td>FK.pr</td>
<td>log-Gaussian</td>
<td>log(ZK.nls - MK.pr)</td>
<td>tau = 4</td>
<td>Where ZK.nls is the Z/K estimate obtained from fitting equation 1 in the main text to the fully selected length classes, aggregated across all years. Precision = 4 gives wide range of uncertainty.</td>
</tr>
</tbody>
</table>
**Table S3.** Data sources of independent stock assessments.

<table>
<thead>
<tr>
<th>Species by area</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northeast Atlantic</strong></td>
<td></td>
</tr>
<tr>
<td><em>Amblyraja radiata</em></td>
<td>DFO (2003, 2017a)</td>
</tr>
<tr>
<td><em>Leucoraja ocellata</em></td>
<td>DFO (2017b)</td>
</tr>
<tr>
<td><em>Squalus acanthias</em></td>
<td>DFO (2014); Fowler and Campana (2015)</td>
</tr>
<tr>
<td><strong>North Sea</strong></td>
<td></td>
</tr>
<tr>
<td><em>Clupea harengus</em></td>
<td><a href="http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/her.27.3a47d.pdf">www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/her.27.3a47d.pdf</a></td>
</tr>
<tr>
<td><em>Melanogrammus aeglefinus</em></td>
<td><a href="http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/had.27.46a20.pdf">www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/had.27.46a20.pdf</a></td>
</tr>
<tr>
<td><em>Pleuronectes platessa</em></td>
<td><a href="http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/ple.27.420.pdf">www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/ple.27.420.pdf</a></td>
</tr>
<tr>
<td><em>Pollachius virens</em></td>
<td><a href="http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/pok.27.3a46.pdf">http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/pok.27.3a46.pdf</a></td>
</tr>
<tr>
<td><em>Scophthalmus maximus</em></td>
<td><a href="http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/tur.27.4.pdf">www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/tur.27.4.pdf</a></td>
</tr>
<tr>
<td><em>Solea solea</em></td>
<td><a href="http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/sol.27.4.pdf">www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/sol.27.4.pdf</a></td>
</tr>
<tr>
<td><strong>Mediterranean</strong></td>
<td></td>
</tr>
<tr>
<td><em>Aristeus antennatus</em></td>
<td><a href="https://gfcmsitestorage.blob.core.windows.net/documents/SAC/SAF/DemersalSpecies/2016/ARA_GSA_01_2015_ESP.pdf">https://gfcmsitestorage.blob.core.windows.net/documents/SAC/SAF/DemersalSpecies/2016/ARA_GSA_01_2015_ESP.pdf</a></td>
</tr>
<tr>
<td><em>Aristaeomorpha foliacea</em></td>
<td><a href="https://gfcmsitestorage.blob.core.windows.net/documents/SAC/SAF/DemersalSpecies/2016/ARA_GSA_05_2015_ESP.pdf">https://gfcmsitestorage.blob.core.windows.net/documents/SAC/SAF/DemersalSpecies/2016/ARA_GSA_05_2015_ESP.pdf</a></td>
</tr>
<tr>
<td>STECF/Jardim et al. (2015)</td>
<td></td>
</tr>
<tr>
<td>STECF/Simmonds et al. (2018)</td>
<td></td>
</tr>
</tbody>
</table>
Table S4. \( \frac{B}{B_{msy}} \) and preceding \( F/M \) values estimated from commercial length frequencies (and marked “est”) compared with \( F/F_{msy} \) and approximated \( \frac{B}{B_0} \) estimates from independent assessments (marked “ind”), for 34 stocks of 23 species. Also indicated are the ratios of mean to optimum length \( \left( \frac{L_{\text{mean}}}{L_{\text{opt}}} \right) \) in the catch and observed to optimum length at first capture \( \left( \frac{L_c}{L_{\text{copt}}} \right) \). The ratio of the 95\(^{th} \) percentile to asymptotic length \( \left( \frac{L_{95\%}}{L_{\text{inf}}} \right) \) and the percentage of mature individuals in the catch (Mat) is indicated. \( F/M \) estimates where confidence limits do not overlap with \( F/F_{msy} \) estimates are marked bold (assuming \( \pm 20\% \) limits for single \( F/F_{msy} \)). \( \frac{B}{B_{msy}} \) estimates where confidence limits do not overlap with independent estimates are marked bold (assuming \( \pm 20\% \) limits for single \( B/B_{msy} \)). Table S3 contains additional information about sources of data for each stock.

<table>
<thead>
<tr>
<th>Species by area</th>
<th>Stock</th>
<th>Years</th>
<th>( F/F_{msy} ) ind</th>
<th>( F/M ) est</th>
<th>( B/B_{msy} ) ind</th>
<th>( B/B_{msy} ) est</th>
<th>( L_{\text{mean}}/L_{\text{opt}} )</th>
<th>( L_{95%}/L_{\text{inf}} )</th>
<th>Mat (%)</th>
<th>Comment/source (ind)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northwest Atlantic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amblyraja radiata</td>
<td>ThornySkate 2000</td>
<td>–</td>
<td>3.5</td>
<td>2.8–4.5</td>
<td>–</td>
<td>0.42</td>
<td>0.29–0.57</td>
<td>1.1</td>
<td>1.1</td>
<td>0.92</td>
</tr>
<tr>
<td>Leucoraja ocellata</td>
<td>WinterSkate 1995–2004</td>
<td>–</td>
<td>1.1</td>
<td>0.8–1.6</td>
<td>0.35</td>
<td>1.0</td>
<td>0.6–1.5</td>
<td>1.1</td>
<td>1.2</td>
<td>0.83</td>
</tr>
<tr>
<td>Squalus acanthias</td>
<td>SpinyDogfish 2001–2006</td>
<td>0.15–0.21</td>
<td>2.0</td>
<td>1.6–3.3</td>
<td>0.86</td>
<td>0.7</td>
<td>0.4–1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>0.98</td>
</tr>
</tbody>
</table>
### North Sea

<table>
<thead>
<tr>
<th>Species</th>
<th>Code</th>
<th>Start Year</th>
<th>End Year</th>
<th>L&lt;sub&gt;50&lt;/sub&gt;</th>
<th>F&lt;sub&gt;F&lt;/sub&gt;</th>
<th>M&lt;sub&gt;F&lt;/sub&gt;</th>
<th>L&lt;sub&gt;0&lt;/sub&gt;</th>
<th>F&lt;sub&gt;F&lt;/sub&gt;</th>
<th>M&lt;sub&gt;F&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clupea harengus</td>
<td>her 27.3a47d</td>
<td>2010–2014</td>
<td>0.67</td>
<td>3.1</td>
<td>0.65</td>
<td>0.59</td>
<td>1.2</td>
<td>0.96</td>
<td>1.0</td>
</tr>
<tr>
<td>Melanogrammus aestegnitus</td>
<td>bad.27.46a2o</td>
<td>2010–2014</td>
<td>1.55</td>
<td>3.6</td>
<td>0.69</td>
<td>0.38</td>
<td>1.0</td>
<td>0.92</td>
<td>1.0</td>
</tr>
<tr>
<td>Pleuronectes platessa</td>
<td>pl.27.420</td>
<td>2010–2014</td>
<td>0.95</td>
<td>2.4</td>
<td>1.4</td>
<td>0.30</td>
<td>0.79</td>
<td>0.87</td>
<td>1.0</td>
</tr>
<tr>
<td>Pollachius virens</td>
<td>pok.27.3a46</td>
<td>2010–2014</td>
<td>0.89</td>
<td>1.4</td>
<td>0.55–0.88</td>
<td>0.53</td>
<td>0.62</td>
<td>0.92</td>
<td>0.7</td>
</tr>
<tr>
<td>Scophthalmus maximus</td>
<td>tur.27.4</td>
<td>2010–2014</td>
<td>0.63</td>
<td>0.84</td>
<td>0.87–1.61</td>
<td>0.85</td>
<td>0.64</td>
<td>0.72</td>
<td>1.0</td>
</tr>
<tr>
<td>Solea solea</td>
<td>sol.27.4</td>
<td>2011–2014</td>
<td>1.5</td>
<td>2.3</td>
<td>0.46–0.69</td>
<td>0.49</td>
<td>0.31–0.65</td>
<td>0.95</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### Mediterranean

<table>
<thead>
<tr>
<th>Species</th>
<th>Code</th>
<th>Start Year</th>
<th>End Year</th>
<th>L&lt;sub&gt;50&lt;/sub&gt;</th>
<th>F&lt;sub&gt;F&lt;/sub&gt;</th>
<th>M&lt;sub&gt;F&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aristeus antennatus</td>
<td>ARA-GSA01</td>
<td>2005–2015</td>
<td>1.9</td>
<td>1.42–2.36</td>
<td>0.37</td>
<td>0.75</td>
</tr>
<tr>
<td>Aristeus antennatus</td>
<td>ARA-GSA05</td>
<td>2002–2015</td>
<td>1.0</td>
<td>1.1–1.85</td>
<td>0.48</td>
<td>0.83</td>
</tr>
<tr>
<td>Aristaeomorpha fowliscea</td>
<td>ARS-18-19</td>
<td>2009–2014</td>
<td>1.1</td>
<td>3.5–4.6</td>
<td>0.13</td>
<td>0.82</td>
</tr>
<tr>
<td>Engraulis encrasicolus</td>
<td>ANE-GSA06</td>
<td>2005–2015</td>
<td>0.9</td>
<td>1.4–2.6</td>
<td>0.65</td>
<td>0.96</td>
</tr>
<tr>
<td>Merluccius merluccius</td>
<td>HKE-GSA09</td>
<td>2006–2015</td>
<td>3.8</td>
<td>4.4–7.0</td>
<td>0.27</td>
<td>0.81</td>
</tr>
<tr>
<td>Merluccius merluccius</td>
<td>HKE-GSA17-18</td>
<td>2009–2015</td>
<td>2.6</td>
<td>12–18.1</td>
<td>0.02</td>
<td>0.88</td>
</tr>
<tr>
<td>Merluccius merluccius</td>
<td>MNE-Aegae</td>
<td>2004–2014</td>
<td>4.68</td>
<td>3.2–4.1</td>
<td>0.11</td>
<td>0.84</td>
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<tr>
<td>Mulloidichthys marmoratus</td>
<td>MUT-GSA25</td>
<td>2005–2015</td>
<td>1.0</td>
<td>1.1–2.0</td>
<td>0.67</td>
<td>0.87</td>
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<tr>
<td>Mullet barbatus</td>
<td>MUT-GSA6</td>
<td>2006–2015</td>
<td>1.6</td>
<td>2.2–5.0</td>
<td>0.27</td>
<td>0.98</td>
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<tr>
<td>Mbar_Aegae</td>
<td>2003–2006</td>
<td>1.18</td>
<td>3.6</td>
<td>2.6–6.7</td>
<td>0.21</td>
<td>0.99</td>
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<td>Mbar_Aegae</td>
<td>2005–2014</td>
<td>1.5</td>
<td>3.7</td>
<td>3.0–5.0</td>
<td>0.2</td>
<td>0.93</td>
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<tr>
<td>Parapeneus longirostris</td>
<td>DPS-GSA10</td>
<td>2009–2015</td>
<td>2.0</td>
<td>2.8</td>
<td>0.26</td>
<td>0.89</td>
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<td>Sardina pilchardus</td>
<td>SpI_Aeage</td>
<td>2004–2008</td>
<td>1.7</td>
<td>4.0</td>
<td>0.32</td>
<td>0.89</td>
</tr>
<tr>
<td>Sepia officinalis</td>
<td>CTC-GSA17</td>
<td>2006–2016</td>
<td>0.8</td>
<td>0.45</td>
<td>1.4</td>
<td>NA</td>
</tr>
</tbody>
</table>

### Notes

- L<sub>50</sub>: L<sub>50</sub> is the size at which half of the population is caught.
- F<sub>F</sub>: F<sub>F</sub> is the fishing mortality rate.
- M<sub>F</sub>: M<sub>F</sub> is the maximum sustainable yield.
- L<sub>0</sub>: L<sub>0</sub> is the length at which 50% of the population is mature.
- F<sub>F</sub> and M<sub>F</sub> are given as ranges where available.
Tropical small reef fish typically grow fast towards their maximum size which coincides with their maximum age. However, in some species, populations have been found whose adults continue to live for several decades after approaching $L_{inf}$ (e.g. Choat and Axe, 1996; Choat et al., 2003; Trip et al., 2008). Robertson et al. (2005) explore possible reasons for such unexpected longevity in the ocean surgeonfish (Acanthurus bahianus) across a wide range of localities and habitats. They find that mean annual temperature at the different localities is the strongest predictor of longevity, accounting for 94% of the variability in the data. They observe fast decrease in numbers in the initial 10 years of life in all localities, with the high mortality rate that is typical for fishes of that size. However, in four out of 10 localities, they find adults that continued living up to 30 years and more, with a much slower decrease in numbers and thus much lower mortality rates, and without observable somatic growth. As they state: “[..] at Bermuda, fish settle inshore, grow to about asymptotic size and then, when 2 to 6 yr old, relocate permanently to outer reefs, where they can reach 32 yr. At Belize, fish settle and attain 10 yr on both inner and outer reefs [..].” Small fish that live for 32 years have to drastically reduce their extrinsic mortality rate, driven mostly by predation, and their intrinsic mortality rate, driven mostly by metabolism, which, in ectotherm species, is mainly a function of water temperature. The depth range of Acanthurus bahianus is 2–40 m (Desoutter, 1990) and water temperature at Bermuda ranges from 27°C at the surface in summer to about 18°C at 40 m depth. Given the evidence that natural mortality is influenced by environmental temperature (Pauly, 1980), we hypothesize that the observed high longevity in Bermuda is caused by low predation mortality and low water temperature in the outer reefs to which the fish relocate permanently. In contrast, the temperature on the
inner and outer reefs in Belize seems to be about the same (about 28°C) and no extended longevity is observed.

Several other studies of long-lived reef fishes also show growth curves with very fast growth up to 0.6–0.8 $L_{\text{inf}}$ and much slower growth and high longevity thereafter. For example, Currey et al. (2009) show data for four species of Lethrinidae. In three of these (see their Table 2 and their Figure 5), the hypothetical negative age at zero length ($t_0$) is −3 to −10 years, suggesting that the growth rate observed only at large sizes does not adequately describe growth rate at small sizes, which must be considerably higher.

Also, juveniles of long-lived reef species such as lutjanids and epinephelids occur in warm water such as sea grass beds and shallow sheltered reefs, whereas the long-lived adults occur in colder water on deeper slopes (Longhurst and Pauly, 1987; Froese and Pauly, 2017). Indeed, Pauly (2010) proposes that the migration to deeper, colder water is the key mechanism allowing these fishes to attain the large size and high longevity that characterize their life histories.

This warm-to-cold hypothesis for explanation of growth and mortality patterns in some long-lived populations of reef fishes differs from the one advanced by Hordyk et al. (2015a,b) and Prince et al. (2015) who (i) propose that high longevity is a general trait of several families of reef fishes such as Acanthuridae or Lethrinidae, (ii) assume that very low mortality acts already during the fast growth phase during the first few years of life, and (iii) therefore assume a very low $M/K$ ratio from early juveniles onward, basically combining the low $M$ of old individuals with the high $K$ of young individuals (see e.g. Table 1 in Prince et al. 2015). Instead, we propose that in these populations, there is a joined stanza in growth and mortality schedules and that growth and no-growth phases should be treated separately.

In summary, it seems that fast early growth coupled with extended longevity around maximum size occurs in some populations where large individuals, as they approach maximum length, permanently relocate from warm shallow water to deep colder water. This life history strategy does not occur in all populations of a species, presumably because not all populations have access to suitable nearby deep habitats.

References


**Detailed results of LBB analysis of simulated and real stocks**

The output shown in the subsequent pages is generated by the LBB R-code. Length frequency (LF) data refer to simulated stocks with trawl-like and gillnet-like selection and to data obtained from real stocks from the North Atlantic, North Sea, Mediterranean, Black Sea, and South Africa. The Comment text includes corresponding values from the simulations or from independent stock assessments.

A generic caption to the figures produced by LBB as shown below is given here:

**Caption for subsequent figures:** The upper left panel shows the standardized length frequencies accumulated over the available years. These accumulated LF data are used to estimate priors for the length at 50% first capture ($L_c$), for asymptotic length ($L_{inf}$), and for total mortality relative to somatic growth ($Z/K$). The blue curve is fitted to fully selected length classes and provides the estimates of $L_{inf}$ and $Z/K$. The upper middle and right panels show the LF data for the first and last year in the time-series. The red curve shows the fit of the LBB master equation, which provides estimates of $Z/K$, $M/K$, $F/K$, $L_c$, and $L_{inf}$. From $L_{inf}$ and $M/K$, the length $L_{opt}$ is calculated, where the biomass of the unexploited stock is maximum. The lower left panel shows the trajectory of mean length $L_{mean}$ (bold black curve) relative to $L_{opt}$, and the trajectory of $L_c$ (black curve) with approximate 95% confidence limits (dotted curves) relative to $L_{c\_opt}$, which is a reference level that maximizes catch and biomass for the given fishing pressure and results in $L_{mean} = L_{opt}$ in the exploited part of the stock. The lower middle panel shows relative fishing pressure $F/M$ (black curve), with approximate 95% confidence limits (dotted curves), with indication of the reference level where $F = M$ (green horizontal line). The lower right panel shows relative biomass $B/B_0$ (black curve) with approximate 95% confidence limits (dotted black curves) with indication of a proxy for the relative biomass that can produce MSY (green dashed line) and a proxy for the precautionary biomass level (red dotted line).
1) Simulations with regular exploitation (True values in Comment, Sim_23.xlsx, LBB_10.R)

Results for fully exploited cod, stock CodSim, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

Linf prior = 118, s.d. = 1.18 (cm)
Z/K prior = 2.9, s.d. = 0.164, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.4 (wide range with tau = 4 in log-normal distribution)
Lc prior = 34.7, SD = 3.47 (cm), alpha prior = 71.9, s.d. = 7.19

General reference points [median across years]:
Linf = 122 (120–124) cm
Lopt = 80 cm, Lopt/Linf = 0.65
Lc_opt = 66 cm, Lc_opt/Linf = 0.54
M/K = 1.58 (1.33–1.85)
F/K = 1.53 (1.22–1.82)
Z/K = 3.11 (2.97–3.25)
F/M = 0.969 (0.667–1.37)
B/B0 F=M Lc=Lc_opt = 0.364
B/B0 = 0.266 (0.16–0.394)
Y/R’ F=M Lc=Lc_opt = 0.0422
Y/R’ = 0.0358 (0.0213–0.0524) (linearly reduced if B/B0 < 0.25)

Estimates for last year 1008:
Lc = 34.7 (34.5–34.9) cm, Lc/Linf = 0.28 (0.283–0.286)
alpha = 64 (61.2–66.4)
Lmean/Lopt = 0.65, Lc/Lc_opt = 0.52, L95th = 118 cm, L95th/Linf = 0.96, Lm50 = NA cm, Mature = NA%
F/K = 1.6 (1.3–1.9)
F/M = 1 (0.714–1.4)
Z/K = 3.14 (3–3.27)
Y/R’ = 0.037 (0.0227–0.054) (linearly reduced if B/B0 < 0.25)
B/B0 = 0.25 (0.155–0.368)
B/Bmsy = 0.69 (0.425–1.01)

Comment: True: Linf=120, Lc=35, alpha=60, M/K=1.54, F/K=1.54, F/M=1, Z/K=3.08, B/B0=0.261, Y/R=0.0377.
Results for overexploited herring, stock **HerringSim**, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

LinF prior = 34.5, s.d. = 0.345 (cm)
Z/K prior = 3.43, s.d. = 0.335, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.93 (wide range with tau=4 in log-normal distribution)
Lc prior = 17.3, s.d. = 1.73 (cm), alpha prior = 45.7, s.d. = 4.57

**General reference points** [median across years]:
- Linf = 35.8 (35.4–36.3) cm
- Lopt = 23 cm, Lopt/Linf = 0.64
- Lc_opt = 20 cm, Lc_opt/Linf = 0.55
- M/K = 1.69 (1.43–2)
- F/K = 2.63 (2.25–2.99)
- Z/K = 4.33 (4.12–4.58)
- F/M = 1.52 (1.16–2)
- B/B0 F=M Lc=Lc_opt = 0.36
- Y/R' F=M Lc=Lc_opt = 0.0376
- Y/R' = 0.0396 (0.0266–0.0543) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 1008:**
- Lc = 18.1 (18–18.2) cm, Lc/Linf = 0.51 (0.504–0.51)
- alpha = 39 (37.8–40)
- Lmean/Lopt = 0.93, Lc/Lc_opt = 0.91, L95th = 34.2 cm, L95th/Linf = 0.96, Lm50 = NA cm, Mature = NA%
- F/K = 2.5 (2.09–2.7)
- F/M = 1.5 (1.03–1.86)
- Z/K = 4.18 (3.96–4.35)
- Y/R' = 0.041 (0.0256–0.0558) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.26 (0.16–0.349)
- B/Bmsy = 0.72 (0.445–0.971)

Comment: Linf=35, Lc=18, alpha=42, M/K=1.6, F/K=2.4, F/M=1.5, Z/K=4.0, B/B0=0.25, Y/R=0.0451.
Results for fully exploited plaice, stock **PlaiceSim**, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf prior</td>
<td>47.7 (47.1–48.3) cm</td>
<td></td>
</tr>
<tr>
<td>Z/K prior</td>
<td>2.44, s.d. = 0.25</td>
<td></td>
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<tr>
<td>F/K prior</td>
<td>0.937 (wide range with tau=4 in log-normal distribution)</td>
<td></td>
</tr>
<tr>
<td>Lc prior</td>
<td>26 s.d. = 2.6 (cm)</td>
<td></td>
</tr>
</tbody>
</table>

**General reference points** (median across years):
- Linf = 47.7 (47.1–48.3) cm
- Lopt = 31 cm, Lopt/Linf = 0.66
- Lc_opt = 25 cm, Lc_opt/Linf = 0.53
- M/K = 1.55 (1.34–1.79)
- F/K = 1.06 (0.752–1.35)
- Z/K = 2.56 (2.41–2.74)
- F/M = 0.667 (0.401–0.986)
- B/B0 = 0.471 (0.235–0.716)
- Y/R' = 0.0385 (0.0193–0.0607) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 1008:**
- Lc = 25.8 (25.7–25.9) cm, Lc/Linf = 0.54 (0.54–0.544)
- alpha = 47.9 (46.3–49.2)
- Lmean/Lopt = 1, L95th = 46.5 cm, L95th/Linf = 0.98, Lm50 = NA cm, Mature = NA%
- F/K = 1.1 (0.823–1.35)
- F/M = 0.79 (0.506–1.06)
- Z/K = 2.55 (2.39–2.67)
- Y/R' = 0.047 (0.0259–0.0692) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.42 (0.234–0.624)
- B/Bmsy = 1.2 (0.64–1.71)

Comment: Linf=48, Lc=26, alpha=48, M/K=1.33, F/K=1.33, F/M=1, Z/K=2.67, B/B0=0.36, Y/R=0.0553.
Results for overexploited shrimp, stock ShrimpSim, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

Linf prior = 6.74, s.d. = 0.0674 (cm)
Z/K prior = 3.47, s.d. = 0.276, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.97 (wide range with tau=4 in log-normal distribution)
Lc prior = 2.29, s.d. = 0.23 (cm), alpha prior = 28.1, s.d. = 2.81

General reference points [median across years]:
Linf = 6.83 (6.74–6.94) cm
Lopt = 4.5 cm, Lopt/Linf = 0.66
Lc_opt = 3.9 cm, Lc_opt/Linf = 0.56
M/K = 1.57 (1.31–1.83)
Z/K = 3.72 (3.54–3.91)
F/M = 1.36 (0.984–1.76)
B/B0 F=M Lc=Lc_opt = 0.363
B/B0 = 0.217 (0.14–0.327)
Y/R = M Lc=Lc_opt = 0.0422
Y/R' = 0.0343 (0.0221–0.0502) (linearly reduced if B/B0 < 0.25)

Estimates for last year 1008:
Lc = 2.54 (2.51–2.57) cm, Lc/Linf = 0.37 (0.367–0.376)
alpha = 26.1 (25.1–26.9)
Lmean/Lopt = 0.77, Lc/Lc_opt = 0.66, L95th = 6.5 cm, L95th/Linf = 0.95, Lm50 = NA cm, Mature = NA%
F/K = 2.2 (1.93–2.62)
F/M = 1.4 (1.08–1.93)
Z/K = 3.81 (3.58–4.11)
Y/R' = 0.034 (0.0232–0.0492) (linearly reduced if B/B0 < 0.25)
B/B0 = 0.21 (0.148–0.314)
B/Bmsy = 0.59 (0.408–0.864)
Comment: Linf=7, Lc=2.5, alpha=28, M/K=1.78, F/K=2.22, F/M=1.25, Z/K=4.0, B/B0=0.232, Y/R=0.0328.
Results for fully exploited sprat, stock **SpratSim**, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

<table>
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<tr>
<th>Parameter</th>
<th>Value (95% confidence limits)</th>
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<tbody>
<tr>
<td>Linf prior</td>
<td>14.7 (14.8–15.2) cm</td>
</tr>
<tr>
<td>Z/K prior</td>
<td>2.87 (2.27–3.77)</td>
</tr>
<tr>
<td>M/K prior</td>
<td>1.62 (1.37–1.86)</td>
</tr>
<tr>
<td>F/K prior</td>
<td>1.57 (1.24–1.82)</td>
</tr>
<tr>
<td>Lc prior</td>
<td>6.5 (6.5–6.5) cm</td>
</tr>
<tr>
<td>alpha prior</td>
<td>38.6 (38.6–38.6)</td>
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**General reference points** [median across years]:

<table>
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<tr>
<th>Parameter</th>
<th>Value (95% confidence limits)</th>
</tr>
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<tbody>
<tr>
<td>Linf</td>
<td>15 (14.8–15.2) cm</td>
</tr>
<tr>
<td>Lopt</td>
<td>9.7 cm, Lopt/Linf = 0.65</td>
</tr>
<tr>
<td>Lc_opt</td>
<td>8.1 cm, Lc_opt/Linf = 0.54</td>
</tr>
<tr>
<td>M/K</td>
<td>1.62 (1.37–1.86)</td>
</tr>
<tr>
<td>F/K</td>
<td>1.57 (1.24–1.82)</td>
</tr>
<tr>
<td>Z/K</td>
<td>3.22 (3.02–3.4)</td>
</tr>
<tr>
<td>F/M</td>
<td>0.982 (0.7–1.35)</td>
</tr>
<tr>
<td>B/B0 F=M Lc=Lc_opt</td>
<td>0.362</td>
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<tr>
<td>B/B0</td>
<td>0.337 (0.206–0.488)</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.0402 (0.0248–0.0589)</td>
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**Estimates for last year 1008**:  

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (95% confidence limits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf</td>
<td>15 (14.8–15.2) cm</td>
</tr>
<tr>
<td>Lc</td>
<td>6.5 (6.5–6.5) cm</td>
</tr>
<tr>
<td>alpha</td>
<td>30.7 (29.5–31.6)</td>
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<tr>
<td>Lmean/Lopt</td>
<td>0.89, Lc/Lc_opt = 0.86, L95th = 14.5 cm, L95th/Linf = 0.96, Lm50 = NA cm, Mature = NA%</td>
</tr>
<tr>
<td>F/K</td>
<td>1.6 (1.31–1.97)</td>
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<tr>
<td>F/M</td>
<td>1 (0.706–1.38)</td>
</tr>
<tr>
<td>Z/K</td>
<td>3.3 (3.07–3.52)</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.04 (0.0239–0.0582) (linearly reduced if B/B0 &lt; 0.25)</td>
</tr>
<tr>
<td>B/B0</td>
<td>0.33 (0.199–0.485)</td>
</tr>
<tr>
<td>B/Bmsy</td>
<td>0.91 (0.55–1.34)</td>
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</tbody>
</table>

Comment: Linf = 15, Lc = 7, alpha = 30, M/K = 1.75, F/K = 1.5, F/M = 0.86, Z/K = 3.25, B/B0 = 0.374, Y/R = 0.0342.
Results for overexploited swordfish, stock **SwordSim**, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

Lin\(\text{f}\) prior = 298, s.d. = 2.98 (cm)
Z/K prior = 3.13, s.d. = 0.141, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.63 (wide range with tau=4 in log-normal distribution)
Lc prior = 89.8, s.d. = 8.98 (cm), alpha prior = 70.9, s.d. = 7.09

**General reference points** [median across years]:
Lin\(\text{f}\) = 309 (305–313) cm
Lopt = 202 cm, Lopt/Linf = 0.65
Lc_opt = 170 cm, Lc_opt/Linf = 0.55
M/K = 1.59 (1.34–1.88)
F/K = 1.81 (1.47–2.12)
Z/K = 3.38 (3.23–3.54)
F/M = 1.14 (0.789–1.59)
B/B0 F=M Lc=Lc_opt = 0.364
B/B0 = 0.23 (0.139–0.333)
Y/R' F=M Lc=Lc_opt = 0.0421
Y/R' = 0.0327 (0.02–0.0478) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 1008:**
Lc = 89.2 (88.6–89.8) cm, Lc/Linf = 0.29 (0.286–0.29)
alpha = 61.7 (59.1–64)
Lmean/Lopt = 0.65, Lc/Lc_opt = 0.52, L95th = 297 cm, L95th/Linf = 0.96, Lm50 = NA cm, Mature = NA%
F/K = 1.9 (1.56–2.16)
F/M = 1.2 (0.849–1.6)
Z/K = 3.42 (3.24–3.55)
Y/R' = 0.031 (0.0189–0.0424) (linearly reduced if B/B0 < 0.25)
B/B0 = 0.21 (0.126–0.283)
B/Bmsy = 0.57 (0.346–0.778)
Comment: Linf=299, Lc=90, alpha=59.8, M/K=1.36, F/K=1.82, F/M=1.33, Z/K=3.18, B/B0=0.198, Y/R=0.0450.
2) Simulation of different exploitation, variable F, and recruitment pulse

Results for lightly exploited cod, stock CodLightSim, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

Linf prior = 119, s.d. = 1.19 (cm)
Z/K prior = 2.21, s.d. = 0.0805, M/K prior = 1.5, s.d. = 0.15
F/K prior = 0.706 (wide range with tau=4 in log-normal distribution)
Lc prior = 34.7, s.d. = 3.47 (cm), alpha prior = 71.2, s.d. = 7.12

General reference points [median across years]:
Linf = 122 (120–123) cm
Lopt = 79 cm, Lopt/Linf = 0.65
Lc_opt = 61 cm, Lc_opt/Linf = 0.5
M/K = 1.6 (1.33–1.87)
F/K = 0.741 (0.47–1.02)
Z/K = 2.37 (2.26–2.48)
F/M = 0.459 (0.257–0.758)
B/B0 F=M Lc=Lc_opt = 0.363
B/B0 = 0.479 (0.207–0.81)
Y/R’ F=M Lc=Lc_opt = 0.0416
Y/R’ = 0.0302 (0.0121–0.0509) (linearly reduced if B/B0 < 0.25)

Estimates for last year 1008:
Lc = 34.7 (34.4–34.9) cm, Lc/Linf = 0.28 (0.283–0.287)
alpha = 62.3 (59.9–64.9)
Lmean/Lopt = 0.7, Lc/Lc_opt = 0.57, L95th = 118 cm, L95th/Linf = 0.97, Lm50 = NA cm, Mature = NA%
F/K = 0.76 (0.425–0.968)
F/M = 0.48 (0.223–0.71)
Z/K = 2.32 (2.24–2.48)
Y/R’ = 0.031 (0.00928–0.04999) (linearly reduced if B/B0 < 0.25)
B/B0 = 0.47 (0.139–0.75)
B/Bmsy = 1.3 (0.384–2.06)

Comment: Linf=120, Lc=35, alpha=60, M/K=1.54, F/K=0.77, F/M=0.5, Z/K=2.31, B/B0=0.458, YR=0.0332,
YR_FMLcopt=0.0444.
Results for very lightly exploited cod, stock **CodVeryLightSim**, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

Linf prior = 121, s.d. = 1.2 (cm)
Z/K prior  = 1.6, s.d. = 0.046 , M/K prior  = 1.5 , s.d. = 0.15
F/K prior  = 0.0978 (wide range with tau=4 in log-normal distribution)
Lc prior   = 35.2, s.d. = 3.52 (cm), alpha prior = 56.5, s.d. = 5.65

**General reference points** [median across years]:
- Linf' = 121 (120–122) cm
- Lopt = 81 cm, Lopt/Linf = 0.67
- Lc_opt = 56 cm, Lc_opt/Linf = 0.46
- M/K = 1.49 (1.37–1.59)
- F/K = 0.0975 (0.0395–0.215)
- Z/K = 1.59 (1.52–1.68)
- F/M = 0.0654 (0.0249–0.156)
- B/B0 F=M Lc=Lc_opt = 0.367
- B/B0 = 0.887 (0.106–2.51)
- Y/R' F=M Lc=Lc_opt = 0.0464
- Y/R' = 0.0087 (0.00106–0.0245) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 1008**:
- Lc  = 34.9 (34.7–35.1) cm, Lc/Linf = 0.29 (0.287–0.291)
- alpha = 58 (6–60.7)
- Lmean/Lopt = 0.74, Lc/Lc_opt = 0.63, L95th = 120 cm, L95th/Linf = 0.99, Lm50 = NA cm, Mature = NA%
- F/K = 0.097 (0.0314–0.208)
- F/M = 0.066 (0.0207–0.149)
- Z/K = 1.57 (1.52–1.67)
- Y/R' = 0.009 (3e-04–0.0241) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.89 (0.0296–2.38)
- B/Bmsy = 2.4 (0.0807–6.48)

Comment: Linf=120, Lc=35, alpha=60, M/K=1.54, F/K=0.0077, F/M=0.005, Z/K=1.55, B/B0=0.991, YR=0.0007.
Results for heavily exploited cod, stock **CodHeavySim**, 999–1008
(95% confidence limits in parentheses) File: SimDat_10.csv

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**Lin** prior = 109, s.d. = 1.09 (cm)
Z/K prior = 6.21, s.d. = 0.464 , M/K prior = 1.5, s.d. = 0.15
F/K prior = 4.71 (wide range with tau=4 in log-normal distribution)
Lc prior = 34.2, s.d. = 3.42 (cm), alpha prior = 61, s.d. = 6.1

**General reference points** [median across years]:

- Lin = 115 (114–117) cm
- Lopt = 76 cm, Lopt/Linf = 0.66
- Lc_opt = 70 cm, Lc_opt/Linf = 0.61
- M/K = 1.55 (1.27–1.84)
- F/K = 5.23 (4.85–5.6)
- Z/K = 6.79 (6.53–7.05)
- F/M = 3.36 (2.65–4.33)

**Estimates for last year 1008:**

- Lc = 34.8 (34.6–34.9) cm, Lc/Linf = 0.3 (0.299–0.302)
- alpha = 57.1 (55.4–58.8)
- Lmean/Lopt = 0.59, Lc/Lc_opt = 0.5, L95th = 108 cm, L95th/Linf = 0.94, Lm50 = NA cm, Mature = NA%
- F/K = 5.2 (4.86–5.5)
- F/M = 3.3 (2.82–4.17)
- Z/K = 6.77 (6.49–7.06)
- Y/R’ = 0.0074 (0.00575–0.00964) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.064 (0.0496–0.0831)
- B/Bmsy = 0.18 (0.136–0.228)

**Comment:** Linf=120, Lc=35, alpha=60, M/K=1.54, F/K=6.15, F/M=4, Z/K=7.69, B/B0=0.047, Y/R=0.0272.
Results for $F=0.2$ below and 0.4 above 40 cm, stock **Codfish**, 999–999
(95% confidence limits in parentheses) File: SimDat_10.csv

Linf prior = 116, s.d. = 1.16 (cm)
Z/K prior = 4.18, s.d. = 2.77, M/K prior = 1.5, s.d. = 0.15
F/K prior = 2.68 (wide range with tau=4 in log-normal distribution)
Lc prior = 37.2, s.d. = 3.72 (cm), alpha prior = 44.4, s.d. = 4.44

**General reference points:**
- Linf' = 120 (118–121) cm
- Lopt = 80 cm, Lopt/Linf' = 0.67
- Lc_opt = 71 cm, Lc_opt/Linf' = 0.59
- M/K = 1.49 (1.14–1.79)
- F/K = 2.7 (2.36–3.1)
- Z/K = 4.21 (4.04–4.4)
- F/M = 1.81 (1.33–2.74)
- B/B0 F=M Lc=Lc_opt = 0.367
- B/B0 = 0.145 (0.0902–0.227)
- Y/R' F=M Lc=Lc_opt = 0.0463
- Y/R' = 0.0227 (0.0142–0.0357) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 999:**
- Lc = 38.6 (38.3–38.9) cm, Lc/Linf = 0.32 (0.319–0.324)
- alpha = 42.3 (40.6–43.5)
- Lmean/Lopt = 0.66, Lc/Lc_opt = 0.55, L95th = 116 cm, L95th/Linf = 0.96, Lm50 = NA cm, Mature = NA%
- F/K = 2.7 (2.36–3.1)
- F/M = 1.8 (1.33–2.74)
- Z/K = 4.21 (4.04–4.4)
- Y/R' = 0.023 (0.0142–0.0357) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.14 (0.0902–0.227)
- B/Bmsy = 0.39 (0.246–0.62)

Comment: Linf = 120, Lc = 35, alpha = 60, M/K = 1.54, F/K = 1.54–3.08, F/M = 1–2, Z/K = 3.08–6.16, B/B0 = 0.142, Y/R = 0.0376
Results for stock with ages 3–3.9 with doubled numbers, stock **CodRecSim, 999–999**
(95% confidence limits in parentheses) File: SimDat_10.csv

Lin\text{f} prior = 118, s.d. = 1.18 (cm)
Z/K prior = 2.84, s.d. = 0.162, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.34 (wide range with tau=4 in log-normal distribution)
Lc prior = 34.2, s.d. = 3.42 (cm), alpha prior = 75.6, s.d. = 7.56

**General reference points:**

- Lin\text{f} = 122 (120–124) cm
- Lopt = 80 cm, Lopt/Linf = 0.65
- Lc\_opt = 67 cm, Lc\_opt/Linf = 0.55
- M/K = 1.59 (1.35–1.97)
- F/K = 1.66 (1.29–2.01)
- Z/K = 3.27 (3.11–3.42)
- F/M = 1.04 (0.664–1.46)
- B/B0 F=M \text{ Lc}=Lc\_opt = 0.364
- B/B0 = 0.24 (0.131–0.363)
- Y/R' F=M \text{ Lc}=Lc\_opt = 0.0419
- Y/R' = 0.0334 (0.0183–0.0504) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 999:**

- Lc = 32.8 (32.6–32.9) cm, Lc/Linf = 0.27 (0.267–0.27)
- alpha = 74 (71.5–76.6)
- L\text{mean}/Lopt = 0.63, Lc/Lc\_opt = 0.49, L95th = 118 cm, L95th/Linf = 0.96, Lm50 = NA cm, Mature = NA%
- F/K = 1.7 (1.29–2.01)
- F/M = 1 (0.664–1.46)
- Z/K = 3.27 (3.11–3.42)
- Y/R' = 0.033 (0.0183–0.0504) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.24 (0.131–0.363)
- B/Bmsy = 0.66 (0.361–0.998)

Comment: Lin\text{f}=120, Lc=35, alpha=60, M/K=1.54, F/K=1.54, F/M=1, Z/K=3.08, B/B0=0.277, Y/R=0.0377
3) Simulations with Gaussian selection (True values in Comment, Sim_23.xlsx, LBB_10.R)

Results for overexploited seabream, stock SeabreamGillSim, 999–1008, Gaussian selection
(95% confidence limits in parentheses) File: SimDat_10.csv

- Linf prior = 14.7, s.d. = 0.147 (cm)
- Z/K prior = 3.92, s.d. = 0.791, M/K prior = 1.5, s.d. = 0.15

**General reference points** [median across years]:
- Linf = 14.9 (14.7 – 15.2) cm
- Lopt = 10 cm, Lopt/Linf = 0.7
- Lc-opt = 9.2 cm, Lc-opt/Linf = 0.62
- M/K = 1.26 (0.994 – 1.52)
- F/K = 2.23 (1.72 – 2.41)
- Z/K = 3.49 (2.94 – 3.79)
- F/M = 1.71 (1.25 – 2.28)
- B/B0 F=M Lmean=Lopt= 0.508
- B/B0 = 0.413 (0.242 – 0.568)
- Y/R' F=M Lmean=Lopt= 0.0524
- Y/R' = 0.0411 (0.0236 – 0.0573) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 1008:**
- GLmean/Linf= 0.53, s.d./Linf = 0.131
- GLmean = 7.88, s.d. = 1.95
- F/K = 2.3 (1.83 – 2.42)
- F/M = 1.8 (1.32 – 2.31)
- Z/K = 3.51 (3.06 – 3.8)
- Y/R' = 0.042 (0.0256 – 0.0567) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.41 (0.254 – 0.564)
- B/Bmsy = 0.81 (0.5 – 1.11)

Comment: Linf=15, GLmean=8, s.d. =2, M/K=1.25, F/K=2.5, F/M=2, Z/K=3.75, B/B0=0.372, Y/R=0.0433.
Results for overexploited cod, stock **CodGillSim**, 999–1008, Gaussian selection (95% confidence limits in parentheses) File: SimDat_10.csv

<table>
<thead>
<tr>
<th>Linf prior</th>
<th>s.d. = 0.964 (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf prior</td>
<td>= 97.1 (95.5–98.8) cm</td>
</tr>
<tr>
<td>Z/K prior</td>
<td>= 4.65, s.d. = 2.1</td>
</tr>
<tr>
<td>M/K prior</td>
<td>= 1.5, s.d. = 0.15</td>
</tr>
</tbody>
</table>

**General reference points** [median across years]:

- **Linf** = 97.1 (95.5–98.8) cm
- **Lopt** = 68 cm, **Lopt**/Linf = 0.7
- **Lc_opt** = 61 cm, **Lc_opt**/Linf = 0.63
- **M/K** = 1.31 (1.04–1.6)
- **F/K** = 3.08 (2.77–3.15)
- **Z/K** = 4.36 (3.99–4.67)
- **F/M** = 2.32 (1.86–2.94)
- **B/B0** = 0.424 (0.302–0.572)
- **Y/R’** = 0.0321 (0.0226–0.043) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 1008:**

- **GLmean**/Linf = 0.46, s.d. = 0.105
- **GLmean** = 45.1, s.d. = 10.2
- **F/K** = 3.1 (2.83–3.15)
- **F/M** = 2.4 (1.93–3.11)
- **Z/K** = 4.32 (3.98–4.63)
- **Y/R’** = 0.032 (0.0225–0.0443) (linearly reduced if B/B0 < 0.25)
- **B/B0** = 0.42 (0.293–0.578)
- **B/Bmsy** = 0.74 (0.51–1.01)

Comment: Linf=120, GLmean=45, s.d. =10, M/K=1.54, F/K=4.62, F/M=3, Z/K=6.15, B/B0=0.418, Y/R=0.0181.
Results for very lightly exploited cod, stock **CodGillVeryLightSim**, 999–1008, Gaussian selection
(95% confidence limits in parentheses) File: SimDat_10.csv

Linf prior = 120, s.d. = 1.2 (cm) (user-defined)
Z/K prior = 3.63, s.d. = 0.857, M/K prior = 1.5, s.d. = 0.15

**General reference points** [median across years]:
- Linf = 120 (118–122) cm, Prior 120 set by user
- Lopt = 80 cm, Lopt/Linf = 0.67
- Lc_opt = 57 cm, Lc_opt/Linf = 0.48
- M/K = 1.51 (1.22–1.81)
- F/K = 0.267 (0.0159–1.05)
- Z/K = 1.79 (1.36–2.56)
- F/M = 0.177 (0.0102–0.718)
- B/B0 F=M Lmean=Lopt = 0.635
- B/B0 = 0.945 (0.329–5.08)
- Y/R F=M Lmean=Lopt = 0.0337
- Y/R′ = 0.0025 (−0.00069–0.0132) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 1008:**
- GLmean/Linf = 0.38, s.d./Linf = 0.0849
- GLmean = 45.6, s.d. = 10.2
- F/K = 0.85 (0.05–1.59)
- F/M = 0.58 (0.0374–1.11)
- Z/K = 2.35 (1.43–3.12)
- Y/R′ = 0.0073 (−0.00249–0.0167) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.84 (−0.285–1.91)
- B/Bmsy = 1.3 (−0.449–3.01)

Comment: Linf=120, GLmean=45, s.d. =10, M/K=1.54, F/K=0.0077, F/M=0.005, Z/K=1.55, B/B0=0.99, Y/R=0.00007.
4) Empirical data from the Northwest Atlantic (Independent assessments in Comment; LBB_10.R)

Results for *Amblyraja radiata*, stock ThornySkate, 2000–2000
(95% confidence limits in parentheses) File: ComDat_1.csv

- Linf prior = 90, s.d. = 0.9 (cm)
- Z/K prior = 6.08, s.d. = 3.8, M/K prior = 1.5, s.d. = 0.15
- F/K prior = 4.58 (wide range with tau=4 in log-normal distribution)
- Lc prior = 58.1, s.d. = 5.81 (cm), alpha prior = 37, s.d. = 3.7

**General reference points** [median across years]:
- Linf = 92.1 (90.8–93.6) cm
- Lopt = 60 cm, Lopt/Linf = 0.65
- Lc_opt = 56 cm, Lc_opt/Linf = 0.61
- M/K = 1.58 (1.36–1.91)
- F/K = 5.6 (4.76–6.27)
- Z/K = 7.17 (6.41–7.84)
- F/M = 3.56 (2.77–4.51)
- B/B0 F=M Lc=Lc_opt = 0.367
- B/B0 = 0.153 (0.107–0.208)
- Y/R’ F=M Lc=Lc_opt = 0.042
- Y/R’ = 0.0299 (0.0208–0.0406) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2000:**
- Lc = 61.5 (61.2–61.9) cm, Lc/Linf = 0.67 (0.665–0.672)
- alpha = 36.6 (35.6–37.7)
- Lmean/Lopt = 1.1, Lc/Lc_opt = 1.1, L95th = 85 cm, L95th/Linf = 0.92, Lm50 = 53 cm, Mature = 95%
- F/K = 5.6 (4.76–6.27)
- F/M = 3.5 (2.77–4.51)
- Z/K = 7.17 (6.41–7.84)
- Y/R’ = 0.03 (0.0208–0.0406) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.15 (0.107–0.208)
- B/Bmsy = 0.42 (0.291–0.567)

Results for *Leucoraja ocellata*, stock WinterSkate, 1995–2004
(95% confidence limits in parentheses) File: ComDat_1.csv

**General reference points** [median across years]:
- $L_{\text{inf}} = 112$ (110–113) cm
- $L_{\text{opt}} = 75$ cm, $L_{\text{opt}}/L_{\text{inf}} = 0.67$
- $L_{\text{c,opt}} = 65$ cm, $L_{\text{c,opt}}/L_{\text{inf}} = 0.58$
- $M/K = 1.49$ (1.25–1.76)
- $F/K = 2.15$ (1.77–2.59)
- $Z/K = 3.59$ (3.29–3.96)
- $F/M = 1.55$ (1.05–2.15)
- $B/B_0 F=M L_{c}=L_{c,opt} = 0.376$
- $B/B_0 = 0.281$ (0.164–0.422)
- $Y/R' F=M L_{c}=L_{c,opt} = 0.0461$
- $Y/R' = 0.0436$ (0.0279–0.0663) (linearly reduced if $B/B_0 < 0.25$

**Estimates for last year 2004:**
- $L_c = 73.7$ (73.3–74.1) cm, $L_c/L_{\text{inf}} = 0.65$ (0.651–0.658)
- $alpha = 37.2$ (35.7–38.7)
- $L_{\text{mean}}/L_{\text{opt}} = 1.1$, $L_c/L_{\text{c, opt}} = 1.1$, $L_{95th} = 93$ cm, $L_{95th}/L_{\text{inf}} = 0.83$, $L_{m50} = 75$ cm, Mature = 63%
- $F/K = 1.8$ (1.4–2.11)
- $F/M = 1.1$ (0.761–1.55)
- $Z/K = 3.32$ (2.99–3.64)
- $Y/R' = 0.04$ (0.0224–0.0578) (linearly reduced if $B/B_0 < 0.25$
- $B/B_0 = 0.38$ (0.213–0.55)
- $B/B_{\text{msy}} = 1$ (0.567–1.46)
- Comment: DFO (2017b)
Results for *Squalus acanthias*, stock **SpinyDogfish**, 2001–2006
(95% confidence limits in parentheses) File: ComDat_1.csv

**Linf prior** = 110, s.d. = 1.1 (cm)
**Z/K prior** = 3.48, s.d. = 0.714, **M/K prior** = 1.5, s.d. = 0.15
**F/K prior** = 1.98 (wide range with tau=4 in log-normal distribution)
**Lc prior** = 68.8, s.d. = 6.88 (cm), **alpha prior** = 39.7, s.d. = 3.97

**General reference points** [median across years]:
- **Linf** = 110 (108–111) cm
- **Lopt** = 74 cm, **Lopt/Linf** = 0.68
- **Lc_opt** = 68 cm, **Lc_opt/Linf** = 0.62
- **M/K** = 1.43 (1.15–1.7)
- **F/K** = 4.05 (3.41–4.6)
- **Z/K** = 5.44 (4.9–5.9)
- **F/M** = 2.87 (2.15–3.84)
- **B/B0** **F=M Lc=Lc_opt** = 0.37
- **Y/R'** **F=M Lc=Lc_opt** = 0.0495

**Estimates for last year 2006:**
- **Lc** = 74.8 (74.5–75.3) cm, **Lc/Linf** = 0.68 (0.68–0.687)
- **alpha** = 39.3 (37.8–40.6)
- **Lmean/Lopt** = 1.1, **Lc_opt = 1.1**, **L95th = 107 cm**, **L95th/Linf = 0.98**, **Lm50 = 82.1 cm**, **Mature = 23%**
- **F/K** = 3.1 (2.75–3.79)
- **F/M** = 2 (1.61–3.23)
- **Z/K** = 4.56 (4.29–5.08)
- **Y/R'** = 0.048 (0.0323–0.0803) (linearly reduced if B/B0 < 0.25)
- **B/B0** = 0.25 (0.166–0.413)
- **B/Bmsy** = 0.67 (0.449–1.12)

Comment: DFO (2014); Fowler and Campana (2015). Lm50 from Campana *et al.* (2009)
5) Empirical data from the North Sea (Independent assessments in Comment; LBB_11.R)

Results for Clupea harengus, stock her.27.3a47d, 2010–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

Lin0 prior = 34.5, s.d. = 0.345 (cm)
Z/K prior = 2.78, s.d. = 1.54, M/K prior = 1.75, s.d. = 0.075 (user-defined)
F/K prior = 1.03 (wide range with tau=4 in log-normal distribution)
Lc prior = 26.5, s.d. = 2.65 (cm), alpha prior = 37, s.d. = 3.7

General reference points [median across years]:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf</td>
<td>34.4 (34.1–34.9) cm</td>
</tr>
<tr>
<td>Lopt</td>
<td>22 cm, Lopt/Linf = 0.64</td>
</tr>
<tr>
<td>Lc_opt</td>
<td>20 cm, Lc_opt/Linf = 0.59</td>
</tr>
<tr>
<td>M/K</td>
<td>1.68 (1.55–1.84)</td>
</tr>
<tr>
<td>F/K</td>
<td>4.76 (4.5–5.99)</td>
</tr>
<tr>
<td>Z/K</td>
<td>6.42 (5.76–7.6)</td>
</tr>
<tr>
<td>F/M</td>
<td>2.89 (2.28–3.81)</td>
</tr>
<tr>
<td>B/B0</td>
<td>0.243 (0.176–0.395)</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.0255 (0.018–0.0328) (linearly reduced if B/B0 &lt; 0.25)</td>
</tr>
</tbody>
</table>

Estimates for last year 2014:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lc</td>
<td>28.7 (28.6–28.8) cm, Lc/Linf = 0.83 (0.831–0.837)</td>
</tr>
<tr>
<td>alpha</td>
<td>43 (42.1–43.9)</td>
</tr>
<tr>
<td>Lmean/Lopt</td>
<td>1.3, Lc/Lc_opt = 1.4, L95th = 33 cm, L95th/Linf = 0.96, Lm50 = 24.1 cm, Mature = 100%</td>
</tr>
<tr>
<td>F/K</td>
<td>5.1 (4.14–5.99)</td>
</tr>
<tr>
<td>F/M</td>
<td>3.1 (2.47–3.81)</td>
</tr>
<tr>
<td>Z/K</td>
<td>6.68 (5.76–7.6)</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.026 (0.018–0.0328) (linearly reduced if B/B0 &lt; 0.25)</td>
</tr>
<tr>
<td>B/B0</td>
<td>0.23 (0.162–0.295)</td>
</tr>
<tr>
<td>B/Bmsy</td>
<td>0.59 (0.414–0.756)</td>
</tr>
</tbody>
</table>

Comment: Gear=OTM_SPF_32–69_0_0. ICES 2014 F/Fmsy=0.67 (0.54–0.82), proxy B/Bmsy=0.65 (0.57–0.75). Lm50 from Froese and Sampang (2013).
Results for *Melanogrammus aeglefinus*, stock **had.27.46a20**, 2010–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 74.9, s.d. = 0.749 (cm)
Z/K prior = 2.82, s.d. = 0.696, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.32 (wide range with tau=4 in log-normal distribution)
Lc prior = 34.2, s.d. = 3.42 (cm), alpha prior = 14.7, s.d. = 1.47

**General reference points** [median across years]:
Linf = 75.4 (74.7–76.4) cm
Lopt = 55 cm, Lopt/Linf = 0.73
Lc_opt = 50 cm, Lc_opt/Linf = 0.66
M/K = 1.14 (0.927–1.41)
F/K = 3.05 (2.66–3.44)
Z/K = 4.08 (3.81–4.46)
F/M = 2.9 (2.13–4.47)

B/B0 F=M Lc=Lc_opt = 0.382
B/B0 = 0.146 (0.0941–0.227)
Y/R’ F=M Lc=Lc_opt = 0.0671
Y/R’ = 0.0429 (0.0263–0.0769) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2014:**
Lc = 50.3 (49.6–50.9) cm, Lc/Linf = 0.67 (0.661–0.679)
alpha = 16.2 (15.7–16.6)
Lmean/Lopt = 1, Lc/Lc_opt = 1, L95th = 69 cm, L95th/Linf = 0.92, Lm50 = 33 cm, Mature = 93%
F/K = 4.5 (3.64–5.11)
F/M = 3.6 (2.7–4.93)
Z/K = 5.68 (4.9–6.27)
Y/R’ = 0.041 (0.0263–0.0597) (linearly reduced if B/B0 < 0.25)
B/B0 = 0.15 (0.0941–0.214)
B/Bmsy = 0.38 (0.247–0.56)

Comment: Gear=OTB DEF >=120 0 0; ICES (2014) F/Fmsy=1.55 (1.24–1.91), proxy SSB/Bmsy=0.69 (0.60–0.77).
Results for *Pleuronectes platessa*, stock ple.27.420, 2010–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 55, s.d. = 0.55 (cm) (user-defined)
Z/K prior = 4.05, s.d. = 0.107, M/K prior = 1.5, s.d. = 0.15
F/K prior = 2.55 (wide range with tau=4 in log-normal distribution)
Lc prior = 20.9, s.d. = 2.09 (cm), alpha prior = 14.7, s.d. = 1.47

**General reference points** [median across years]:
- Linf = 55.6 (54.6–56.5) cm
- Lopt = 38 cm, Lopt/Linf = 0.68
- Lc_opt = 34 cm, Lc_opt/Linf = 0.61
- M/K = 1.38 (1.16–1.63)
- F/K = 2.9 (2.52–3.32)
- Z/K = 4.12 (3.88–4.49)
- F/M = 2.14 (1.62–2.74)
- B/B0 F=M Lc=Lc_opt = 0.37
- B/B0 = 0.135 (0.0981–0.192)
- Y/R’ F=M Lc=Lc_opt = 0.0506
- Y/R’ = 0.0251 (0.0152–0.0356) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2014:**
- Lc = 19.5 (19–20.1) cm, Lc/Linf = 0.36 (0.354–0.374)
- alpha = 16.4 (15.7–17)
- Lmean/Lopt = 0.69, Lc/Lc_opt = 0.57, L95th = 47 cm, L95th/Linf = 0.87, Lm50 = 22.1 cm, Mature = 49%
- F/K = 2.9 (2.52–3.36)
- F/M = 2.4 (1.84–3.46)
- Z/K = 4.11 (3.78–4.49)
- Y/R’ = 0.023 (0.0152–0.0356) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.11 (0.0718–0.168)
- B/Bmsy = 0.3 (0.194–0.435)

Comment: TBB_DEF_70–99_0_0; ICES (2014) F/Fmsy=0.95 (0.81–1.1), proxy SSB/Bmsy=1.4 (1.2–1.6). Lm50 from Froese and Sampang (2013)
Results for *Pollachius virens*, stock *pok.27.3a46*, 2010–2014 (95% confidence limits in parentheses) File: ComDat_1.csv

**General reference points** [median across years]:

- Linf prior = 120, s.d. = 1.2 (cm) (user-defined)
- Z/K prior = 3.78, s.d. = 0.106, M/K prior = 1.5, s.d. = 0.15
- F/K prior = 2.28 (wide range with tau=4 in log-normal distribution)
- Lc prior = 43.4, s.d. = 4.33 (cm), alpha prior = 94.8, s.d. = 9.48

**Estimates for last year 2014:**

- Lc = 43.2 (43–43.4) cm, Lc/Linf = 0.34 (0.335–0.338)
- alpha = 86.9 (83.2–91.6)
- Lmean/Lopt = 0.7, Lc/Lc_opt = 0.62, L95th = 118 cm, L95th/Linf = 0.92, Lm50 = 55 cm, Mature = 39%
- F/K = 2.3 (2.02–2.67)
- F/M = 1.4 (1.09–2.2)
- Z/K = 3.87 (3.7–4.06)
- Y/R' = 0.03 (0.0189–0.0466) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.19 (0.123–0.304)
- B/Bmsy = 0.53 (0.336–0.83)

Comment: OTB_DEF_>=120_0_0. ICES (2014) F/Fmsy=0.89 (0.64–1.2), proxy SSB/Bmsy=0.69 (0.55–0.88). Lm50 from FishBase.
Results for *Scophthalmus maximus*, stock tur.27.4, 2010–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

\[
\begin{align*}
\text{Linf prior} & = 81.5, \text{ s.d.} = 0.815 \text{ (cm)} \\
\text{Z/K prior} & = 5.25, \text{ s.d.} = 3.37, \text{ M/K prior} = 1.5, \text{ s.d.} = 0.15 \\
\text{F/K prior} & = 3.75 \text{ (wide range with tau=4 in log-normal distribution)} \\
\text{Lc prior} & = 26.5, \text{ s.d.} = 2.65 \text{ (cm)}, \text{ alpha prior} = 52.9, \text{ s.d.} = 5.29
\end{align*}
\]

**General reference points** [median across years]:

\[
\begin{align*}
\text{Linf} & = 82.6 \text{ (81.1–84 cm)} \\
\text{Lopt} & = 55 \text{ cm}, \text{ Lopt/Linf} = 0.67 \\
\text{Lc_opt} & = 49 \text{ cm}, \text{ Lc_opt/Linf} = 0.59 \\
\text{M/K} & = 1.47 \text{ (1.2–1.74)} \\
\text{F/K} & = 2.63 \text{ (2.31–3)} \\
\text{Z/K} & = 4.12 \text{ (3.87–4.32)} \\
\text{F/M} & = 1.76 \text{ (1.34–2.4)} \\
\text{B/B0 F=M Lc} & = \text{Lc_opt} = 0.368 \\
\text{B/B0} & = 0.143 \text{ (0.0977–0.203)} \\
\text{Y/R' F=M Lc} & = \text{Lc_opt} = 0.0473 \\
\text{Y/R'} & = 0.0221 \text{ (0.015–0.0315)} \text{ (linearly reduced if B/B0 < 0.25)}
\end{align*}
\]

**Estimates for last year 2014:**

\[
\begin{align*}
\text{Lc} & = 24.5 \text{ (24.4–24.7 cm)}, \text{ Lc/Linf} = 0.3 \text{ (0.296–0.3)} \\
\text{alpha} & = 54.1 \text{ (51.1–56.2)} \\
\text{Lmean/Lopt} & = 0.64, \text{ Lc/Lc_opt} = 0.5, \text{ L95th} = 59 \text{ cm}, \text{ L95th/Linf} = 0.72, \text{ Lm50} = 28 \text{ cm}, \text{ Mature} = 79\% \\
\text{F/K} & = 1.2 \text{ (0.986–1.53)} \\
\text{F/M} & = 0.84 \text{ (0.65–1.32)} \\
\text{Z/K} & = 2.65 \text{ (2.47–2.81)} \\
\text{Y/R'} & = 0.042 \text{ (0.0263–0.0677)} \text{ (linearly reduced if B/B0 < 0.25)} \\
\text{B/B0} & = 0.31 \text{ (0.198–0.511)} \\
\text{B/Bmsy} & = 0.85 \text{ (0.539–1.39)}
\end{align*}
\]

Comment: Gear=TBBDDEF_70–99_0_0; ICES (2014) F/Fmsy=0.63 (0.48–0.84), SSB/Bmsy=1.18 (0.87–1.61). Lm50 from Froese and Sampang (2013)
Results for *Solea solea*, stock **sol.27.4**, 2011–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 50, s.d. = 0.5 (cm) (user-defined)
Z/K prior = 4.62, s.d. = 0.0379, M/K prior = 1.5, s.d. = 0.15
F/K prior = 3.12 (wide range with tau=4 in log-normal distribution)
Lc prior = 25.5, s.d. = 2.55 (cm), alpha prior= 65, s.d. = 6.5

**General reference points** [median across years]:
- Linf = 49.5 (48.7–50.2) cm
- Lopt = 35 cm, Lopt/Linf = 0.7
- Lc_opt = 32 cm, Lc_opt/Linf = 0.64
- M/K = 1.27 (1.01–1.56)
- F/K = 3.6 (3.1–3.97)
- Z/K = 4.65 (4.37–4.9)
- F/M = 2.65 (1.94–3.59)
- B/B0 F=M Lc=Lc_opt = 0.371
- B/B0 = 0.143 (0.0913–0.205)
- Y/R' F=M Lc=Lc_opt = 0.058
- Y/R' = 0.0332 (0.0202–0.0534) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2014:**
- Lc = 27.5 (27.3–27.7) cm, Lc/Linf = 0.53 (0.53–0.537)
- alpha = 36.8 (35.1–37.9)
- Lmean/Lopt = 0.95, Lc/Lc_opt = 0.87, L95th = 49 cm, L95th/Linf = 0.95, Lm50 = 18.8 cm, Mature = 100%
- F/K = 3.9 (3.21–4.21)
- F/M = 2.3 (1.56–2.73)
- Z/K = 5.57 (5.17–5.88)
- Y/R' = 0.031 (0.0194–0.0406) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.18 (0.115–0.241)
- B/Bmsy = 0.49 (0.31–0.649)

Comment: Gear=TBB_DEF_70–99_0_0; ICES (2014) F/Fmsy=1.5 (1.15–1.8), proxy SSB/Bmsy=0.57 (0.46–0.69). Lm50 from Froese and Sampang (2013)
6) Empirical data from the Mediterranean (Independent assessments in Comment; LBB_11.R)

Results for Aristaeus antennatus, stock ARA-GSA01, 2005–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 7.92, s.d. = 0.0792 (cm)
Z/K prior = 4.88, s.d. = 0.915, M/K prior = 1.5, s.d. = 0.15
F/K prior = 3.35 (wide range with tau=4 in log-normal distribution)
Lc prior = 2.35, s.d. = 0.235 (cm), alpha prior = 51.5, s.d. = 5.15

General reference points [median across years]:
Linf = 7.88 (7.74–8.05) cm
Lopt = 5.3 cm, Lopt/Linf = 0.67
Lc_opt = 4.7 cm, Lc_opt/Linf = 0.6
M/K = 1.48 (1.2–1.8)
F/K = 3.35 (2.9–3.71)
Z/K = 4.75 (4.53–4.99)
F/M = 2.19 (1.59–3.12)
B/B0 F=M Lc=Lc_opt = 0.367
B/B0 = 0.117 (0.075–0.16)
Y/R’ F=M Lc=Lc_opt = 0.0468
Y/R’ = 0.017 (0.0111–0.0232) (linearly reduced if B/B0 < 0.25)

Estimates for last year 2015:
Lc = 2.26 (2.25–2.28) cm, Lc/Linf = 0.28 (0.281–0.285)
alpha = 53.5 (51.6–55.3)
Lmean/Lopt = 0.61, Lc/Lc_opt = 0.48, L95th = 6 cm, L95th/Linf = 0.75, Lm50 = 1.5 cm, Mature = 100%
F/K = 2.6 (2.32–2.86)
F/M = 1.8 (1.42–2.36)
Z/K = 4.04 (3.84–4.24)
Y/R’ = 0.02 (0.0141–0.0273) (linearly reduced if B/B0 < 0.25)
B/B0 = 0.13 (0.0947–0.183)
B/Bmsy = 0.37 (0.258–0.498)

Comment: F/Fmsy2015=1.9 in official assessment, which matches with LBB F/M=1.6–3.1 and B/Bmsy=0.17–0.34.
Results for *Aristeus antennatus*, stock ARA-GSA05, 2002–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

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Linf prior = 7.92, s.d. = 0.0792 (cm)
Z/K prior = 4.57, s.d. = 1.12, M/K prior = 1.5, s.d. = 0.15
F/K prior = 3.07 (wide range with tau=4 in log-normal distribution)
Lc prior = 2.14, s.d. = 0.214 (cm), alpha prior = 75.1, s.d. = 7.51

**General reference points** [median across years]:
- Linf = 7.8 (7.65–7.92) cm
- Lopt = 5.2 cm, Lopt/Linf = 0.67
- Lc_opt = 4.6 cm, Lc_opt/Linf = 0.59
- M/K = 1.49 (1.2–1.78)
- F/K = 2.77 (2.4–3.2)
- Z/K = 4.25 (4.06–4.48)
- F/M = 1.85 (1.39–2.68)
- B/B0 F=M Lc=Lc_opt = 0.367
- B/B0 = 0.125 (0.077–0.192)
- Y/R' F=M Lc=Lc_opt = 0.0466
- Y/R' = 0.0175 (0.0107–0.0273) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2015:**
- Lc = 2.17 (2.15–2.18) cm, Lc/Linf = 0.29 (0.283–0.287)
- alpha = 69.8 (66.7–72.7)
- Lmean/Lopt = 0.64, Lc/Lc_opt = 0.47, L95th = 6.3 cm, L95th/Linf = 0.83, Lm50 = 1.5 cm, Mature = 100%
- F/K = 2.2 (1.88–2.42)
- F/M = 1.4 (1.11–1.85)
- Z/K = 3.69 (3.49–3.9)
- Y/R' = 0.026 (0.018–0.0356) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.18 (0.122–0.241)
- B/Bmsy = 0.48 (0.332–0.656)

Comment: F/Fmsy2015=1.0 in official assessment.
Results for *Aristaeomorpha foliacea*, stock ARS-GSA18-19, 2009–2014 (95% confidence limits in parentheses) File: ComDat_1.csv

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Linf prior = 7.16, s.d. = 0.0716 (cm)
Z/K prior = 6.67, s.d. = 5.48, M/K prior = 1.5, s.d. = 0.15
F/K prior = 5.17 (wide range with tau=4 in log-normal distribution)
Lc prior = 2.5, s.d. = 0.25 (cm), alpha prior = 27.9, s.d. = 2.79

**General reference points** [median across years]:

- Linf = 7.03 (6.94–7.12) cm
- Lopt = 5 cm, Lopt/Linf = 0.71
- Lc_opt = 4.7 cm, Lc_opt/Linf = 0.66
- M/K = 1.23 (0.971–1.57)
- F/K = 5.63 (5.14–6.14)
- Z/K = 6.97 (6.59–7.39)
- F/M = 4.29 (3.19–5.63)
- B/B0 F=M Lc=Lc_opt = 0.377

**Estimates for last year 2014:**

- Lc = 2.81 (2.79–2.82) cm, Lc/Linf = 0.4 (0.402–0.406)
- alpha = 37.9 (37.1–38.7)
- Lmean/Lopt = 0.68, Lc/Lc_opt = 0.6, L95th = 5.7 cm, L95th/Linf = 0.82, Lm50 = 3.3 cm, Mature = 29%
- F/K = 5.8 (5.3–6.25)
- F/M = 5.1 (3.54–6.64)
- Z/K = 6.92 (6.61–7.34)
- Y/R' = 0.01 (0.00666–0.0153) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.05 (0.0315–0.0727)
- B/Bmsy = 0.13 (0.0836–0.193)

Comment: LFs with multiple peaks (Recruitment? Gillnets included?). F/Fmsy2014=1.1 in official assessment.
Results for *Engraulis encrasicolus*, stock **ANE-GSA06**, 2005–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

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**Linf prior** = 18, s.d. = 0.18 (cm)
**Z/K prior** = 2.62, s.d. = 1.01 , **M/K prior** = 1.5, s.d. = 0.15
**F/K prior** = 1.12 (wide range with tau=4 in log-normal distribution)

**Lc prior** = 10.7, s.d. = 1.07 (cm), alpha prior = 26.4, s.d. = 2.64

**General reference points** [median across years]:
- **Linf** = 17.5 (17.3–17.6) cm
- **Lopt** = 12 cm, **Lopt/Linf** = 0.68
- **Lc_opt** = 10 cm, **Lc_opt/Linf** = 0.58
- **M/K** = 1.39 (1.11–1.58)
- **F/K** = 2.1 (1.43–2.45)
- **Z/K** = 3.05 (2.88–3.51)
- **F/M** = 1.17 (0.549–1.87)
- **B/B0 F=M Lc=Lc_opt** = 0.37
- **Y/R’ F=M Lc=Lc_opt** = 0.0505
- **Y/R’** = 0.0286 (0.0122–0.0529) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2015**: 
- **Lc** = 11.1 (11–11.1) cm, **Lc/Linf** = 0.66 (0.659–0.668)
- **alpha** = 28.1 (27.3–28.9)
- **Lmean/Lopt** = 1.1, **Lc/Lc_opt** = 1.1, **L95th** = 16 cm, **L95th/Linf** = 0.96, **Lm50** = 12 cm, **Mature = 22%**
- **F/K** = 2.4 (1.95–2.77)
- **F/M** = 2 (1.35–2.57)
- **Z/K** = 3.66 (3.22–3.99)
- **Y/R’** = 0.068 (0.0392–0.0936) (linearly reduced if B/B0 < 0.25)
- **B/B0** = 0.24 (0.14–0.335)
- **B/Bmsy** = 0.65 (0.378–0.904)

Comment: **F/Fmsy2015=0.9** in official assessment.

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(95% confidence limits in parentheses) File: ComDat_1.csv

$L_{\text{inf}}$ prior = 18, s.d. = 0.18 (cm)
$Z/K$ prior = 3.55, s.d. = 1.3, $M/K$ prior = 1.5, s.d. = 0.15
$F/K$ prior = 2.05 (wide range with tau=4 in log-normal distribution)
$L_c$ prior = 11.2, s.d. = 1.12 (cm), $\alpha$ prior = 40.3, s.d. = 4.03

**General reference points** [median across years]:
- $L_{\text{inf}}$ = 18.2 (17.9–18.5) cm
- $L_{\text{opt}}$ = 12 cm, $L_{\text{opt}}/L_{\text{inf}}$ = 0.66
- $L_{c_{\text{opt}}}$ = 11 cm, $L_{c_{\text{opt}}}/L_{\text{inf}}$ = 0.58
- $M/K$ = 1.57 (1.29–1.87)
- $F/K$ = 3.1 (2.45–3.65)
- $Z/K$ = 4.88 (4.34–5.4)
- $F/M$ = 1.76 (1.24–2.46)
- $B/B_0$ $F=M$ $L_c=L_{c\text{ opt}}$ = 0.363
- $B/B_0$ = 0.289 (0.17–0.42)
- $Y/R'$ $F=M$ $L_c=L_{c\text{ opt}}$ = 0.0424
- $Y/R'$ = 0.0394 (0.0245–0.058) (linearly reduced if $B/B_0 < 0.25$)

**Estimates for last year 2014:**
- $L_c$ = 12.2 (12–12.3) cm, $L_c/L_{\text{inf}}$ = 0.67 (0.667–0.679)
- $\alpha$ = 26.2 (25.2–27)
- $L_{\text{mean}}/L_{\text{opt}}$ = 1.2, $L_c/L_{c_{\text{opt}}}$ = 1.2, $L_{95th}$ = 17 cm, $L_{95th}/L_{\text{inf}}$ = 0.94, $L_{50}$ = 10 cm, Mature = 91%
- $F/K$ = 3.1 (2.49–3.64)
- $F/M$ = 1.5 (1.2–2.05)
- $Z/K$ = 5.08 (4.58–5.61)
- $Y/R'$ = 0.025 (0.0169–0.0353) (linearly reduced if $B/B_0 < 0.25$)
- $B/B_0$ = 0.32 (0.219–0.457)
- $B/B_{\text{msy}}$ = 0.89 (0.604–1.26)

Comment: $F/F_{\text{msy2015}}=1.8$ in official assessment.
Results for *Engraulis encrasicolus*, stock *Eengr_Aegean*, 2003–2008
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 19, s.d. = 0.19 (cm)
Z/K prior = 6.74, s.d. = 3.74, M/K prior = 1.5, s.d. = 0.15
F/K prior = 5.24 (wide range with tau=4 in log-normal distribution)
Lc prior = 11.7, s.d. = 1.17 (cm), alpha prior = 32.3, s.d. = 3.23

**General reference points** [median across years]:
- Linf = 18.9 (18.5–19.3) cm
- Lopt = 13 cm, Lopt/Linf = 0.67
- Lc_opt = 12 cm, Lc_opt/Linf = 0.63
- M/K = 1.49 (1.25–1.83)
- F/K = 8.33 (7.14–9.87)
- Z/K = 10.4 (9.13–11.9)
- F/M = 4.52 (3.62–5.89)
- B/B0 F=M, Lc=Lc_opt = 0.367
- B/B0 = 0.132 (0.086–0.178)
- Y/R' F=M, Lc_opt = 0.0462
- Y/R' = 0.019 (0.0129–0.0268) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2008:**
- Lc = 12.1 (12–12.1) cm, Lc/Linf = 0.66 (0.657–0.664)
- alpha = 38.1 (37.1–38.9)
- Lmean/Lopt = 0.97, Lc/Lc_opt = 1, L95th = 14.5 cm, L95th/Linf = 0.79, Lm50 = 11 cm, Mature = 88%
- F/K = 5.5 (5.03–6.23)
- F/M = 5.1 (3.86–7.05)
- Z/K = 6.65 (6.12–7.19)
- Y/R' = 0.036 (0.023–0.0522) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.099 (0.0639–0.145)
- B/Bmsy = 0.27 (0.174–0.396)

Comment: Official 2008 assessment F/Fmsy=1.5 and B/Bmsy=0.44. Lm50 from Tsikliiras and Stergiou (2014)
Results for Merluccius merluccius, stock HKE-GSA09, 2006–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 96.9, s.d. = 0.969 (cm)
Z/K prior = 11.5, s.d. = 5.71 , M/K prior = 1.5, s.d. = 0.15
F/K prior = 10 (wide range with tau=4 in log-normal distribution)
Lc prior = 8.67, s.d. = 0.867 (cm), alpha prior = 50.7, s.d. = 5.07

General reference points [median across years]:
Linf               = 96.7 (94.8–98.2) cm
Lopt               = 65 cm, Lopt/Linf = 0.67
Lc_opt             = 63 cm, Lc_opt/Linf = 0.65
M/K                = 1.47 (1.17–1.77)
F/K                = 11.8 (11.3–12.3)
Z/K                = 13.2 (12.8–13.7)
F/M                = 8.27 (6.76–10.8)
B/B0 F=M Lc=Lc_opt = 0.368
B/B0               = 0.00469 (0.00335–0.00635)
Y/R' F=M Lc=Lc_opt = 0.0474
Y/R'               = 0.000109 (7.8e–05–0.000145) (linearly reduced if B/B0 < 0.25)

Estimates for last year 2015:
Lc         = 7.71 (7.59–7.82) cm, Lc/Linf = 0.081 (0.0798–0.0822)
alpha      = 60.9 (59–62.9)
Lmean/Lopt = 0.25, Lc/Lc_opt = 0.12, L95th = 77 cm, L95th/Linf = 0.81, Lm50 = 35 cm, Mature = 1.5%
F/K        = 8.1 (7.66–8.53)
F/M        = 5.7 (4.44–7.01)
Z/K        = 9.61 (9.29–9.91)
Y/R'       = 0.00018 (0.000132–0.000247) (linearly reduced if B/B0 < 0.25)
B/B0       = 0.0071 (0.00507–0.00952)
B/Bmsy     = 0.019 (0.0138–0.0259)
Comment: F/Fmsy2015=3.8 in official assessment.
Results for *Merluccius merluccius*, stock HKE-GSA17-18, 2009–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

---

Linf prior = 77.9, s.d. = 0.779 (cm)
Z/K prior = 7.73, s.d. = 2.75, M/K prior = 1.5, s.d. = 0.15
F/K prior = 6.23 (wide range with tau=4 in log-normal distribution)
Lc prior = 15.3, s.d. = 1.53 (cm), alpha prior = 9.6, s.d. = 0.96

**General reference points** [median across years]:

Linf = 75.1 (73.4–76.3) cm
Lopt = 55 cm, Lopt/Linf = 0.73
Lc_opt = 53 cm, Lc_opt/Linf = 0.7
M/K = 1.12 (0.902–1.38)
F/K = 7.25 (6.91–8.09)
Z/K = 7.94 (7.58–8.7)
F/M = 8.33 (6.48–10.9)
B/B0 F=M Lc=Lc_opt = 0.382
B/B0 = 0.0141 (0.00986–0.0197)
Y/R' F=M Lc=Lc_opt = 0.069
Y/R' = 0.00146 (0.00102–0.00203) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2015:**

Lc = 23.9 (23–24.6) cm, Lc/Linf = 0.32 (0.306–0.328)
alpha = 11.9 (11.5–12.3)
Lmean/Lopt = 0.49, Lc/Lc_opt = 0.45, L95th = 66 cm, L95th/Linf = 0.88, Lm50 = 33 cm, Mature = 5.7%
F/K = 10 (9.55–11.3)
F/M = 12 (9.06–18.1)
Z/K = 11.3 (10.4–12.1)
Y/R' = 8e–04 (0.000455–0.00131) (linearly reduced if B/B0 < 0.25)
B/B0 = 0.0077 (0.00438–0.0126)
B/Bmsy = 0.02 (0.0115–0.0329)

Comment: F/Fmsy2015=2.6 in official assessment.
Results for *Merluccius merluccius*, stock **Mmer_Aegean**, 2004–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>(95% Confidence Limits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf prior</td>
<td>88 cm</td>
<td>(88.7–92.1) cm</td>
</tr>
<tr>
<td>Z/K prior</td>
<td>6.29</td>
<td>(0.573–1.5)</td>
</tr>
<tr>
<td>F/K prior</td>
<td>4.79</td>
<td>(wide range with tau=4 in log-normal distribution)</td>
</tr>
<tr>
<td>Lc prior</td>
<td>13.3 cm</td>
<td>(1.33–5.21 cm)</td>
</tr>
</tbody>
</table>

### General reference points [median across years]:
- **Linf** = 90.5 (88.7–92.1) cm
- **Lopt** = 58 cm, **Lopt/Linf** = 0.64
- **Lc_opt** = 56 cm, **Lc_opt/Linf** = 0.61
- **M/K** = 1.67 (1.38–1.98)
- **F/K** = 9.4 (8.79–10.2)
- **Z/K** = 10.5 (9.92–11.2)
- **F/M** = 6.52 (5.37–8.28)
- **B/B0 F=M Lc=Lc_opt = 0.36**
- **B/B0** = 0.0226 (0.0169–0.0299)
- **Y/R' F=M Lc=Lc_opt = 0.0384**
- **Y/R' = 0.00165 (0.00123–0.00218)** (linearly reduced if B/B0 < 0.25)

### Estimates for last year 2014:
- **Lc** = 16 (15.8–16.4) cm, **Lc/Linf** = 0.18 (0.174–0.181)
- **alpha** = 38.7 (37–40.6)
- **Lmean/Lopt** = 0.45, **Lc/Lc_opt** = 0.29, **L95th = 76 cm, L95th/Linf = 0.84, Lm50 = 30 cm, Mature = 18%**
- **F/K** = 5.1 (4.76–5.53)
- **F/M** = 3.2 (2.57–4.05)
- **Z/K** = 6.78 (6.43–7.01)
- **Y/R' = 0.0027 (0.00194–0.00357)** (linearly reduced if B/B0 < 0.25)
- **B/B0** = 0.039 (0.0283–0.0522)
- **B/Bmsy** = 0.1 (0.0787–0.145)

Comment: Official assessment F/Fmsy2007=4.68. Lm50 from Tsikliras and Stergiou (2014)
Results for *Merluccius merluccius*, stock **Mmer_Ionian**, 2014–2016
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 75.9, s.d. = 0.759 (cm)
Z/K prior = 8.79, s.d. = 22.7, M/K prior = 1.5, s.d. = 0.15
F/K prior = 7.29 (wide range with tau=4 in log-normal distribution)
Lc prior = 20.4, s.d. = 2.04 (cm), alpha prior = 15.6, s.d. = 1.56

**General reference points** [median across years]:

- Linf = 76.1 (74.8–77.3) cm
- Lopt = 52 cm, Lopt/Linf = 0.69
- Lc_opt = 51 cm, Lc_opt/Linf = 0.67
- M/K = 1.38 (1.12–1.65)
- F/K = 13.5 (12.6–14.5)
- Z/K = 14.8 (14–16)
- F/M = 10.7 (8.56–14)
- B/B0 F=M Lc=Lc_opt = 0.37
- B/B0 = 0.0194 (0.0144–0.0256)
- Y/R' F=M Lc=Lc_opt = 0.0508
- Y/R' = 0.00195 (0.00143–0.00261) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2016:**

- Lc = 30.4 (30.1–30.9) cm, Lc/Linf = 0.41 (0.404–0.414)
- alpha = 19.8 (9.4–20.3)
- Lmean/Lopt = 0.67, Lc/Lc_opt = 0.6, L95th = 68 cm, L95th/Linf = 0.91, Lm50 = 30 cm, Mature = 17%
- F/K = 17 (16.2–18.4)
- F/M = 15 (12–20.7)
- Z/K = 18.2 (17.3–19.6)
- Y/R' = 0.0015 (0.000996–0.00211) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.011 (0.00718–0.0152)
- B/Bmsy = 0.029 (0.0194–0.0412)

Comment: Official assessment F/Fmsy2016=2.62 and B/Bmsy2016=0.34. Lm50 from Tsikliras and Stergiou (2014)
Results for *Mullus barbatus*, stock MUT-GSA25, 2005–2015 (95% confidence limits in parentheses) File: ComDat_1.csv

- **Linf** prior = 26, s.d. = 0.26 (cm) (user-defined)
- **Z/K** prior = 4.62, s.d. = 0.183, **M/K** prior = 1.5, s.d. = 0.15
- **F/K** prior = 3.12 (wide range with tau=4 in log-normal distribution)
- **Lc** prior = 12.2, s.d. = 1.22 (cm), **alpha** prior = 42.2, s.d. = 4.22

**General reference points** [median across years]:
- **Linf** = 26.5 (26–26.9) cm
- **Lopt** = 18 cm, **Lc_opt/Linf** = 0.66
- **Lc_opt** = 16 cm, **Lc_opt/Linf** = 0.6
- **M/K** = 1.52 (1.27–1.77)
- **F/K** = 3.81 (3.28–4.22)
- **Z/K** = 5.44 (5.14–5.77)
- **F/M** = 2.37 (1.75–3.2)
- **B/B0** F=M Lc=Lc_opt = 0.366
- **B/B0** = 0.146 (0.101–0.207)
- **Y/R’ F=M Lc=Lc_opt** = 0.0447
- **Y/R’** = 0.0263 (0.0174–0.0359) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2015:**
- **Lc** = 12.4 (12.3–12.5) cm, **Lc/Linf** = 0.47 (0.467–0.474)
- **alpha** = 37.8 (35.4–39.2)
- **Lmean/Lopt** = 0.87, **Lc/Lc_opt** = 0.79, **L95th** = 25 cm, **L95th/Linf** = 0.95, **Lm50** = 9 cm, Mature = 100%
- **F/K** = 2.2 (1.79–2.59)
- **F/M** = 1.4 (1.06–2.01)
- **Z/K** = 3.69 (3.44 – 3.95)
- **Y/R’** = 0.047 (0.0286–0.0681) (linearly reduced if B/B0 < 0.25)
- **B/B0** = 0.25 (0.151–0.36)
- **B/Bmsy** = 0.67 (0.413–0.985)

Comment: **F/Fmsy2015**=1.0 in official assessment.
Results for *Mullus barbatus*, stock MUT-GSA6, 2006–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 290, s.d. = 2.9 (cm)
Z/K prior = 3.86, s.d. = 0.533, M/K prior = 1.5, s.d. = 0.15
F/K prior = 2.36 (wide range with tau=4 in log-normal distribution)
Lc prior = 117, s.d. = 11.7 (cm), alpha prior = 13.8, s.d. = 1.38

**General reference points** [median across years]:
- Linf' = 285 (282–289) mm
- Lopt = 202 mm, Lopt/Linf' = 0.71
- Lc_opt = 185 mm, Lc_opt/Linf = 0.65
- M/K = 1.23 (0.978–1.48)
- F/K = 2.98 (2.65–3.42)
- Z/K = 4.38 (4.03–4.75)
- F/M = 3.06 (2.21–4.51)
- B/B0 F=M Lc=Lc_opt = 0.377
- Y/R' F=M Lc_opt = 0.0604

**Estimates for last year 2015:**
- Lc = 142 (140–144) mm, Lc/Linf = 0.5 (0.493–0.507)
- alpha = 16.7 (16.2–17.2)
- Lmean/Lopt = 0.79, Lc/Lc_opt = 0.77, L95th = 280 mm, L95th/Linf = 0.98, Lm50 = 12 mm, Mature = 100%
- F/K = 3 (2.54–3.35)
- F/M = 3.4 (2.21–4.97)
- Z/K = 3.81 (3.61–4.18)
- Y/R' = 0.038 (0.0207–0.0569) (linearly reduced if B/B0 < 0.25)

Comment: F/Fmsy=1.6 in official assessment.
Results for *Mullus barbatus*, stock **Mbar_Aegean**, 2003–2016
(95% confidence limits in parentheses) File: ComDat_1.csv

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>(95% Confidence Limits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf</td>
<td>31.0 cm</td>
<td>28.7 cm–30.1 cm</td>
</tr>
<tr>
<td>Z/K prior</td>
<td>3.99</td>
<td>3.67–4.27</td>
</tr>
<tr>
<td>F/K prior</td>
<td>2.49</td>
<td>2.20–2.77</td>
</tr>
<tr>
<td>Lc</td>
<td>11.2 cm</td>
<td>10.6 cm–11.6 cm</td>
</tr>
<tr>
<td>F/M</td>
<td>3.01</td>
<td>2.63–3.61</td>
</tr>
<tr>
<td>B/B0</td>
<td>0.079</td>
<td>0.042–0.122</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.0244</td>
<td>0.0122–0.0463</td>
</tr>
</tbody>
</table>

**General reference points** [median across years]:
- Linf = 29.7 (29.2–30.3) cm
- Lopt = 21 cm, Lopt/Linf = 0.7
- Lc_opt = 19 cm, Lc_opt/Linf = 0.64
- M/K = 1.28 (1.03–1.59)
- F/K = 3.41 (3–3.8)
- Z/K = 4.85 (4.49–5.17)
- F/M = 3.01 (2.12–4.39)

**Estimates for last year 2016:**
- Lc = 12.3 (12.2–12.3) cm, Lc/Linf = 0.42 (0.417–0.422)
- alpha = 31 (30.1–31.8)
- Lmean/Lopt = 0.69, Lc/Lc_opt = 0.64, L95th = 29 cm, L95th/Linf = 0.99, Lm50 = 13 cm, Mature = 49%
- F/K = 3.3 (2.99–3.6)
- F/M = 3.6 (2.63–6.7)
- Z/K = 4.19 (4.04–4.34)
- Y/R' = 0.0244 (0.0122–0.0463) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.079 (0.0396–0.15)
- B/Bmsy = 0.21 (0.106–0.4)

Comment: Official assessment in 2007 F/Fmsy=1.18 and B/Bmsy=0.91. Lm50 from Tsiklaras and Stergiou (2014)
Results for *Mullus barbatus*, stock **Mbar_Ionian**, 2005–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

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Lin\(\text{f} \text{ prior } \sim 35, \text{ s.d. } = 0.35 \text{ (cm) (user-defined)}

Z/K prior $= 4.85, \text{ s.d. } = 0.499, M/K \text{ prior } = 1.5, \text{ s.d. } = 0.15$

F/K prior $= 3.35$ (wide range with $\tau=4$ in log-normal distribution)

Lc prior $= 11.7, \text{ s.d. } = 1.17 \text{ (cm), alpha prior } = 26.2, \text{ s.d. } = 2.62$

**General reference points** [median across years]:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Median</th>
<th>95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lin(\text{f} )</td>
<td>35.6</td>
<td>(34.1–35.5) cm</td>
</tr>
<tr>
<td>Lopt</td>
<td>23 cm</td>
<td>Lopt/Linf = 0.67</td>
</tr>
<tr>
<td>Lc_opt</td>
<td>22 cm</td>
<td>Lc_opt/Linf = 0.64</td>
</tr>
<tr>
<td>M/K</td>
<td>1.48</td>
<td>(1.21–1.74)</td>
</tr>
<tr>
<td>F/K</td>
<td>9.95</td>
<td>(8.8–11)</td>
</tr>
<tr>
<td>Z/K</td>
<td>11.5</td>
<td>(10.4–12.4)</td>
</tr>
<tr>
<td>F/M</td>
<td>6.36</td>
<td>(5.22–8.27)</td>
</tr>
<tr>
<td>B/B0 F=M Lc=Lc_opt</td>
<td>0.367</td>
<td></td>
</tr>
<tr>
<td>B/B0</td>
<td>0.0547</td>
<td>(0.0383–0.0749)</td>
</tr>
<tr>
<td>Y/R' F=M Lc=Lc_opt</td>
<td>0.0463</td>
<td></td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.00908</td>
<td>(0.00636–0.0124) (linearly reduced if B/B0 &lt; 0.25)</td>
</tr>
</tbody>
</table>

**Estimates for last year 2014:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Median</th>
<th>95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lc</td>
<td>13.3</td>
<td>(13.1–13.4) cm, Lc/Linf = 0.39 (0.383–0.392)</td>
</tr>
<tr>
<td>alpha</td>
<td>28.4</td>
<td>(27.7–29.2)</td>
</tr>
<tr>
<td>Lmean/Lopt</td>
<td>0.7</td>
<td>Lc/Lc_opt = 0.6, L95th = 32 cm, L95th/Linf = 0.93, Lm50 = 13 cm, Mature = 66%</td>
</tr>
<tr>
<td>F/K</td>
<td>5.2</td>
<td>(4.86–5.67)</td>
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<tr>
<td>F/M</td>
<td>3.7</td>
<td>(2.98–5)</td>
</tr>
<tr>
<td>Z/K</td>
<td>6.61</td>
<td>(6.33–6.99)</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.012</td>
<td>(0.00811–0.0163) (linearly reduced if B/B0 &lt; 0.25)</td>
</tr>
<tr>
<td>B/B0</td>
<td>0.07</td>
<td>(0.048–0.0965)</td>
</tr>
<tr>
<td>B/Bmsy</td>
<td>0.19</td>
<td>(0.131–0.263)</td>
</tr>
</tbody>
</table>

Comment: Official assessment $F/Fmsy2007=1.5$. Lm50 from Tsikiras and Stergiou (2014)
Results for *Parapenaeus longirostris*, stock DPS-GSA10, 2009–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 4.4, s.d. = 0.044 (cm)
Z/K prior = 4.42, s.d. = 1.56, M/K prior = 1.5, s.d. = 0.15
F/K prior = 2.92 (wide range with tau=4 in log-normal distribution)
Lc prior = 1.73, s.d. = 0.173 (cm), alpha prior = 32.4, s.d. = 3.24

**General reference points** [median across years]:

- Linf = 4.23 (4.16–4.31) cm
- Lopt = 3 cm, Lopt/Linf = 0.71
- Lc_opt = 2.7 cm, Lc_opt/Linf = 0.65
- M/K = 1.2 (0.897–1.54)
- F/K = 3.08 (2.64–3.34)
- Z/K = 4.18 (3.91–4.48)
- F/M = 2.67 (1.86–3.59)
- B/B0 F=M Lc=Lc_opt = 0.378
- B/B0 = 0.12 (0.0715–0.172)
- Y/R' F=M Lc=Lc_opt = 0.0635
- Y/R' = 0.0308 (0.0172–0.0442) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2015:**

- Lc = 1.61 (1.6–1.62) cm, Lc/Linf = 0.38 (0.374–0.379)
- alpha = 38 (36.9–38.9)
- Lmean/Lopt = 0.7, Lc/Lc_opt = 0.59, L95th = 3.8 cm, L95th/Linf = 0.89, Lm50 = 2.5 cm, Mature = 7%
- F/K = 3.8 (3.43–4.17)
- F/M = 2.8 (2.23–3.8)
- Z/K = 5.13 (4.82–5.46)
- Y/R' = 0.018 (0.0126–0.0251) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.098 (0.0687–0.136)
- B/Bmsy = 0.26 (0.182–0.361)
- Comment: F/Fmsy2015=2.0 in official assessment.
Results for *Sardina pilchardus*, stock Spill_Aegean, 2004–2014
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 22, s.d. = 0.22 (cm)
Z/K prior = 5.44, s.d. = 2.83, M/K prior = 1.6, s.d. = 0.075 (user-defined)
F/K prior = 3.84 (wide range with tau=4 in log-normal distribution)
Lc prior = 11.7, s.d. = 1.17 (cm), alpha prior = 25.6, s.d. = 2.56

**General reference points** [median across years]:

- Linf = 21.3 (21–21.7) cm
- Lopt = 14 cm, Lopt/Linf = 0.67
- Lc_opt = 13 cm, Lc_opt/Linf = 0.62
- M/K = 1.47 (1.34–1.61)
- F/K = 5.29 (4.87–5.94)
- Z/K = 6.82 (6.38–7.44)
- F/M = 3.54 (3.03–4.19)
- B/B0 F=M Lc=Lc_opt = 0.367
- B/B0 = 0.133 (0.106–0.163)
- Y/R' F=M Lc=Lc_opt = 0.0472
- Y/R' = 0.028 (0.0229–0.0345) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2014:**

- Lc = 12.4 (12.4–12.5) cm, Lc/Linf = 0.6 (0.594–0.601)
- alpha = 32.4 (31.6–33.1)
- Lmean/Lopt = 0.96, Lc/Lc_opt = 0.94, L95th = 18.5 cm, L95th/Linf = 0.89, Lm50 = 12 cm, Mature = 64%
- F/K = 5.8 (5.32–6.45)
- F/M = 4 (3.45–4.73)
- Z/K = 7.22 (6.79–7.84)
- Y/R' = 0.027 (0.0218–0.0332) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.12 (0.0951–0.145)
- B/Bmsy = 0.32 (0.259–0.394)

Comment: Official assessment F/Fmsy=1.7 and B/Bmsy=0.34. Lm50 from Tsikiras and Stergiou (2014)
Results for *Sepia officinalis*, stock CTC-GSA17, 2006–2016, Gaussian selection (95% confidence limits in parentheses) File: ComDat_1.csv

General reference points [median across years]:
- Linf = 27.1 (26.5–27.6) cm
- Lopt = 19 cm, Lopt/Linf = 0.7
- Lc_opt = 17 cm, Lc_opt/Linf = 0.64
- M/K = 1.28 (0.992–1.55)
- F/K = 3.8 (3.16–4.63)
- Z/K = 4.69 (4.13–5.49)
- F/M = 2.56 (2.21–3.14)

Estimates for last year 2016:
- GLmean/Linf = 0.38, s.d./Linf = 0.12
- GLmean = 10.4, s.d. = 3.24
- F/K = 0.66 (0.0555–3.16)
- F/M = 0.45 (0.0353–1.85)
- Z/K = 2.15 (1.5–4.98)
- Y/R' = 0.0087 (–0.00273–0.0516) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.81 (–0.256–4.83)

Comment: Caught to equal parts with trawls and trammel nets and traps. Trawl-like selection suggests strong overexploitation. Gaussian selection gives results similar to official assessment, with F/Fmsy2016=0.8.
7) **Empirical data from the Black Sea** (Independent assessment in Comment; LBB_11.R)

Results for *Merlangius merlangus*, stock **Whiting_BS**, 2016–2016
(95% confidence limits in parentheses) File: ComDat_1.csv

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Linf prior = 22.3, s.d. = 0.223 (cm)
Z/K prior = 3.97, s.d. = 3.1, M/K prior = 1.8, s.d. = 0.075 (user-defined)
F/K prior = 2.17 (wide range with tau=4 in log-normal distribution)
Lc prior = 10.7, s.d. = 1.07 (cm), alpha prior = 19.3, s.d. = 1.93

**General reference points** [median across years]:
- Linf = 20.3 (20.1–20.6) cm
- Lopt = 14 cm, Lopt/Linf = 0.69
- Lc_opt = 12 cm, Lc_opt/Linf = 0.6
- M/K = 1.38 (1.24–1.5)
- F/K = 2.15 (1.92–2.38)
- Z/K = 3.52 (3.32–3.77)
- F/M = 1.55 (1.32–1.84)
- B/B0 F=M Lc=Lc_opt = 0.371
- B/B0 = 0.256 (0.203–0.315)
- Y/R' F=M Lc=Lc_opt = 0.0518
- Y/R’ = 0.0571 (0.0453–0.0704) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2016**:  
- Lc = 11.2 (11.2–11.3) cm, Lc/Linf = 0.55 (0.55–0.555)
- alpha = 31.4 (0.7–31.9)
- Lmean/Lopt = 0.96, Lc/Lc_opt = 0.93, L95th = 19 cm, L95th/Linf = 0.94, Lm50 = 14.5 cm, Mature = 12%
- F/K = 2.2 (1.92–2.38)
- F/M = 1.6 (1.32–1.84)
- Z/K = 3.52 (3.32–3.77)
- Y/R’ = 0.057 (0.0453–0.0704) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.26 (0.203–0.315)
- B/Bmsy = 0.69 (0.547–0.851)

Comment: Froese et al. (2016) estimate for 2014 F/Fmsy=1.5 (1.1–2.2), B/Bmsy=0.54 (0.36–0.74). Lm50 from STECF (2017)
Results for *Sprattus sprattus*, stock Spr BS, 2008–2015
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 12, s.d. = 0.12 (cm)
Z/K prior = 2.01, s.d. = 2.51, M/K prior = 1.5, s.d. = 0.15
F/K prior = 0.512 (wide range with tau=4 in log-normal distribution)
Lc prior = 6.63, s.d. = 0.663 (cm), alpha prior = 17.3, s.d. = 1.73

**General reference points** [median across years]:
- Linf = 11.9 (11.8–12.2) cm
- Lopt = 7.1 cm, Lopt/Linf = 0.59
- Lc_opt = 5.9 cm, Lc_opt/Linf = 0.49
- M/K = 2.06 (1.88–2.27)
- F/K = 2.12 (1.51–3.09)
- Z/K = 4.25 (3.78–4.79)
- F/M = 0.96 (0.681–1.45)
- B/B0 F=M Lc=Lc_opt = 0.353
- B/B0 = 0.443 (0.12–0.75)
- Y/R' = M Lc = Lc_opt = 0.0264
- Y/R' = 0.0176 (0.00999–0.0297) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2015:**
- Lc = 7.84 (7.67–7.98) cm, Lc/Linf = 0.66 (0.644–0.67)
- alpha = 16.7 (16.2–17.3)
- Lmean/Lopt = 1.1, Lc/Lc_opt = 1.3, L95th = 11 cm, L95th/Linf = 0.92, Lm50 = 7.8 cm, Mature = 48%
- F/K = 3.8 (3.11–4.96)
- F/M = 2.4 (1.86–3.5)
- Z/K = 5.46 (4.74–6.36)
- Y/R' = 0.039 (0.0267–0.0633) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.22 (0.149–0.353)
- B/Bmsy = 0.62 (0.422–1)

Comment: Froese *et al.* (2016) estimate for 2014 F/Fmsy=0.83 (0.7–1.1), B/Bmsy=1.1 (0.8–1.3). Lm50 from STECF (2017)
Results for *Trachurus mediterraneus*, stock **MHMackerel_BS**, 2016–2016
(95% confidence limits in parentheses) File: ComDat_1.csv

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**Linf** prior = 20, s.d. = 0.2 (cm) (user-defined)
**Z/K** prior = 6.22, s.d. = 0.606, **M/K** prior = 1.5, s.d. = 0.15
**F/K** prior = 4.72 (wide range with tau=4 in log-normal distribution)
**Lc** prior = 6.12, s.d. = 0.612 (cm), **alpha** prior = 44.4, s.d. = 4.44

**General reference points** [median across years]:
- **Linf** = 20 (19.6–20.3) cm
- **Lopt** = 13 cm, **Lopt/Linf** = 0.66
- **Lc_opt** = 12 cm, **Lc_opt/Linf** = 0.62
- **M/K** = 1.56 (1.25–1.78)
- **F/K** = 7.69 (7.31–8.24)
- **Z/K** = 9.22 (8.89–9.67)
- **F/M** = 4.93 (4.03–6.38)

**Estimates for last year 2016:**
- **Lc** = 6.76 (6.73–6.8) cm, **Lc/Linf** = 0.34 (0.337–0.341)
- **alpha** = 44.4 (43.1–45.8)
- **Lmean/Lopt** = 0.6, **Lc/Lc_opt** = 0.55, **L95th** = 16 cm, **L95th/Linf** = 0.8, **Lm50** = 12.5 cm, Mature = 0.17%
- **F/K** = 7.7 (7.31–8.24)
- **F/M** = 4.9 (4.03–6.38)
- **Z/K** = 9.22 (8.89–9.67)
- **Y/R'** = 0.005 (0.00363–0.00667) (linearly reduced if B/B0 < 0.25)

**Comment:** Froese *et al.* (2016) estimate for 2014 F/Fmsy=7 (5–9), B/Bmsy=0.11 (0.09–0.15). Lm50 from STECF (2017). Linf from FishBase.
8) **Empirical data from South Africa** (Independent assessment in Comment; LBB_11.R)

Results for *Argyrozoa argyrozoa*, stock CRPN-S, 2008–2010
(95% confidence limits in parentheses) File: ComDat_1.csv

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**Linf prior** = 63.9, s.d. = 0.639 (cm)
**Z/K prior** = 2.72, s.d. = 0.384, **M/K prior** = 1.5, s.d. = 0.15
**F/K prior** = 1.22 (wide range with tau=4 in log-normal distribution)
**Lc prior** = 31.6, s.d. = 3.16 (cm), **alpha prior** = 42.8, s.d. = 4.28

**General reference points** [median across years]:
- Linf = 62.9 (62.4–63.6) cm
- Lopt = 41 cm, Lopt/Linf = 0.65
- Lc_opt = 33 cm, Lc_opt/Linf = 0.53
- M/K = 1.61 (1.31–1.84)
- F/K = 1.23 (1.01–1.65)
- Z/K = 2.76 (2.64–2.95)
- F/M = 0.822 (0.581–1.31)
- B/B0 F=M Lc=Lc_opt = 0.363
- B/B0 = 0.405 (0.226–0.691)
- Y/R' F=M Lc=Lc_opt = 0.041
- Y/R' = 0.0404 (0.0263–0.0622) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2010:**
- Lc = 31.8 (31.6–32) cm, Lc/Linf = 0.5 (0.495–0.5)
- alpha = 40.7 (39.4–42.5)
- Lmean/Lopt = 0.93, Lc/Lc_opt = 0.95, L95th = 62 cm, L95th/Linf = 0.97, Lm50 = 26.7 cm, Mature = 99%
- F/K = 1.6 (1.36–1.95)
- F/M = 0.99 (0.735–1.46)
- Z/K = 3.22 (3.07–3.48)
- Y/R' = 0.04 (0.0263–0.0622) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.35 (0.226–0.533)
- B/Bmsy = 0.96 (0.624–1.47)

Comment: SB/SB0 = 0.423 (0.243–0.631) and SB/SBmsy = 1.21 (0.696–1.803) in official assessment 2011.
Results for *Argyrozoa argyrozoa*, stock CRPN-SE, 2008–2010
(95% confidence limits in parentheses) File: ComDat_1.csv

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Linf prior = 58.9, s.d. = 0.589 (cm)
Z/K prior = 3.03, s.d. = 1.06, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.53 (wide range with tau=4 in log-normal distribution)
Lc prior = 33.1, s.d. = 3.31 (cm), alpha prior = 43.8, s.d. = 4.38

**General reference** points [median across years]:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf</td>
<td>59.2  (58.5–60.2) cm</td>
</tr>
<tr>
<td>Lopt</td>
<td>40 cm, Lopt/Linf = 0.68</td>
</tr>
<tr>
<td>Lc_opt</td>
<td>34 cm, Lc_opt/Linf = 0.58</td>
</tr>
<tr>
<td>M/K</td>
<td>1.44 (1.21–1.72)</td>
</tr>
<tr>
<td>F/K</td>
<td>1.95 (1.71–2.28)</td>
</tr>
<tr>
<td>Z/K</td>
<td>3.37 (3.14–3.64)</td>
</tr>
<tr>
<td>F/M</td>
<td>1.39 (1.06–1.97)</td>
</tr>
<tr>
<td>B/B0</td>
<td>F=M Lc=Lc_opt = 0.36</td>
</tr>
<tr>
<td>B/B0</td>
<td>0.286 (0.195–0.423)</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.0539 (0.033–0.0724) (linearly reduced if B/B0 &lt; 0.25)</td>
</tr>
</tbody>
</table>

**Estimates for last year 2010:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lc</td>
<td>34.5 (34.4–34.7) cm, Lc/Linf = 0.57 (0.568–0.573)</td>
</tr>
<tr>
<td>alpha</td>
<td>46.2 (45.1–47.5)</td>
</tr>
<tr>
<td>Lmean/Lopt</td>
<td>0.97, Lc/Lc_opt = 1, L95th = 58 cm, L95th/Linf = 0.96, Lm50 = 26.7 cm, Mature = 100%</td>
</tr>
<tr>
<td>F/K</td>
<td>2.3 (1.84–2.56)</td>
</tr>
<tr>
<td>F/M</td>
<td>1.6 (1.12–2.01)</td>
</tr>
<tr>
<td>Z/K</td>
<td>3.71 (3.44–3.99)</td>
</tr>
<tr>
<td>Y/R'</td>
<td>0.054 (0.033–0.0724) (linearly reduced if B/B0 &lt; 0.25)</td>
</tr>
<tr>
<td>B/B0</td>
<td>0.26 (0.161–0.353)</td>
</tr>
<tr>
<td>B/Bmsy</td>
<td>0.71 (0.436–0.958)</td>
</tr>
</tbody>
</table>

Comment: SB/SB0 = 0.377 (0.245–0.529) and SB/SBmsy = 1.076 (0.699–1.511) in official assessment 2011.
Results for Argyrosomus inodorus, stock KOB-S, 2008–2010
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 115, s.d. = 1.15 (cm) (user-defined)
Z/K prior = 2.54, s.d. = 0.0708, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.04 (wide range with tau=4 in log-normal distribution)
Lc prior = 50, s.d. = 5 (cm), alpha prior = 236, s.d. = 23.6

General reference points [median across years]:
- Linf = 125 (123–126) cm
- Lopt = 82 cm, Lopt/Linf = 0.66
- Lc_opt = 70 cm, Lc_opt/Linf = 0.56
- M/K = 1.58 (1.31–1.81)
- F/K = 1.92 (1.63–2.19)
- Z/K = 3.45 (3.28–3.57)
- F/M = 1.3 (0.934–1.71)
- B/B0 = M Lc=Lc_opt = 0.364
- B/B0 = 0.247 (0.159–0.343)
- Y/R' = M Lc=Lc_opt = 0.0426
- Y/R' = 0.0405 (0.0254–0.0593) (linearly reduced if B/B0 < 0.25)

Estimates for last year 2010:
- Linf = 49.3 (49.3–49.4) cm, Lc/Linf = 0.4 (0.401–0.402)
- alpha = 256 (248–266)
- Lmean/Lopt = 0.77, Lc/Lc_opt = 0.71, L95th = 114 cm, L95th/Linf = 0.93, Lm50 = 37.5 cm, Mature = 100%
- F/K = 1.9 (1.63–2.19)
- F/M = 1.3 (0.934–1.71)
- Z/K = 3.45 (3.28–3.57)
- Y/R' = 0.044 (0.0286–0.0616) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.25 (0.159–0.343)
- B/Bmsy = 0.68 (0.438–0.941)

Comment: SB/SB2011 = 0.178 (0.128–0.229) and SB/SBmsy2011 = 0.509 (0.367–0.653) in official assessment.
Results for *Argyrosomus inodorus*, stock KOB-SE, 2008–2010
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 115, s.d. = 1.15 (cm) (user-defined)
Z/K prior = 4.34, s.d. = 0.095, M/K prior = 1.5, s.d. = 0.15
F/K prior = 2.84 (wide range with tau=4 in log-normal distribution)
Lc prior = 50.5, s.d. = 5.05 (cm), alpha prior = 496, s.d. = 49.6

**General reference points** [median across years]:
- Linf = 118 (116–119) cm
- Lopt = 78 cm, Lopt/Linf = 0.66
- Lc_opt = 68 cm, Lc_opt/Linf = 0.57
- M/K = 1.54 (1.23–1.8)
- F/K = 2.47 (2.13–3.13)
- Z/K = 4.08 (3.79–4.52)
- F/M = 1.56 (1.22–2.4)
- B/B0 F=M Lc=Lc_opt = 0.366
- B/B0 = 0.217 (0.143–0.317)
- Y/R' F=M Lc=Lc_opt = 0.0443
- Y/R' = 0.039 (0.0253–0.0585) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2010:**
- Lc = 49.4 (49.3–49.4) cm, Lc/Linf = 0.4 (0.404–0.405)
- alpha = 479 (450–502)
- Lmean/Lopt = 0.77, Lc/Lc_opt = 0.73, L95th = 112 cm, L95th/Linf = 0.92, Lm50 = 37.5 cm, Mature = 100%
- F/K = 2.2 (1.91–2.53)
- F/M = 1.5 (1.11–2.07)
- Z/K = 3.69 (3.53–3.87)
- Y/R' = 0.04 (0.0266–0.0585) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.22 (0.144–0.317)
- B/Bmsy = 0.59 (0.394–0.867)

Comment: SB/SB0 = 0.214 (0.161–0.273) and SB/SBmsy = 0.611 (0.459–0.78) in official assessment 2011.
Results for *Chrysoblephus puniceus*, stock SLNG-E, 2008–2010
(95% confidence limits in parentheses) File: ComDat_1.csv

Linf prior = 45, s.d. = 0.45 (cm)
Z/K prior = 2.83, s.d. = 0.947, M/K prior = 1.5, s.d. = 0.15
F/K prior = 1.33 (wide range with tau=4 in log-normal distribution)
Lc prior = 24, s.d. = 2.4 (cm), alpha prior = 29.7, s.d. = 2.97

**General reference points** [median across years]:

- Linf = 44.3 (43.8–44.9) cm
- Lopt = 30 cm, Lopt/Linf = 0.68
- Lc_opt = 25 cm, Lc_opt/Linf = 0.56
- M/K = 1.38 (1.06–1.63)
- F/K = 1.27 (0.912–1.7)
- Z/K = 2.73 (2.48–3.01)
- F/M = 0.84 (0.546–1.6)
- B/B0 = M = Lc = Lc_opt = 0.371
- B/B0 = 0.412 (0.195–0.688)
- Y/R = F = M = Lc = Lc_opt = 0.051
- Y/R' = 0.0473 (0.0215–0.0882) (linearly reduced if B/B0 < 0.25)

**Estimates for last year 2010:**

- Lc = 25.8 (25.6–26) cm, Lc/Linf = 0.58 (0.575–0.582)
- alpha = 32.7 (31.9–33.8)
- Lmean/Lopt = 0.96, Lc/Lc_opt = 1, L95th = 44 cm, L95th/Linf = 0.99, Lm50 = 24 cm, Mature = 87%
- F/K = 1.8 (1.5–2.04)
- F/M = 1.4 (1.05–1.92)
- Z/K = 3.02 (2.85–3.26)
- Y/R' = 0.063 (0.041–0.0905) (linearly reduced if B/B0 < 0.25)
- B/B0 = 0.29 (0.191–0.422)
- B/Bmsy = 0.79 (0.515–1.14)

Comment: SB/SB = 0.391 (0.238–0.578) and SB/SBmsy = 0.945 (0.558–1.449) in official assessment 2011.