Advances developing ad-hoc MSE for Sole in divisions 8.c and 9.a

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Abstract

The common sole (*Solea solea*) is a valuable fish species in the Iberian Atlantic waters (ICES Subdivisions 8.c and 9.a) but concerns have arisen regarding the performance of the current harvest control rule, the *rfb* rule (method 2.1 in ICES, 2022), as it resulted in substantial advised catch reductions of 36% in 2021 and 35% in 2023. These results are in contrast with the data-poor assessment methods results which suggested compatibility with sustainable stock exploitation. Consequently, we have decided to explore a proposal for a new catch rule that may work better for the common sole. Hence, we are currently in the process of developing an ad-hoc Management Strategy Evaluation (MSE). For that we use the Fisheries Library in R (FLR project) and also the knowledge and code available at Fisher et al. (2020) and Fisher et al. (2021) where a MSE procedure has been developed for analyzing the performance of the *rfb* rule. This working document outlines the initial stages of our ad-hoc MSE for common sole in Iberian Atlantic waters, and highlights the initial progress made.

Introduction

The common sole (*Solea solea*, Linnaeus, 1758) is a species of flatfish which is widely distributed in Northeast Atlantic shelf waters, from the northwest of Africa to southern Norway, including the North Sea, the western Baltic and the Mediterranean Sea. Inhabiting sandy and muddy bottoms (Quero et al., 1986), this species is generally targeted by multi-species fleets (gillnetters and trawlers) and has traditionally been considered of great relevance due to its high commercial value (Teixeira and Cabral, 2010).

The unit management of the common sole stock in the Iberian Atlantic waters includes the ICES Subdivisions 8.c and 9.a. Actually, this sole stock is considered in category 3 since 2021 and its advice is derived using the *rfb* rule (method 2.1 in ICES, 2022; catch rule simulation-test at Fischer et al., 2020). This harvest control rule (HCR) provides advice based on the stock trend from a biomass index, the mean length in the catch relative to an MSY length proxy and a biomass safeguard to ensure compliance with ICES precautionary approach. More precisely, the *rfb* catch rule is defined as

$$A_{y+1} = C_{y-1} \times r \times f \times b \times m,$$

where the advised catch for next year A_{y+1} is based on the most recent year's observed catch C_{y-1} adjusted by the following components:

$$r = \frac{\sum_{i=y-2}^{y-1}(I_i/2)}{\sum_{i=y-5}^{y-3}(I_i/3)}, \; f = \frac{\bar{L}_{y-1}}{L_{F=M}}, \; b = min\left\{1, \frac{I_{y-1}}{I_{trigger}}\right\} \qquad \text{(Eq. 1)}$$

being I_i the biomass index, $\bar{L}_{y-1}$ the mean catch length above the length of first capture and $L_{F=M}$ a theoretical MSY reference length, proposed by Beverton and Holt (1957), and $I_{trigger} = 1.4\, I_{loss}$, where I_{loss} is the lowest observed biomass index value. The m component is set at 0.9 since this is the recommended value for medium-lived stocks with k in $[0.2, 0.32]$ as the common sole. Finally, it is important to mention that, when $b \geq 1$ a stability clause limiting the catch advised change to +20% and -30% of the previous catch advice is applied.

As previously stated, the *rfb* rule was first applied to advise common sole 8c.9a catches in 2021 by the Working Group for the Bay of Biscay and the Iberian Waters Ecoregion (WGBIE 2021) after the benchmark workshop on selected stocks in the western waters in 2021 (WKWEST; ICES, 2021). The group's decision established that catches should not exceed 320 tonnes for each of the years 2022 and 2023, leading to a 36% reduction from the 2021 catch advice of 502 tonnes, derived from the precautionary approach for stocks in category 5.

Similarly, the WGBIE decision on 2023 established that catches should not exceed 209 tonnes for each of the years 2024 and 2025, leading to a 35% reduction from the 2023 catch advice of 320 tonnes. In Table 1, you can observe the values of each of the *rfb* components for its 2021 and 2023 applications. Notably, the two components based on the index remain below 1 in both years, while the component based on the length in the catches exceeds 1.

The fact that the length-based component (f) exceeds one is consistent with the findings derived from data poor length-based methods. Particularly, the following methods were applied for common sole: Length-Based Indicators (LBI; Froese, 2004; ICES, 2015), the Length-Based Spawning Potential Ratio (LBSPR; Hordyk et al., 2015) and the mean length-based mortality estimators (MLZ; Then et al., 2018). All three methods yielded results that are in accordance with a sustainable exploitation of the stock.

On the other hand, two biomass indices are available for this stock: a standardized commercial LPUE (Landings per Unit of Effort) from Portugal and a standardized biomass index from the Spanish IBTS-Q4 bottom-trawl survey (G2784). This last index is provided by applying a spatio-temporal Bayesian model to the raw data of the survey. Among these two options considered for use in the *rfb* rule, the decision, made in the WKWEST 2021 benchmark, was to use a weighted sum of the Portuguese LPUE and the Spanish Bayesian survey index. The weights vary by year in accordance with the percentage of catches from each of the countries. Figure 1 displays the combined index, which is utilized to derive the index-based component (r, b) of the catch rule. We can observe a decreasing trend in the combined index from 2013, which aligns with the r and b values. However, while the index has decreased by 7% (percentage of difference between the 2020 and 2022 values), the advised catch has been reduced from 502 to 209 tonnes which corresponds to a 58% decrease.

As a result, it appears that the *rfb* rule could be overly conservative in managing the catch of common sole. This is further supported by the data-poor methods LBI and LBSPR, which indicate that the length compositions align with a MSY (Maximum Sustainable Yield) exploitation scenario. Consequently, the objective is to propose a new catch rule that may better suit the common sole. To achieve this, we are in the process of developing an ad-hoc Management Strategy Evaluation (MSE) procedure and this document aims to outline the initial stages of this process.

The rest of this document is organized as follows. First, provide an overview of the general materials and methods utilized during the early stages of the MSE development. Then, the preliminary operating models and the sampling process are described emphasizing the decisions made. An analysis of the behavior of different indicators of stock biomass or fishing pressure is presented below to determine which of them are more appropriate to be used as a multiplier of last year's observed catch in defining the a new catch rule. Finally, we describe the first version of our proposed new catch rule that we are in the process of testing, but the results seem promising.

Component	2021	2023
r	0.90	0.85

m	0.90	0.90
f	1.03	1.04
b	0.91	0.82

Table 1: Values of the *rfb* rule components for common sole in 2021 and 2023 applications

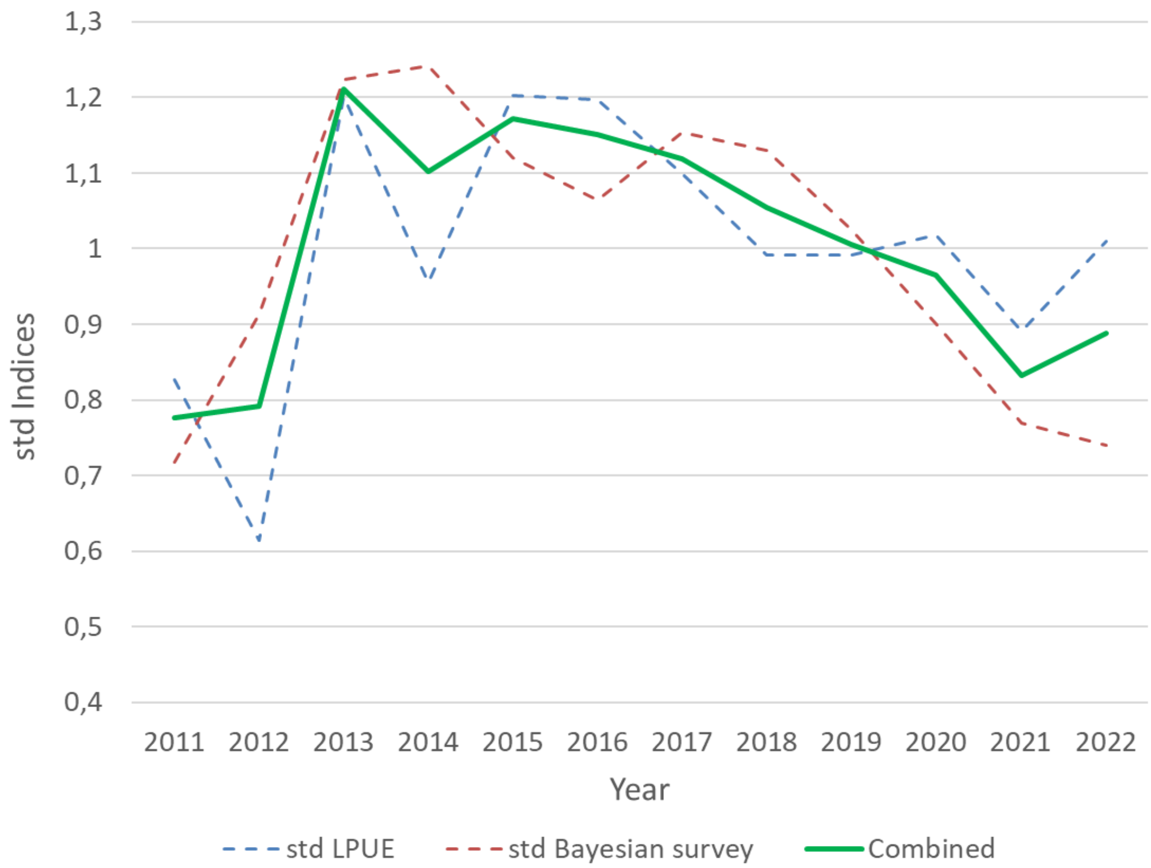


Figure 1: Portuguese LPUE (std LPUE), Spanish Bayesian survey index (std Bayesian survey) and their combined version through a weighted sum where the weights vary by year in accordance with the percentage of catches from each of the countries.

Material and methods

The initial phase of the MSE procedure involves the creation of the Operational Models (OMs). For that, we use the Fisheries Library in R (FLR, Kell et al., 2007) software, in particular, the FLR package FLife to simulate stocks based on life-history parameters. More specifically, in the initial stage of the common sole MSE, we create age-structured OMs using the FLife

package and the following life-history parameters: allometric parameters for length–weight, a and b relationship, von Bertalanffy growth model parameters L_∞, k, and t_0, and length at *50%* maturity L_{50}. The code used for this purpose is based on the code developed by Fisher et al. (2020), which can be found at https://github.com/shfischer/wklifeVII, and was created to assess the performance of the *rfb* rule through simulations across twenty-nine fish stocks covering a wide range of life histories.
In the considered OMs, growth was modelled with the von Bertalanffy growth equation, recruitment by a Beverton–Holt stock recruit function, virgin spawning stock biomass (SSB) set to 1000 (units), the maximum age a_{max} and plus-group set as the age (rounded up) where the stock reached *95%* of L_∞, maturity modelled with a sigmoid function centered on a_{50}, and fisheries selectivity modelled as a logistic function. The age range for computing *fbar* has been set to 2-9, based on the overall length frequency distribution (LFD) computed from common sole commercial catches from 2011–2021. Further details regarding key aspects of the OMs are discussed in the following section.

Once OMs have been established, the sampling process should be carried out. At this stage, we integrate the approaches and codes presented by Fisher et al. (2020) and Fisher et al. (2021) to develop a unified and adapted code that provides an index of relative biomass and length frequency distributions for simulated common sole stocks. The code derived from Fisher et al. (2021) can be found at https://github.com/shfischer/GA_MSE_PA/tree/PA and includes an updated version of Fisher et al. (2020)'s code, designed to assess the performance of an optimized *rfb* rule using a genetic algorithm. Specific details about the LFDs and index definitions are provided in the sampling section below.

Finally, the calculation of the original *rfb* rule and also of our proposal (detailed in section “First catch rule proposal”) is carried out based on Fisher et al. (2021) code, also the stock projection based on the catch rule value is runned based on such code using the mse FLR package.

Operating Models

While there are numerous processes to consider when defining the OMs, we have prioritized the following processes and parameters as the initial focal points: recruitment variability, steepness of the Beverton-Holt model and natural mortality.

In our MSE framework, the source of stochasticity in the OM comes from the recruitment variability, as in Fisher et al. (2020, 2021). Therefore, the selection of suitable values for the coefficient of variability (CV) in recruitment emerges as a crucial consideration in the OMs definition. Consequently, an analysis of the variability within the recruitment estimates of ICES data-rich sole stocks has been conducted. More precisely, we computed the CV associated to the recruitment time series estimates of each one of the following sole stocks: sol.27.20-24, sol.27.4, sol.27.7a, sol.27.7d, sol.27.7e, sol.27.7fg and sol.27.8ab. Finally, the CV’s are summarized by calculating their median, along with the 20th and 80th percentiles, thereby offering both extreme values, one on the lower end and another on the upper, with the median representing a plausible value for recruitment variability. The values obtained, and consequently, those taken into consideration in the definition of the set of OMs, are as follows: 0.36 for the 20th percentile, 0.43 for the median, and 0.78 for the 80th percentile.

The steepness of the stock-recruitment relationship plays a key role in assessing the risks associated with different management strategies. A steeper curve indicates the ability of the population to recover quickly from low stock sizes, thus reducing the risk of population collapse. Hence, the incorporation of OMs that consider a range of steepness values is essential. Then, we have adopted three values, according to the median, 20th percentile and 80th percentile extracted from the steepness values obtained by Myers (2011) for different stocks of *Solea solea*. These values are as follows: 0.72 for the 20th percentile, 0.84 representing the median, and 0.91 for the 80th percentile. We expect this approach to ensure a comprehensive representation of steepness variability, improving the robustness of our management strategy framework.

Natural mortality (M) is one of the more challenging parameters to estimate accurately in fish stocks, therefore, it is critical to include diverse M values in our set of OMs. Actually, in the application of the data-poor assessment methods, LBI, LBSPR and MLZ, to assess common sole in divisions 8c and 9a, a value of $M = 0.31$ is used. However, this selection lacks a reasoned justification. Consequently, as a first option, we decided to estimate a global natural mortality value using a set of empirical methods implemented in the metaM function of the R package FSA (Ogle et al. 2023). These methods calculate M based on von Bertalanffy parameters, maximum age, or the age at which half the fish in the population become mature (a_{50}). The chosen methods, among the options available in the metaM function, and their estimates are presented in Figure 2. The M vector at age in the OM is set as a constant value equal to the median of these M estimates, which is 0.3743, as indicated by the horizontal line in Figure 2.

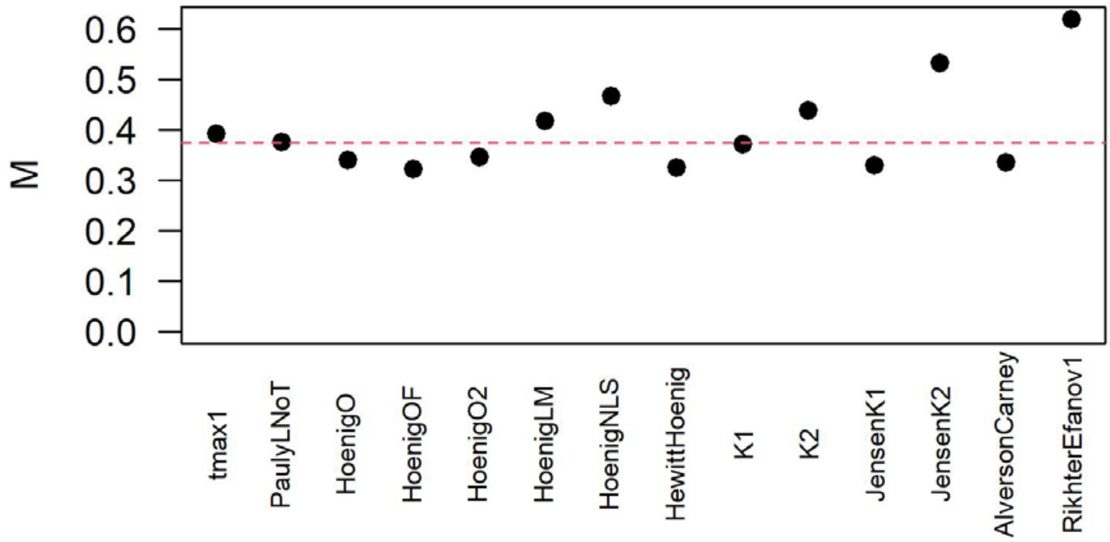


Figure 2: M estimates derived from the empirical methods implemented in the FSA package. Horizontal red line represented the median of the different M estimates.

Given the notable vulnerability of young ages to predation and environmental risks, we also consider an alternative not constant M at age vector to address this issue. The M at age vector is obtained by calculating the median of the M at age vectors derived from the empirical estimators of Gislason (2010), Charnov et al. (2013), Lorenzen (1996) and Cook (2013). The estimates obtained using these M estimators and the their median (final M estimator) are presented in Figure 3.

Finally, it is worth mentioning that in our simulation framework, the maximum age is set to be the age corresponding to a length equal to $0.95 \times L_{\infty}$, i.e., $a_{max} = -ln(0.05)/k + t_0$. The von Bertalanffy growth parameters L_{∞}, k, and t_0 are based on Teixeira and Cabral (2010).

$$L_{\infty} = (L_{\infty,female} + L_{\infty,male})/2 = (52.15 + 46.69)/2 = 49.4$$

$$k = (k_{female} + k_{male})/2 = (0.23 + 0.21)/2 = 0.22$$

$$t_0 = (t_{0,female} + t_{0,male})/2 = (-0.11 + -1.57)/2 = -0.84$$

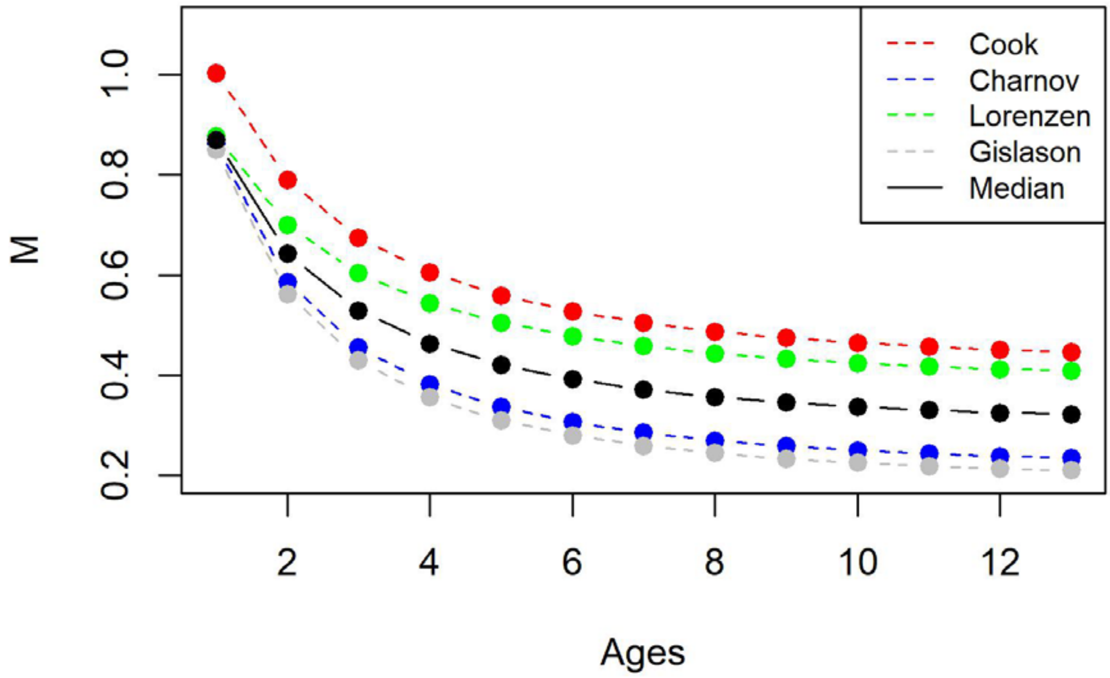


Figure 3: M estimates derived from the empirical methods of Gislason (2010), Charnov et al. (2013), Lorenzen (1996) and Cook (2013), and their median (final M at age estimates).

Sampling process

The sampling process conducted on our OMs focuses on obtaining an index of relative biomass and a length frequency distribution. This distribution is particularly essential for proposing new catch rules based on alternative indicators derived from the LFDs information.

The index of relative biomass is computed as follows:

$$I_y = \left(\sum_{t=1}^{a_{max}} s_t N_{t,y} W_{t,y}\right) \times e_y,$$

being $N_{t,y}$ the population number at age t and year y, $W_{t,y}$ the population weight at age t and year y, e_y is the log-normal error term derived from a log-normal distribution centered in one with coefficient of variation CV_I taking a value from the set {0, 0.1, 0.2, 0.3} to see the effect of biomass index noise on the performance of the catch rule, and finally s_t is the selectivity defined as $s_t = \frac{1}{1+e^{-3\times(t-1-(a_{max}/8))}}$. Figure 4 shows the selectivity index values. Please note that our selectivity formulation has been adapted from the approach used in Fisher et al. (2020) for replicating the selectivity patterns observed in the polyvalent fleet and in the Spanish IBTS-Q4 bottom-trawl whose data is used to derive the indices of relative biomass in Figure 1. Specifically, we noticed that the mean of the historical minimum length in the data used to calculate the Portuguese LPUE is 19.32 cm, whereas in the Spanish IBTS-Q4 bottom-trawl data it is 22.21 cm. As a result, we adjusted the denominator in the selectivity formulation to reduce the selectivity associated with ages before maturity, as can be seen in Figure 4.

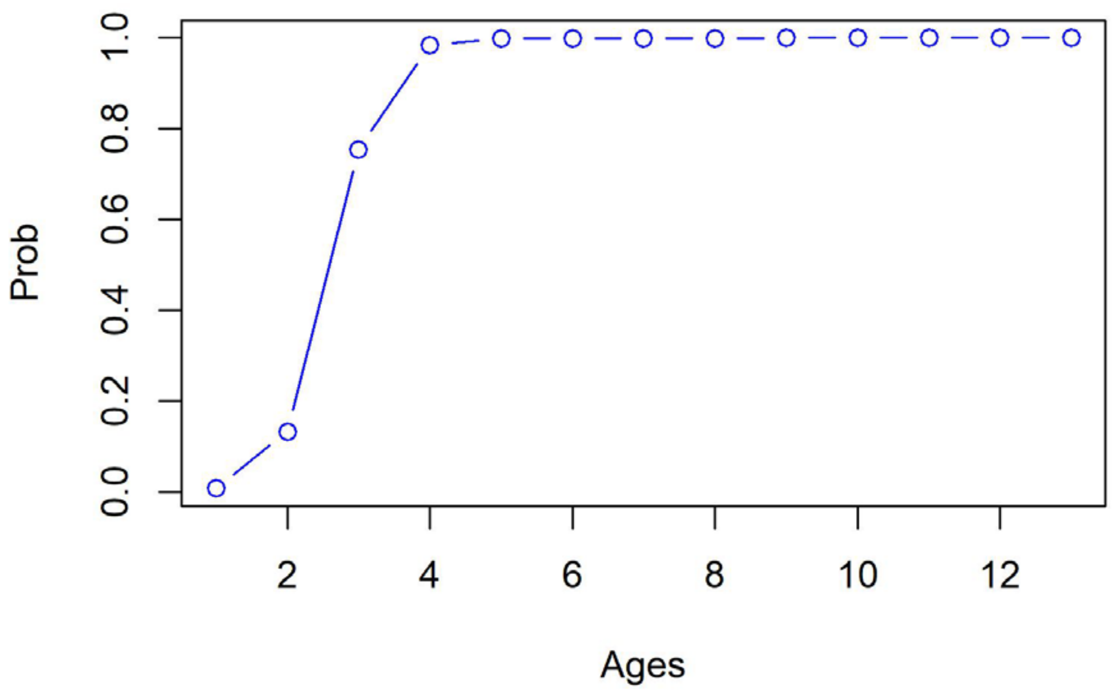


Figure 4: The selectivity of the index of relative biomass used in the sampling process over our OMs.

Catch length frequencies were generated by applying a simulated inverse age-length key to the catch at age distribution according to Simon et al. (2020), see their supplementary material for more details. Essentially, the key steps are as described in Figure 5. One notable difference compared to Simon et al. (2020) is that the standard deviation associated with the normal distribution is determined from a coefficient of variation (CV), acknowledging that the level of variability may vary among different age groups. Specifically, $\sigma_{L_t} = CV \times L_t$, with a CV value of 0.1. Finally, to introduce variability into the resulting distribution obtained from the steps in Figure 5, noise is incorporated. This noise is derived from a log-normal error term derived from a log-normal distribution with a mean of one and a coefficient of variation CV_L.

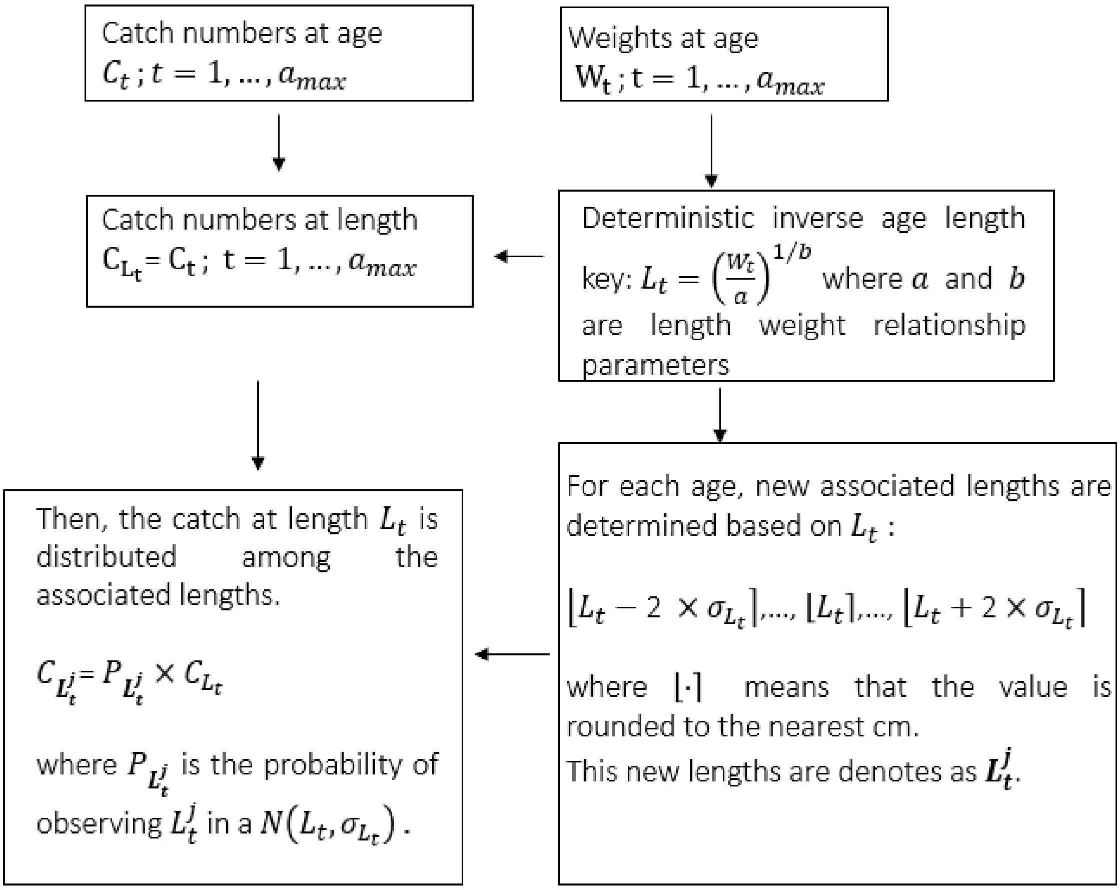


Figure 5: The key steps in the simulation of catch length frequencies.

Analysis of potential stock status indicators

The first step in the process of proposing a new catch rule for common sole was to assess how well different indicators reflected stock status in our simulation framework. The aim of the analysis was to decide which indicators would be of interest for inclusion in our new catch rule for common sole. The set of indicators considered in this analysis is described below. These include some of the ones used in the *rfb rule* (Eq. 1)

1) As a first indicator of biomass stock trend based on a index of relative biomass, the *r* component in the *rfb* rule (Eq. 1) was considered. This component is known as the '2-over-3' component of the *rfb* according to its definition, which is the rate of change of the biomass index based on the average of the last two years of the index relative to the average of the three years before the last two years. In addition to the '2-over-3' component, we also analyzed the '1-over-4' and '1-over-3' versions of this component to see if these alternatives could better reflect the local biomass trend of the stock.

2) As a proxy for fishing mortality (F), we analyzed the behavior of the component f in the *rfb* rule, (Eq. 1), defined as the ratio between $\bar{L}_{y-1}$, the mean catch length above the length of the first catch, and $L_{F=M}$, a theoretical MSY reference length.
3) On the other hand, the ratio of the spawning potential ratio estimate (SPR) to a MSY SPR proxy was considered as an indicator of changes in stock biomass. The SPR was not included in the *rfb* catch rule, but we proposed it as an interesting indicator to be tested, as it had been shown to be useful in many simulation studies to classify stocks according to their exploitation level. Two versions of this indicator were considered. The first version calculated SPR_y by applying the LBSRP method (Hordyk, 2015) to the current year's length frequency distribution. The second version uses the combined length frequency distribution of the current and previous year $(y-1)$ to calculate SPR_y. A smoother transition between years is possible with this second option. The MSY SPR proxy was defined as the median of the SPR equilibrium values on a set of different OMs considering F_{msy} exploitation. The obtained value was 0.358.

To check the performance of these indicators, we created different operational models according to the methodology described above (section “Material and methods”), i.e. the FLR package FLife, which allows us to simulate stocks based on the life history parameters. The simulated SSB and F time series were then compared with the indicators time series to check their behavior.

Specifically, for this analysis we considered a trajectory of fishing mortality ranging from different exploitation levels over the stock's 100-year history to see if the indicators could detect these changes. In particular, the fishing mortality starts at 0.2 x F_{msy} for 20 years, increases linearly from this to 0.9 x F_{crash} for 20 years, remains constant at 0.9 x F_{crash} for 20 years, and decreases linearly to F_{msy} for 20 years (Figure 6).

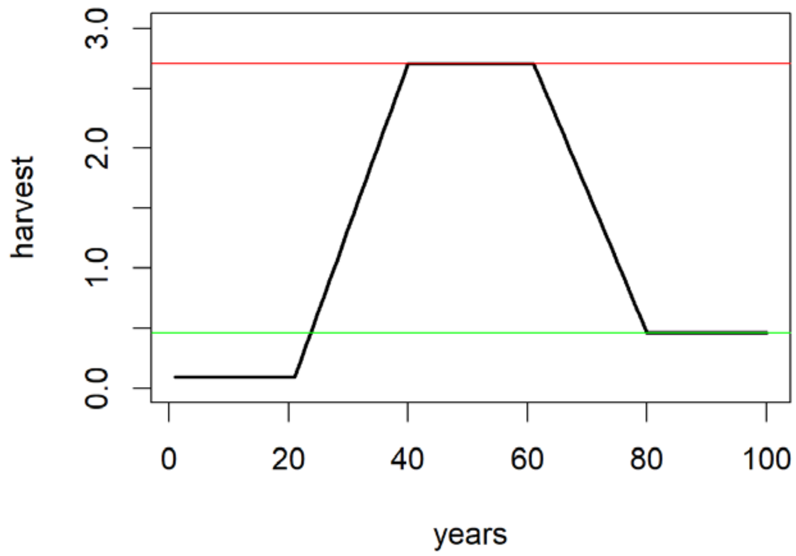


Figure 6. Fishing mortality trend over the 100 years of stock history. Starting at 0.2 x F_{msy}, increasing to 0.9 x F_{crash}, and returning to F_{msy}.

The two natural mortality options described above (section "Operating Models") and the most plausible steepness value, the median value, which is 0.84, are considered in the OMs definition. On the other hand, a grid of different values for recruitment, relative biomass index and LFDs coefficient of variability was also considered to see how the performance of the indicators changes in the face of different degrees of variability.

Regarding the first set of indicators, the '2 over 3', '1 over 4' and '1 over 3' versions of the r component, it can be concluded that the three indicators correctly capture the changes in the biomass trend and that there are no clear differences between them. For example, Figure 7 shows these indicators together with the B/B_{msy} trend in one of the scenarios, namely the one with constant M at age=0.3743, recruitment coefficient of variation=0.05 and no noise in the biomass index. Figure 7 shows that there is a first period where the indicators are less than 1 because the biomass is declining, then the biomass is almost constant and therefore the indicators are close to 1, reflecting that the biomass is stable and hence there is no need of change in the catch recommendation, then the biomass starts to decline and accordingly the indicators drop below 1. After a few years of decrease in the indicators, we start to see an increase. The question is: ¿why are we seeing an increase when the biomass continues to decrease? Because the biomass is declining, but at a lower rate than previously, and hence the indicators increase but remain below 1 until the biomass starts to increase and therefore exceed 1. Indicators ending in 1 make sense because 1 indicates a stable biomass and therefore, if we translate this into the catch rule, a multiplier of 1 means no need to change the catch recommendation.

On the other hand, it is worth noting that the indicators respond correctly to the increase of uncertainty in recruitment or to the inclusion of noise in the relative biomass index, since the medians of these indicators in a scenario with low uncertainty are very similar to those obtained in a scenario with high variability in recruitment or in the relative biomass index. In fact, Figure 8 shows that the median of the indicators calculated using a biomass index with a CV_I of 0.2 coincides with the median of the indicators calculated using the biomass index without considering uncertainty. This is clearly a desirable property for an indicator.
Given the similarity in the performance of the '2 over 3', '1 over 4' and '1 over 3' versions of the r component, it is considered appropriate to utilize the '2 over 3' indicator which is the one employed in the *rfb* rule.

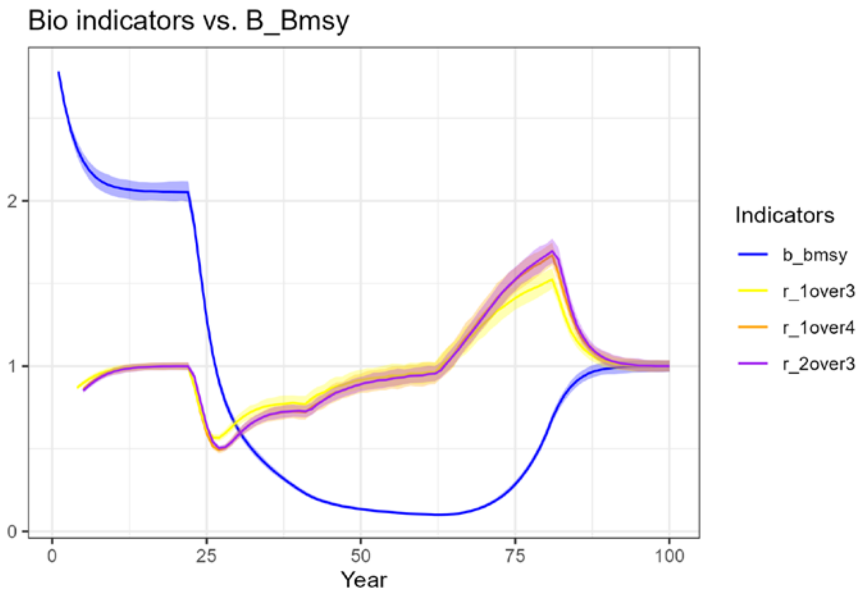


Figure 7. B/B_{msy} trend and the '2 over 3', '1 over 4' and '1 over 3' versions of the r component in the scenario with constant M at age=0.3743, recruitment coefficient of variation=0.05 and no noise in the biomass index.

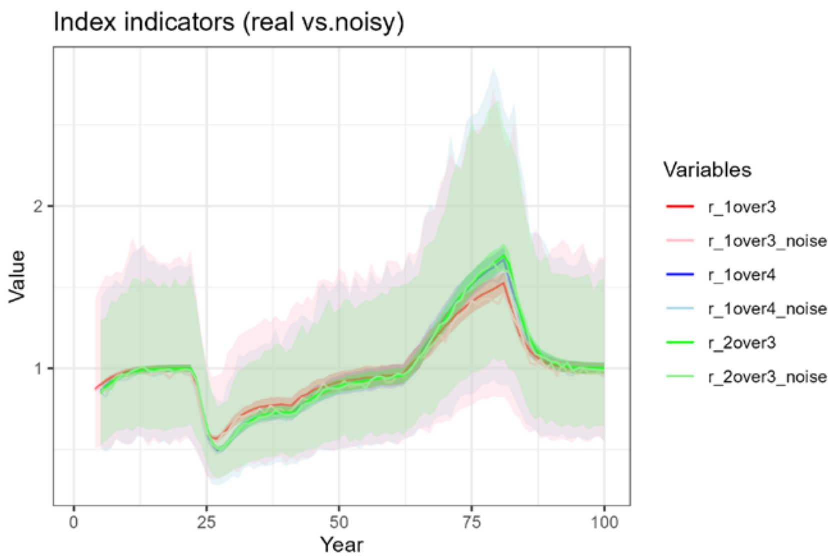


Figure 8. The '2 over 3', '1 over 4' and '1 over 3' versions of the r component using the biomass index without noise and with a CV_I=0.2.

We also analyzed the performance of the indicator $\bar{L}_{y-1}/L_{F=M}$. A an example of the performance of this indicator is shown in Figure 9, which shows the inverse of this indicator together with the time series of relative fishing mortality in one of the scenarios, namely the one with constant M at age=0.3743, recruitment coefficient of variation=0.05 and no noise in the length frequency distribution. We use the indicator's inverse because it is easily compared to fishing mortality, in the sense that as fishing mortality increases or decreases, the indicator's inverse is expected to reflect these changes. Figure 9 shows that the indicators start with a stable value close to 1 in the first years, then the F increases and the inverse of the indicator also increases and remains above 1 until fishing mortality decreases and the indicator settles around 1. The indicator is effective in detecting shifts in fishing mortality trends, but it's important to recognise that its drawback is that its value does not adequately reflect the magnitude of fishing mortality change. For example, in Figure 9, we can see that when the fishing mortality is almost 6 times F_{msy}, the indicator is only slightly greater than 1. Specifically, the minimum value of the inverse of this indicator is 0.85 and the maximum is 1.10, a small difference considering that the fishing mortality goes from 0.2 x F_{msy} to 0.9 x F_{crash}. This behavior is also observed in the other scenarios leading to the conclusion that, due to the magnitude issue mentioned above, it may not be appropriate to directly include this indicator as a multiplier in the catch rule.

Another aspect of the performance of this indicator that is worth noting is that a higher coefficient of variation in the length frequency distribution or in the recruitment does not translate into a higher uncertainty in the indicator. To illustrate this, Figure 10 a) shows the inverse of the indicator and relative biomass trend for the same scenario as Figure 8 but with the recruitment CV increased to 0.3 and Figure 10 b) the same but with the length frequency distribution CV_L increased to 0.2. In both cases, the uncertainty associated with the indicator is similar to the one observed in the scenario with a low level of variability described in Figure 9.

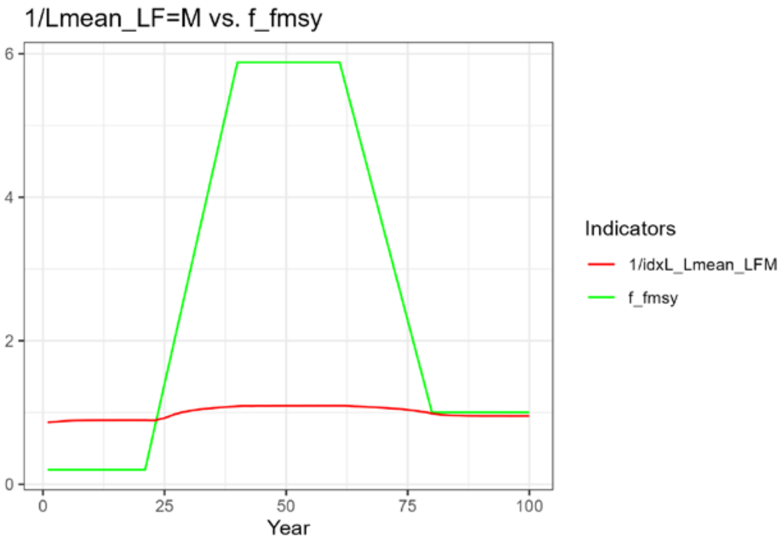
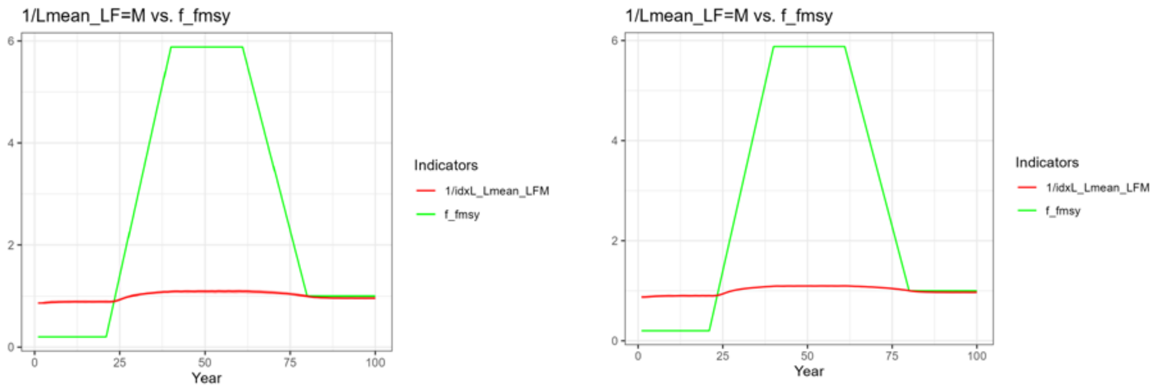


Figure 9. Indicator $\bar{L}_{y-1}/L_{F=M}$ (red line) plotted with the relative fishing mortality time series (green line) for a constant M scenario at age=0.3743, recruitment CV=0.05 and no noise in the length frequency distribution.



a) Increased recruitment variability (CV = 0.3).

b) Increased LFDs variability (CV_L = 0.2).

Figure 10. Illustration of the $\bar{L}_{y-1}/L_{F=M}$ response to increased recruitment or length frequency distribution variability.

Finally, we also analyzed the performance of the two versions of the SPR component defined as the ratio of the spawning potential ratio estimate (SPR_{y-1}) to a MSY SPR proxy. The two versions of this component differ in that one, which we can refer to as SPR1, computes SPR_y from the length frequency distribution of the current year, whereas the other, which we can refer to as SPR2, computes SPR_y from the combined length frequency distribution of the current and previous year ($y-1$). The idea behind this analysis is to check whether the combined SPR is less noisy reducing recruitment variability and sampling noise. As an

example of the behavior of these indicators, Figure 11 shows the relative biomass time series (B/B_{msy}) with the two versions of the SPR indicators in the scenario of constant M at age=0.3743, recruitment CV=0.05 and no noise in the length frequency distribution. Figure 11 shows the two versions of the SPR1 and SPR2 indicators: one labeled “real” and the other labeled “use”. In this context, “real” means that the MSY SPR proxy used in the ratio to define the indicator corresponds to the real value in the considered scenario. Conversely, “use” indicates that this proxy is set to the value that we propose to use in practice, i.e. 0.358, derived from the median of the SPR equilibrium values in the different operating models at a F_{msy} exploitation. Figure 11 shows how the indicators correctly track the trend changes in the relative biomass time series, and how the magnitude of the change in our SPR indicators adequately represents the magnitude of the change in the relative biomass time series, unlike the $\bar{L}_{y-1}/L_{F=M}$ indicator. In this scenario, there is almost no difference between the "use" and "real" versions, as the "real" and "use" MSY SPR proxies are very similar in this scenario, but if we move to other scenarios, differences can be seen. For example, Figure 12 shows the graph for the scenario using the M at age vector defined in the “Operating Models” section, and there we can see how the "use" version does not finish the time series in 1 as it should, reflecting that the biomass is at B_{msy}. This shows the crucial importance of choosing an adequate value for the MSY SPR proxy.
On the other hand, if we increase the coefficient of variability of the recruitment or LFDs, we see that the uncertainty of the indicators increases, as expected. However, the medians are very similar to the medians of the indicators in the low variability scenario (Figure 13).

From this analysis we can conclude that both versions of the SPR indicator perform similarly, so we decide to use the one that calculates SPR_y from the current year's length frequency distribution.

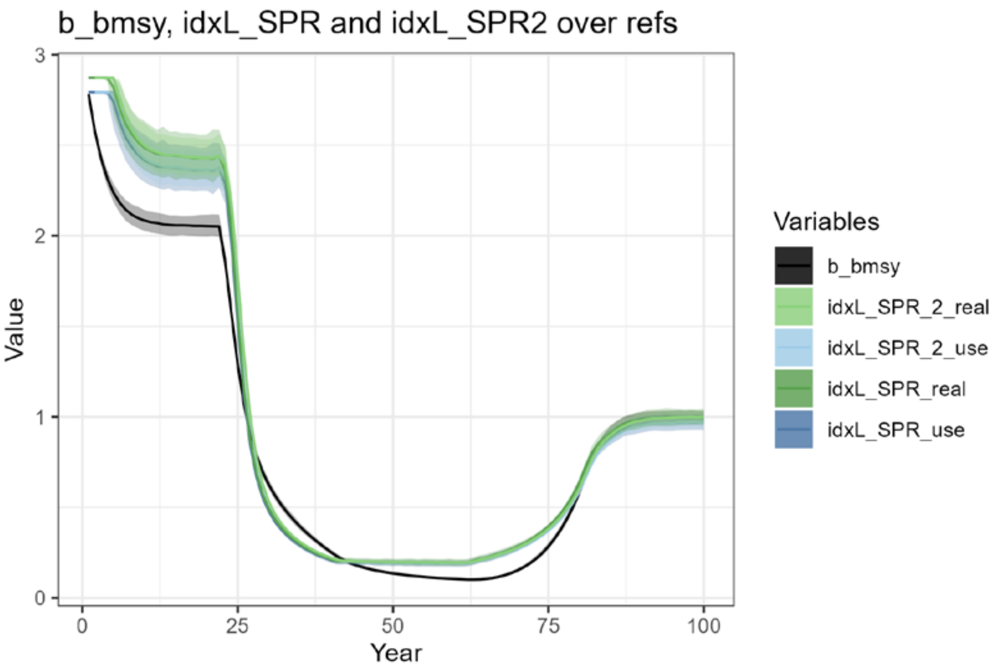


Figure 11. Relative biomass time series (B/B_{msy}) with the two versions of the SPR indicators in the scenario of constant M at age=0.3743, recruitment CV=0.05 and no noise in the length frequency distribution.

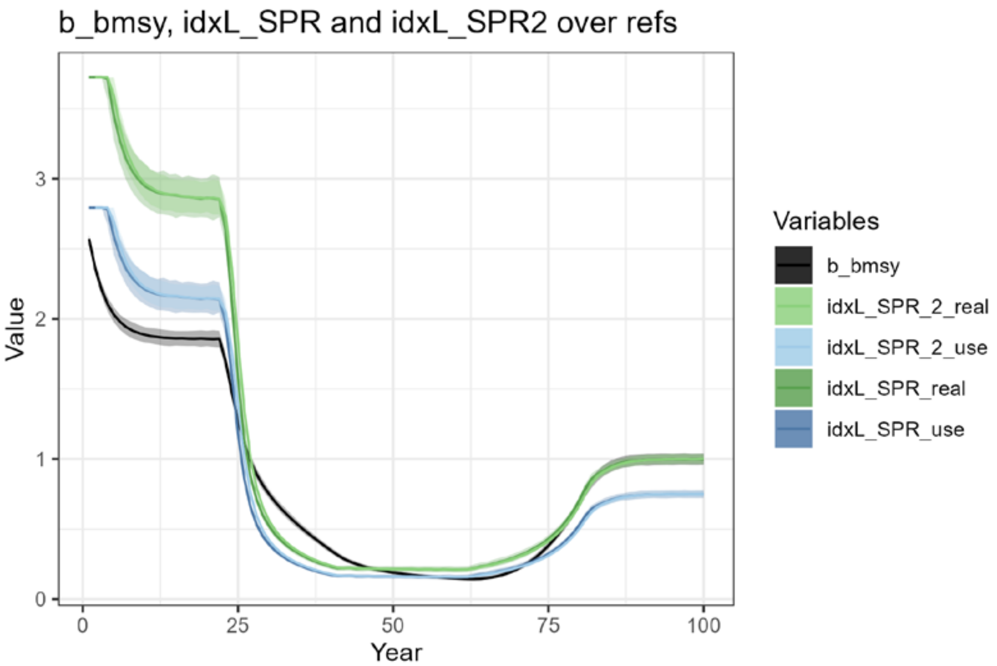
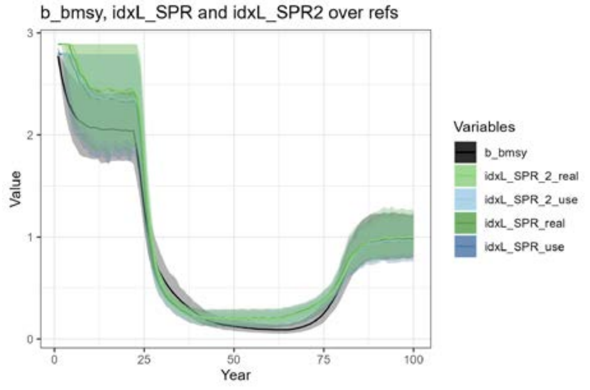
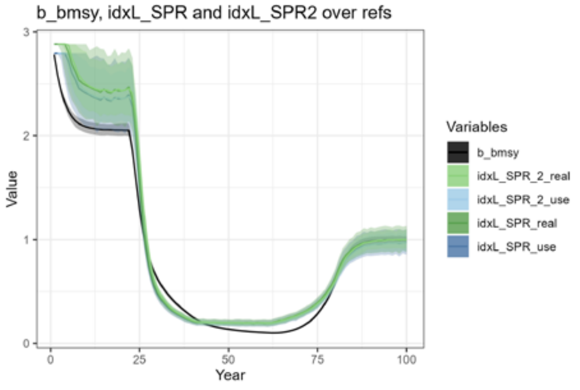


Figure 12. Relative biomass time series (B/B_{msy}) with the two versions of the SPR indicators in the scenario of M at age vector defined in the "Operating Models" section, recruitment CV=0.05 and no noise in the length frequency distribution.



a) Increased recruitment variability (CV = 0.3).



b) Increased length LFDs (CV_L= 0.2).

Figure 13. Illustration of the SPR indicator response to increased recruitment or length frequency distribution. Scenario of constant M at age=0.3743.

First catch rule proposal

Based on the indicators analysis, we initiated a brainstorming to propose a new catch rule with the aim of improving the performance of the existing *rfb* rule. We opted to begin with a simpler rule than the *rfb* one. Given the promising performance of the "2 over 3" r component and the SPR component, our initial proposal is as follows:

$$A_{y+1} = C_{y-1} \times r \times f, \qquad \text{(Eq. 2)}$$

where A_{y+1} is the advised catch for next year, C_{y-1} is previous observed catch, r is the "2 over 3" component following the definition in the *rfb* rule, and f is defined as the ratio of spawning potential ratio estimate (SPR_{y-1}) to a MSY SPR proxy.

The first experiments with this rule highlighted the problem that we are effectively making a decision for years $y+1$ and $y+2$ (in the case of biennial TACs, as in the case of sole) using information from year $y-1$ in the f component and from years $y-1$ to $y-5$ in the r component, which means that the indicator's information is delayed and, for example, if a reduction in catches is required, this is done with a delay and the consequences of this delay cannot in some cases be resolved later by the catch rule.

We therefore assume that the m component has been included in the *rfb* rule to deal with this situation. However, we believe that instead of the m-component, which always leads to additional catch reductions regardless of stock status, we can define a more specific rule that activates a protection mechanism when necessary.

We then propose to proceed as shown in Figure 14. First we calculate the advised catch for the following year using (Eq. 2), and then we carry out a series of checks to see if there is any evidence that this advised catch should be reduced as a precautionary action.

The first check focuses on whether the advice is too high in relation to historical catches, c_{hist}, i.e. the catches of the stock prior to the first application of the catch rule. We do this by comparing the advice with c_{hist} times mul_1, the value of mul_1 would be selected according to the best balance between maximizing yield and minimizing risks from a range of values, that in our first approach, would include values between 1.05 and 1.30.

If the advice large than c_{hist} times mul_1 the precautionary mechanism is activated and the advice for year $y+1$ cannot be too high respect to the previous advice, and how higher it can be is determined by mul_2, which is also chosen from a grid of values, that in our first trial, would include values between 1.05 and 1.30. This makes it possible to increase the advice if this is the case but not very quickly if we are recommending values that are too high relative to the historical situation. On the other hand, we retain the advice derived from (Eq. 2) if the advice is not larger than c_{hist} times mul_1.

After this first check, a second one is carried out to detect the possibility of a period of decline in biomass, by checking the r component, if this occurs, a second precautionary mechanism is activated. More precisely, we check whether or not the r component in year $y-1$ is larger than the r component in year $y-2$, if $r_{y-1} > r_{y-2}$ the advice value derived from (Eq. 2) can be retained whereas in the case of $r_{y-1} \leq r_{y-2}$ an additional check should be carried out to see if the advice needs to be reduced. Specifically, we check the SPR component, i.e. the f component, and if this is high, that is, larger than the mul_3 threshold, also selected by simulation from a grid with values between 1.3 to 1.7, we can maintain our advice because, although the r component decreases from $y-2$ to $y-1$, the SPR is high, leading to the conclusion that there is no clear reason to apply a reduction. However, if the f component is not large than mul_3, the advice should be not more than a certain percentage of the last advice. This percentage mul_4 should also be chosen from a grid of values between 0.8 and 1.1.

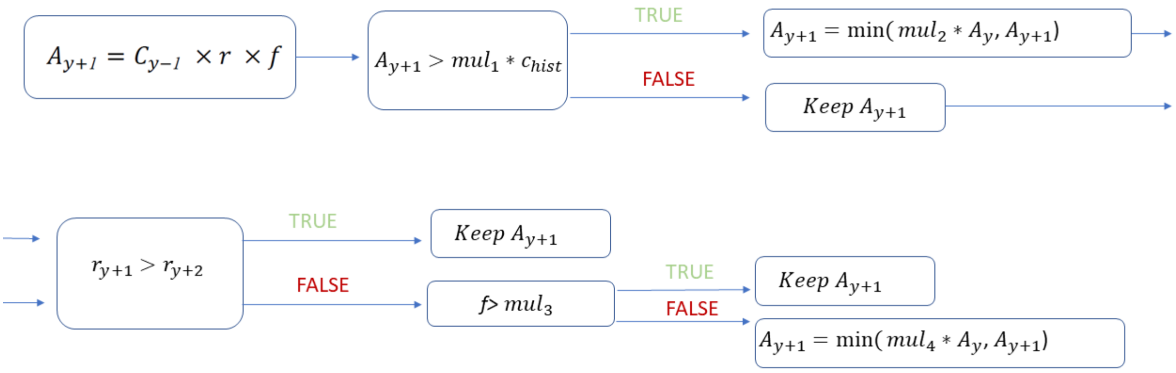


Figure 14. Scheme of our proposal catch rule.

Initial results from this novel catch rule, for specific values of mul_i, $i = 1,\dots,4$, have shown a promising performance. Hence, the next step involves exploring the grids of values of each mul_i, $i = 1,\dots,4$, to determine their optimal values. It should also be noted that the range of values for each multiplier above is a first proposal and they may be extended if the results of the simulations suggest that other values should be explored.

Conclusions

In summary, this document provides a comprehensive overview of the initial stages and critical discussion points involved in the development of an ad-hoc MSE for common sole (*Solea solea*). More precisely, the OMs construction and the sampling procedure, for biomass indices and LFDs, are described, an analysis of different indicators that can be included in the catch rule definition is presented and after that the initial catch rule definition is described.

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