**Assessing the sensitivity of length-indicator methods for resources in the Atlantic waters**

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**Abstract**

**(Coming soon)**

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**Introduction**

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**Material and Methods**

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**Statistical analysis**

One of the most difficult problems in fisheries is to assess the status of stocks that have insufficient data to conduct a conventional stock assessment, such stocks are known as data-poor or limited. Data-limited stock assessment models provide management advice for those data-poor stocks. Numerous data-limited length-based methodologies have been developed since length-frequency data are often the primary data type collected since it is relatively inexpensive and straightforward to obtain. In this article, we focus on the application of two data-limited length-based methodologies: length based indicators (LBI; developed by WKLIFE V, 2015, although it had been defined previously by Froese, 2004) and length-based spawning potential ratio (LBSPR; Hordyk et al., 2015a,b). LBI method consists on a set of length-based indicators selected for analyzing catch/landings–length composition and classify the stocks according to conservation/sustainability, yield optimization and MSY (maximum sustainable yield) considerations. On the other hand, LBSPR method is a length-based model that assesses stock status by comparing the spawning potential as measured through the length composition data to that expected in an unfished stock. A brief explanation of both methodologies is provided in the following sections.

**LBI method**

Length-based indicators describe length frequencies of catch/landings and are compared to appropriate reference points related to conservation, optimal yield and length distribution relative to expectations under MSY assumptions.

LBI method requires the following data: length at maturity (Lmat), von Bertalanffy growth parameter (L∞), ratio of natural mortality to von Bertalanffy growth rate (M/k), catch/landings at length per year, length–weight relationship parameters (a and b parameter in the equation W=aLb being W and L the corresponding weight and length, respectively). Instead of the values of parameters a and b we can use the mean weights-at-length per year as an input in the model.

Table 1 present the indicators, reference points, indicator ratios and their expected values.

In Table 1 the indicators L95% and Lmax5% analyze the conservation of large individuals through the comparison of such indicators, which characterize the upper portion of the length frequency distribution, to the reference point L∞. The corresponding ratio provides information about the degree of truncation of the population length structure that may be caused by fishing, and is expected to be above 0.8, based on a simulation study carried out by Miethe and Dobby (2015).

The indicator Pmega (Table 1) is the proportion of mega-spawners in the stock (fish larger than the optimum length plus 10%) and follows the idea summarized by Froese (2004) as “Let the mega-spawners live”. Froese (2004) and ICES (2015) concluded that values above 0.3 correspond to health stocks.

On the other hand, indicators L25% and Lc relate to the conservation of immatures, and follow the principle “Let them spawn” (Froese, 2004). Hence, the the ratio of both indicators to the reference point Lmat is expected to be greater than 1 (Table 1).

Finally, in Table 1, we describe two indicator ratios (Lmean/Lopt and Lmaxy/Lopt) relate to the optimal yield which follow the principle “Let them grow” (Froese, 2004) and a ratio indicator (Lmean/LF=M) focus on MSY considerations since its reference point is the length at which F=M and F=M is considered as proxy for MSY.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Indicator | Calculation | Reference | Indicator ratio | Expected value | Property |
| Lmax5% | Mean length of largest 5% | L∞ | Lmax5%/L∞ | >0.8 | Conservation (large individuals); CL |
| L95% | 95th percentile | L∞ | L95%/L∞ | >0.8 | Conservation (large individuals);CL |
| Pmega | Proportion of individuals above Lopt + 10% | 0.3-0.4 | Pmega | >0.3 | Conservation (large individuals); CL |
| L25% | 25th percentile of length distribution | Lmat | L25%/Lmat | >1 | Conservation (immatures); CI |
| Lc | Length at first catch (length at 50% of mode) | Lmat | Lc/Lmat | >1 | Conservation (immatures);CI |
| Lmean | Mean length of individuals > Lc | Lopt=3L∞/(3+(M/k)) | Lmean/Lopt | ≈1 | Optimal yield; OY |
| Lmaxy | Length class with maximum biomass in catch | Lopt=3L∞/(3+(M/k)) | Lmaxy/Lopt | ≈1 | Optimal yield; OY |
| Lmean | Mean length of individuals > Lc | LF=M= (1-a)Lc+aL∞  a=1/((M/k)+1) | Lmean/LF=M | ≈1 | MSY |

Table 1: Summary of the length based indicators with the corresponding reference points, indicator ratios and expected values grouped in terms of conservation/sustainability, optimal yield and MSY considerations.

**LBSPR method**

The original LBSPR model described by Hordyk et al. (2015a, b) is based on a conventional age-structured equilibrium population model. The method uses maximum likelihood methods to find the values of relative

fishing mortality (F/M) and selectivity-at-length that minimize the difference between the observed and the expected length composition

of the catch, and calculates the resulting SPR. An inconvenient of this model is that the selectivity is age-based not length-based, whereas, selectivity in fish is often length-dependent, which results in differential fishing mortality rates across fish of the same age; an effect known as “Lee’s Phenomenon” (Lee, 1912). The age-structured LBSPR model did not account for Lee’s Phenomenon, and is therefore expected to over-estimate fishing mortality when selectivity is length-dependent. For this reason in this article we consider an extension of such model proposed by Hordyk et al. (2016) which consists on a length-structured version of the LBSPR model that uses growth-type-groups (GTG) to account for length-based selectivity (known as GTG-LBSPR model). Throughout the article we make a slight abuse of notation referring to such model simply as LBSPR. The LBSPR model uses length composition to estimate the spawning potential ratio (SPR) for data-limited stocks by developing a computationally efficient length-structured per recruit model that splits the population into a number of sub-cohorts, or growth-type-groups, to account for length-dependent fishing mortality rates.

The LBSPR model requires the following parameters: an estimate of the ratio M/k, L∞, and knowledge of maturity-at-size, and uses data on the length composition of the catch to estimate the SPR.

**Sensitivity analysis**

ICES (2018) and Hordyk (2015b) pointed out the relevance of examining the sensitivity of the model to error in the input parameters, for LBI and LBSPR methods, respectively. In both cases the accuracy of the model results depends on the precision of the life history parameters. The simulation study carried out by Hordyk (2015b) shows that the estimation model was considerably sensitive to the variation/misspecification of the parameters L∞ and M/k. For this reason, sensitivity of the model results due to variation in such parameters has been evaluated for our real cases of study (names of the species). Firstly, the LBI and LB-SPR methods have been applied using the M/k and L∞ values fixed by the researcher after a literature review and/or the analysis of other reliable information about the species. We refer to such values as M/kLIT and L∞LIT, and to the corresponding model as reference model. Hence, to analyze the effect of underestimation and overestimation of these parameters the model is recalculated using a lower or upper bound of one of the two parameters instead of the reference value M/kLIT or L∞LIT. That is, we adjust the models summarized in Table 2.

|  |  |  |
| --- | --- | --- |
| Model | L∞ value | M/k value |
| 1: Reference model | L∞LIT | M/kLIT |
| 2: Underestimated M/k | L∞LIT | 0.75\*M/kLIT |
| 3: Overestimated M/k | L∞LIT | 1.25\*M/kLIT |
| 4: Underestimated L∞ | 0.75\*L∞LIT | M/kLIT |
| 5: Overestimated L∞ | 1.25\*L∞LIT | M/kLIT |
| 6: M/k=1.5 | L∞LIT | 1.5 |

Table 2: Description of the 6 parameter configurations to understand the robustness and sensitivity of the LBI and LBSPR methods.

The upper and lower bounds of parameters M/kLIT or L∞LIT in Table 2 follow the simulation study of Hordyk (2015b). Furthermore, we have also considered M/k=1.5 since the results of Jensen (1996) suggest that an optimal value for M/k is 1.5.

After adjusting each of the 6 models described in Table 2 the results of models 2-6 are compared with the results provided by the reference model analyzing in this way the effect of variability on the parameters M/k or L∞.

**Results**

Throughout the current Section the results of the sensitivity analysis carried for LBI and LBSPR methods are summarized and commented.

**LBI results**

Firstly, the results derived from the analysis of LBI method has been summarized in Tables 3 and 4. The first one consider the results of N. norvegicus FU25 and FU2627 (Males and Females), whereas the second one contains the information of the remaining species (G.melastomus, E. encrasicolus, P. bogaraveo, T. luscus, and P. Pollachius).

Tables 3 and 4 focus on reporting for models 2-6 which conclusions have been changed respect to the ones in the reference model (model 1).

More precisely, each row of Tables 3 and 4 reports the information of one of the 7 species addressed in this article, whereas each column reports the conclusions from model 2 to model 6 respect to model 1. The information in column *i* is the following:

1. If the relation between an indicator ratio and the corresponding expected value in model 1 remains in model *i,* for all years,then such indicator ratio is not mentioned in column *i*.
2. If an indicator ratio is below the corresponding expected value in model 1 whereas in model *i* the opposite result is obtained then such indicator ratio is typed in green in column *i* with the percentage of the years in which this change has occurred.
3. Analogous to 2. , if an indicator ratio is above the corresponding expected value in model 1 whereas in model *i* the opposite result is obtained then such indicator ratio is typed in red in column *i* with the percentage of the years in which this change has been observed.

According with the above explanation throughout this article we said that the conclusion derived from an indicator changes from one model to another when the value of such indicator in one model is above (below) the expected value whereas, for the other model, we obtain the opposite relation among both quantities. Minor changes in the indicator values (changes which do not lead to different conclusions) are not relevant in this study.

Tables 3 and 4 shows, as expected, that variation of the parameter M/k leads to changes in the conclusions derived from the indicator ratios Lmean/Lopt, Lmean/LF=M and Pmega. Such indicators relates to the optimal yield, MSY and conservation of large individuals, respectively. Overestimation of M/k (model 3 of Table 2) leads to a more optimistic perception of the state

of stock, since as we can see in Tables 3 and 4 the values of the indicator ratios changes from below to the expected value to above it. Whereas the opposite behavior is detected under underestimation of M/k (model 2 of Table 2). The conclusions of model 6 of Table 2 (M/k=1.5) depend on whether M/kLIT is less than or greater than 1.5 and therefore if we are in a particular case of underestimation or overestimation.

Taking into account that 3 different models varying the value of parameter M/k has been adjusted for each of the 7 stocks (and that 2 stocks are divided in females and males) we have 27 different models to assess the sensitivity of LBI for variability on M/k. It is important to mention that changes in the conclusions derived from Lmean/Lopt and Lmean/LF=M indicators

arise in 74% of the models whereas for Pmega such value is 33%. Hence in for our stocks it seems clear that underestimation or overestimation of M/k has more effect on the conclusions derived from Lmean/Lopt and Lmean/LF=M  than from those from Pmega. To wit, the effect of underestimation or overestimation of this parameter in our stocks changes (in a huge percentage of the cases) the conclusions relate to MSY and OY properties.

Note that the percentages (of years for which the conclusion derived from the indicator is changes respect to model 1) in Tables 3 and 4 are below 50% except in 6 cases corresponding to N. norvegicus FU2627 Females (M/k=1.5), G.melastomus (under- and over-estimation), E. Encrasicolus (underestimation) and P. Bogaraveo (overestimation). Finally, it is worth to mention that species T. Luscus is the unique species for which no changes in the conclusions have been detected in spite of the variation on M/k parameter.

After analyzing the sensitive of LBI to variations on M/k value, we focus now on the sensitivity of the method to variations on L∞ value. Tables 3 and 4 shows that variation of the parameter L∞ leads to changes in the conclusions derived from the indicator ratios Lmean/Lopt, Lmean/LF=M, Pmega and .Lmax5%/L∞. Such indicators relates to the optimal yield, MSY and conservation of large individuals, respectively. Underestimation of L∞  (model 4 of Table 2) leads to a more optimistic perception of the state of stock, since as we can see in Tables 3 and 4 the values of the indicator ratios changes from below to the expected value to above it. Whereas the opposite behavior is detected under underestimation of L∞ (model 5 of Table 2).

Taking into account that 2 different models varying the value of parameter L∞ has been adjusted for each of the 7 stocks (and that 2 stocks are divided in females and males) we have 18 different models to assess the sensitivity of LBI for variability on L∞. Changes in the conclusions derived from Pmega and .Lmax5%/L∞ indicators arise in 66% of the models whereas for Lmean/Lopt and Lmean/LF=M such value is 88% and 83%. Note that the percentages are close to each other, hence, for our stocks, it seems that underestimation or overestimation of L∞ has more or less the same effect on the conclusions derived from the four indicators. Note that for all species (except N. norvegicus FU2627 Males) at least for one indicator the percentage (of years for which the conclusion derived from the indicator changes respect to model 1, Tables 3 and 4) is above 50%. Finally, it is worth to mention that species T. Luscus is the unique species for which no changes in the conclusions have been detected in spite of overestimation of L∞, however for this species the model has not been robust to the underestimation of such parameter.

Conclusions above support that LBI method is more sensitive to the variation/misspecification of L∞ than the variation/misspecification of M/k. However, we have verified that both parameters have a huge influence on the final conclusions and that the method is clearly sensitive to the variation/misspecification of both parameters.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Specie | 0.75\*M/kLIT | 1.25\*M/kLIT | 0.75\*L∞LIT | 1.25\*L∞LIT | M/k=1.5 |
| N. norvegicus FU25 Males | **OY:**  Lmean/Lopt (3%)  **MSY:**  Lmean/LF=M (5%) | **OY:**  Lmean/Lopt (18%)  **MSY:**  Lmean/LF=M (8%) | **CL:**  Lmax5%/L∞ (58%)  Pmega (32%)  **OY:**  Lmean/Lopt (92%)  **MSY:**  Lmean/LF=M (63%) | **OY:**  Lmean/Lopt (3%)  **MSY:**  Lmean/LF=M (5%) | **OY:**  Lmean/Lopt (3%)  **MSY:**  Lmean/LF=M (5%) |
| N. norvegicus FU25 Females | **OY:**  Lmean/Lopt (32%)  **MSY:**  Lmean/LF=M (8%) | **CL:**  Pmega (3%)  **OY:**  Lmean/Lopt (47%)  **MSY:**  Lmean/LF=M (21%) | **CL:**  Lmax5%/L∞ (100%)  Pmega (89%)  **OY:**  Lmean/Lopt (68%)  **MSY:**  Lmean/LF=M (84%) | **OY:**  Lmean/Lopt (32%)  **MSY:**  Lmean/LF=M (8%) | **OY:**  Lmean/Lopt (32%)  **MSY:**  Lmean/LF=M (8%) |
| N. norvegicus FU2627 Males | **CL:**  Pmega (16%)  **OY:**  Lmean/Lopt (25%)  **MSY:**  Lmean/LF=M (16%) | **CL:**  Pmega (12%)  **OY:**  Lmean/Lopt (12%)  **MSY:**  Lmean/LF=M (16%) | **CL:**  Lmax5%/L∞ (44%)  Pmega (47%)  **OY:**  Lmean/Lopt (41%)  **MSY:**  Lmean/LF=M (38%) | **CL:**  Lmax5%/L∞ (47%)  Pmega (19%)  **OY:**  Lmean/Lopt (41%)  **MSY:**  Lmean/LF=M (34%) | **CL:**  Pmega (16%)  **OY:**  Lmean/Lopt (25%)  **MSY:**  Lmean/LF=M (16%) |
| N. norvegicus FU2627 Females | **CL:**  Pmega (38%)  **OY:**  Lmean/Lopt (19%)  **MSY:**  Lmean/LF=M (31%) | **CL:**  Pmega (9%)  **OY:**  Lmean/Lopt (9%)  **MSY:**  Lmean/LF=M (9%) | **CL:**  Lmax5%/L∞ (47%)  Pmega (38%)  **OY:**  Lmean/Lopt (16%)  **MSY:**  Lmean/LF=M (12%) | **CL:**  Lmax5%/L∞ (47%)  Pmega (53%)  **OY:**  Lmean/Lopt (53%)  **MSY:**  Lmean/LF=M (50%) | **CL:**  Pmega (53%)  **OY:**  Lmean/Lopt (44%)  **MSY:**  Lmean/LF=M (50%) |

Table 3: Summary of the results of the sensitivity analysis carried out for LBI method applied to N. norvegicus FU25 and FU2627 (Males and Females).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Specie | 0.75\*M/kLIT | 1.25\*M/kLIT | 0.75\*L∞LIT | 1.25\*L∞LIT | M/k=1.5 |
| G.melastomus | **CL:**  Pmega (50%) | **CL:**  Pmega (50%) | **CL:**  Pmega (50%)  **MSY:**  Lmean/LF=M (100%) | **CL:**  Pmega (50%)  Lmax5%/L∞ (100%)  **OY:**  Lmean/Lopt (100%) |  |
| E. encrasicolus | **OY:**  Lmean/Lopt (56%)  **MSY:**  Lmean/LF=M (6%) | **OY:**  Lmean/Lopt (22%)  **MSY:**  Lmean/LF=M (19%) | **CL:**  Lmax5%/L∞ (81%)  Pmega (97%)  **OY:**  Lmean/Lopt (31%)  **MSY:**  Lmean/LF=M (75%) | **CL:**  Lmax5%/L∞ (19%)  **OY:**  Lmean/Lopt (66%)  **MSY:**  Lmean/LF=M (6%) | **MSY:**  Lmean/LF=M (3%) |
| P. bogaraveo | **OY:**  Lmean/Lopt (17%)  **MSY:**  Lmean/LF=M (4%) | **OY:**  Lmean/Lopt (78%)  **MSY:**  Lmean/LF=M (22%) | **CL:**  Lmax5%/L∞ (22%)  Pmega (100%)  **OY:**  Lmean/Lopt (83%)  **MSY:**  Lmean/LF=M (91%) | **CL:**  Lmax5%/L∞ (74%)  **OY:**  Lmean/Lopt (17%)  **MSY:**  Lmean/LF=M (4%) | **OY:**  Lmean/Lopt (35%)  **MSY:**  Lmean/LF=M (4%) |
| T. luscus |  |  | **CL:**  Lmax5%/L∞ (80%)  Pmega (5%)  **OY:**  Lmean/Lopt (100%)  **MSY:**  Lmean/LF=M (40%) |  |  |
| P. pollachius | **OY:**  Lmean/Lopt (22%)  **MSY:**  Lmean/LF=M (11%) | **OY:**  Lmean/Lopt (33%)  **MSY:**  Lmean/LF=M (33%) | **CL:**  Lmax5%/L∞ (89%)  Pmega (56%)  **MSY:**  Lmean/LF=M (56%)  **OY:**  Lmean/Lopt (67%) | **OY:**  Lmean/Lopt (22%)  **MSY:**  Lmean/LF=M (22%)  **CL:**  Lmax5%/L∞ (11%) | **OY:**  Lmean/Lopt (11%) |

Tabla 4: Summary of the results of the sensitivity analysis carried out for LBI method applied to G.melastomus, E. encrasicolus, P. bogaraveo, T. luscus, and P. Pollachius.

**LBSPR results**

The results of the sensitivity analysis carried out for LBSPR method has been summarized in Figures 1 and 2, which shows the SPR and F/M estimates of the LBSPR method with a smoother line for all the 6 parameter configurations in Table 2. Figure 1 reports such information for

N. norvegicus FU25 and FU2627 (Males and Females), whereas Figure 2 contains the information of the remaining species (G.melastomus, E.encrasicolus, P. bogaraveo, T. luscus, and P. Pollachius).

Before proceeding to discuss the information contained in the plots, we must clarify some details about them. In Figure 1, for N. norvegicus FU2627 Males the dark blue line (M/k=1.5) does not appear on the corresponding graph, since it overlaps with the red line (0.75\*M/kLIT=0.75\*2=1.5). In Figure 2, for G. Melastomus the dark blue line (M/k=1.5) is also missed, in this case it overlaps with the black line (reference model) since M/kLIT is 1.5. Finally, for E.encrasicolus (Figure 2) we can observe that for the setting of overestimation of L∞ one of the estimates of F/M is unexpected due to its high value (≈150).

Figures 1 and 2 show that, as expected, the variation on parameters M/k

and L∞ leads to different conclusions about the stock state.

In general, overestimation of M/k leads to a more optimistic perception of the state of stock, since as we can see in Figures 1 and 2 the smoother line of SPR estimates is always above to the corresponding one for the reference model, which lead to the opposite behavior in the F/M plot. Whereas the opposite behavior is detected under underestimation of M/k As in the LBI method, the conclusions for setting M/k=1.5 depend on whether M/kLIT is less than or greater than 1.5 and therefore if we are in a particular case of underestimation or overestimation.

After analyzing the sensitive of LBSPR method to variations on M/k value, we focus now on the sensitivity of the method to variations on L∞ value. Figures 1 and 2 show that underestimation of L∞ leads to a more optimistic perception of the state of stock, since the smoother line of SPR estimates is always above to the corresponding one for the reference model. Whereas the opposite behavior is detected under underestimation of L∞.

More precisely, it is important to stand out that for all species (except T. Luscus) the setting 1.25\*L∞LITlead to conclude that the stock in the last years is above the upper limit of the MSY level (0.40) when for all species (except N. Norvegicus FU2627) such conclusion does not hold in the reference model for which the conclusion is that the stock is below the lower limit of MSY level (0.35). Note that for N. Norvegicus FU2627 the conclusion above the state of the stock is the same as in the reference model however in the setting 1.25\*L∞LIT we conclude that the stock is above the upper limit of the MSY level for almost all the years when in the reference model some of the years have values above the interval for which the stock is at MSY level. Note also that T. Luscus the conclusions derived from the reference model also differ from the ones reported in setting 1.25\*L∞LIT since in the first one we conclude that the stock is collapsed whereas in the second one the SPR estimates are closed to the lower limit of the interval (0.35-0.40) for which the conclusion is that the stock is at MSY level.

Figure 1: Plots of the SPR and F/M estimates of the LBSPR method with a smoother line derived from the sensitivity analysis carried out for LBSPR method applied to N. norvegicus FU25 and FU2627 (Males and Females).

Horizontal dotted lines delimit the range where the stock is considered at MSY level, whereas horizontal dashed lines delimit the range where the stock is considered collapsed.

Figure 2: Plots of the SPR and F/M estimates of the LBSPR method with a smoother line derived from the sensitivity analysis carried out for LBSPR method applied to G.melastomus, E. encrasicolus, P. bogaraveo, T. luscus, and P. Pollachius. Horizontal dotted lines delimit the range where the stock is considered at MSY level, whereas horizontal dashed lines delimit the range where the stock is considered collapsed.

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