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

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**Abstract**

**(Coming soon)**

**Keywords: (Coming soon)**

**Introduction**

**(Coming soon)**

**Material and Methods**

**Species data**

**(Coming soon)**

**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 explained.

Firstly, the results derived from the analysis of LBI method has been summarized in Tables 3 and 4 which report the results of models 2-6 with respect to 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 results from model 2 to model. 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.

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| --- | --- | --- | --- | --- | --- |
| 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: Results of the sensitive ana

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| --- | --- | --- | --- | --- | --- |
| 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: peces, caption coming soon