Ad-hoc MSE for Common Sole in Divisions 8.c and 9.a: Description of Operating Models

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1 OMs description

This document provides a detailed description of the operating models (OMs) considered in our Management Strategy Evaluation (MSE) for common sole in divisions 8.c and 9.a. The aim of this document is to describe and justify the decisions taken in the definition of the baseline OM and the set of alternative OMs that account for uncertainties associated with key processes.

The baseline OM represents the most plausible scenario based on the available information and is described in Table 1. The rationale behind the decisions made to define each of the processes in this OM is detailed throughout Section 2. Additionally, details on some of the parameters in the sampling process are provided in Table 2.

Table 1: Baseline OM Description

Process	Definition
SR (Steepness)	The steepness value is 0.84, median value reported by [Myers et al., 1999].
SR (Recruitment variability)	The coefficient of variation (CV) is 0.43. It is the median value of the CVs derived from the recruitment estimates of ICES data-rich sole stocks.
Natural mortality	Age-variable M equal to the median of different empirical estimators.
Selectivity	Logistic derived from LBSPR (Length-Based Spawning Potential Ratio; [Hordyk et al., 2014]) estimates; $SL_{50} = 29.21$, $SL_{95} = 36.92$
Length-weight relationship	[Alonso-Fernández et al., 2021]; $a = 0.009476898, b = 3.018329$
Growth	[Teixeira and Cabral, 2010]; $L_\infty = 49.4$,$k = 0.22$, $t_0 = -0.84$
Maturity	[Teixeira, 2009]; $L_{50} = 35.9$, $L_{95} = 1.1 \times L_{50} = 39.5$
Fishing Mortality	Last historical year equal to F_{MSY}, the preceding years follow the pattern shown in Figure 1, which covers a wide range of F values.

As mentioned, to address uncertainties in key processes, a set of alternative OMs has been developed, as summarized in Table 3. These alternative OMs are considered to test that the proposed catch rule remains robust against various sources of uncertainty.

As mentioned previously, in the baseline OM, fishing mortality over the 100-years of historical period follows the trajectory shown in Figure 1, ending in the last at the F_{MSY} value. The decision to have the trajectory end at F_{MSY} is based on the fact that results from length-based data-poor

Table 2: Selectivity and noise parameters in the biomass index and length frequency distributions (LFDs) sampling.

Source	**Details**
Biomass Index	Selectivity equal to commercial one and noise CV = 0.2
LFDs	CV noise = 0.2

Table 3: List of alternative operating models.

	Category	**ID**	**Difference**	**OM type**
1	SR	Low steepness	Steepness value equal to 0.72; 20% percentile of [Myers et al., 1999]	Reference
2		High CV in Recruitment	CV in recruitment= 0.6; percentile 70% of CVs derived from recruitment estimates of ICES data-rich sole stocks.	Robustness
3	Natural mortality	Constant M	M median of different empirical estimators, value= 0.3743	Reference
4		Low mortality	M equal to 0.1 for all ages	Robustness
5	Growth	Low L_∞	L_∞ 10% less than reference one (k adjusted accordingly); L_∞ =44.415, k = 0.3721644	Robustness
6		High L_∞	L_∞ 10% more than reference one (k adjusted accordingly); L_∞ =54.285, k = 0.1518894	Robustness
7	Selectivity	Double normal selectivity	Selectivity with asymptote at 0.6 (instead of 1)	Reference
8	Maturity	Low L_{50}	[Jardim et al., 2011]; $L_{50} = 26cm$	Reference

assessment methods suggested compatibility with sustainable stock exploitation. However, to account for the uncertainty associated with the level of exploitation, alternative OMs are also considered. These models follow the description in Table 1 or Table 3, but with modified fishing mortality. Specifically, in the last year, fishing mortality is set to F corresponding to $0.5 \times SSB_{MSY}$ instead of F_{MSY}.

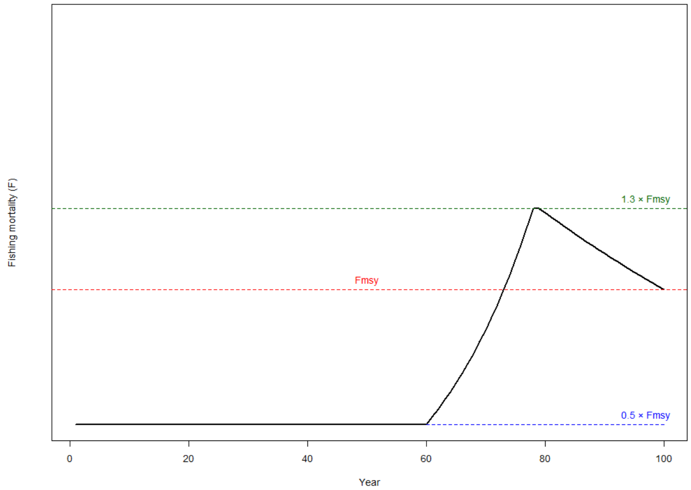

Figure 1: Fishing mortality trend over the 100 years of stock history. Starting at $0.5\times F_{msy}$, increasing to $1.3\times F_{msy}$, and returning to F_{msy}

2 Rationale behind decisions

2.1 Growth

We evaluated two potential data sources: [Teixeira and Cabral, 2010] and [Dinis, 1986]. Both datasets yield very similar growth curves when combined males and females. However, we chose [Teixeira and Cabral, 2010] for the baseline OM because their study used bimonthly samples collected between January 2003 and June 2005 from commercial fishing vessels operating with gillnets and bottom trawls along the Portuguese coast. In contrast, the data from [Dinis, 1986] were limited to the estuary of the Tagus River (Portugal), representing a more localized area.

To define the alternative growth curves considered in the set of OMs, a regression model was developed to explain the growth rate (k) in relation to the asymptotic length (L_∞) and sex. This model was fitted using FishBase growth data from the Atlantic regions of France, Portugal, and Spain. Additionally, we incorporated data from [Dinis, 1986] and [Andrade, 1990]), although the latter provides information only for males. After fitting the model, we predicted the k values associated with a 10% underestimation and a 10% overestimation of L_∞ for both sexes. These predicted values were then averaged by sex, resulting in the alternative growth curves presented in Figure 2.

2.2 Stock recruitment relationship

2.2.1 Recruitment variability

In our MSE framework, the source of stochasticity in the OM comes from the recruitment variability. 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 70th percentile, thereby offering a plausible and extreme value for recruitment variability. The values obtained, and consequently, those taken into consideration in the definition of the set of OMs, are as follows: 0.43 for the median and 0.6 for the 70th percentile.

It is important to note that these CV values are used to define the variability in recruitment residuals, i.e., the deviation of recruitment estimates from the values predicted by the stock–recruitment (SR) model. Hence, ideally, the CV's would be calculated from the residuals of the SR relationship for each stock. However, since this is not possible in most cases—because a stock–recruitment function

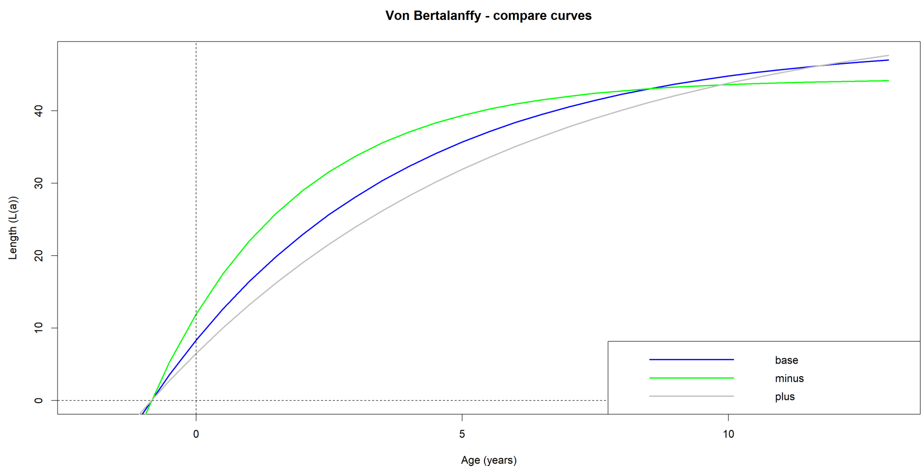

Figure 2: Growth. [Teixeira and Cabral, 2010] curves and alternatives of 10% underestimation (minus) and a 10% overestimation (plus) of L_∞.

is not fitted in the majority of ICES stock assessments—we decided to estimate the CV based on the absolute recruitment estimates provided by ICES assessments, as this is the information available. Hence, to account for uncertainty, we have also considered the higher CV of 0.6 in the set of alternative operational models (OMs).

2.2.2 Stepness

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 an OM that considers an alternative value of steepness is essential. Then, we have adopted two values, according to the median and 20th percentile extracted from the steepness values of [Myers et al., 1999] for Solea. These values are as follows: 0.72 for the 20th percentile and 0.84 representing the median.

2.3 Natural Mortality

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 to assess common sole in divisions 8c and 9a, a value of M=0.31 is used. However, this selection lacks a reasoned justification. On the contrary, in the remaining ICES sole stocks, a constant age-specific mortality vector set at 0.1, is used, but, as in the previous case, this choice also lacks a well-founded justification.

Given the notable vulnerability of young ages to predation and environmental risks, we 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 et al., 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.

As an alternative, 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 are: tmax1, PaulyLNoT, HoenigO, HoenigOF, HoenigO2, HoenigLM, HoenigNLS, HewittHoenig, K1, K2, JensenK1, JensenK2, AlversonCarney, and RikhterEfanov1.. The M vector at age in the OM is set as a constant value equal to the median of these M estimates, which is 0.359.

On the other hand, given that a constant age-specific mortality rate of 0.1 is used for other ICES sole stocks we have decided to include this as an alternative OM.

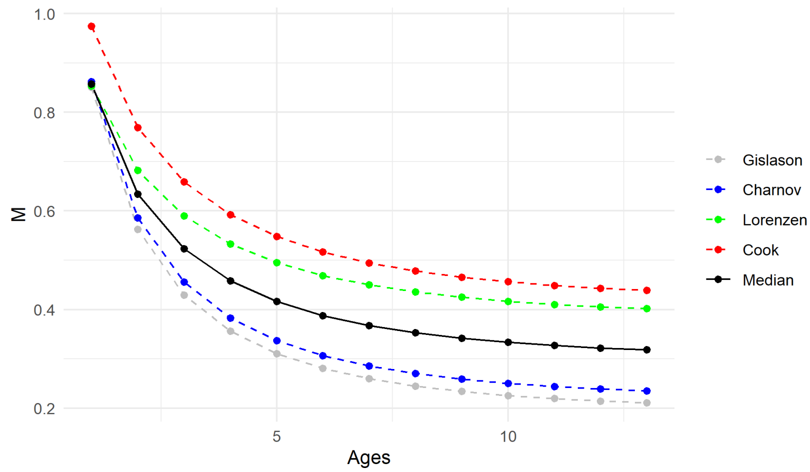

Figure 3: M estimates derived from the empirical methods of [Gislason et al., 2010], [Charnov et al., 2013], [Lorenzen, 1996] and [Cook, 2013], and their median (final M at age estimates).

2.4 Weight-length

We have reviewed several studies related to length-weight relationships, including [Dinis, 1986], [Froese et al., 2014], [Veiga et al., 2009], and [Alonso-Fernández et al., 2021], see Figure 4. For comparison purposes, the W-L curve used for the common sole in Divisions 8a and 8b is also shown. Some of the curves presented in these studies are quite similar, particularly those of [Dinis, 1986] and [Froese et al., 2014], which are nearly coincident.

Among the studies reviewed, we excluded the work of [Dinis, 1986] and [Veiga et al., 2009] from consideration in our OMs, as they focus on estuaries: the Tagus River estuary and the Arade estuary, respectively. Additionally, we discarded the study by [Froese et al., 2014], as their estimates are derived from a Bayesian hierarchical approach using all available W-L relationships for sole, which may include sole stocks far from our stock area, which may exhibit different dynamics. Finally, we decided to use the study by [Alonso-Fernández et al., 2021], as it covers the Galician coast, one of the areas with the highest presence and abundance of *Solea solea* species.

2.5 Maturity

We have analyzed several studies on maturity: the thesis by [Teixeira, 2009] and the working document by [Jardim et al., 2011], presented to the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk, and Megrim (WGHMM) in 2011. Additionally, we considered [Dinis, 1986], but ultimately excluded it because it reports the same value for both males and females, and the reason for this is unclear.

Therefore, we propose to use the results from [Teixeira, 2009] in our baseline OM, while considering [Jardim et al., 2011] as an alternative. This decision is based on the fact that the growth parameters for the baseline OM are also derived from [Teixeira and Cabral, 2010], as well as the limited information in Jardim's working document above how the analysis was carried out. We consider [Jardim et al., 2011] a suitable alternative for maturity as it is consistent with the values used for the Bay of Biscay sole stock (sol.27.8ab), see Figure 5.

In order to derive L_{95} from L_{50}, we analysed the relationship between these values in the maturity curve for sole in Divisions 8a and 8b. On this basis we concluded that the following relationship is appropriate: $L_{95} = 1.1 \times L_{50}$. The finalcurves are in Figure 6.

2.6 Selectivity

The logistic selectivity curve used in the baseline OM is derived from the estimates of SL_{50} and SL_{95}, which correspond to the length at which 50% and 95% of the population are selected, respectively, derived from LBSPR method applied to the joint (all years into one) commercial length distribution of

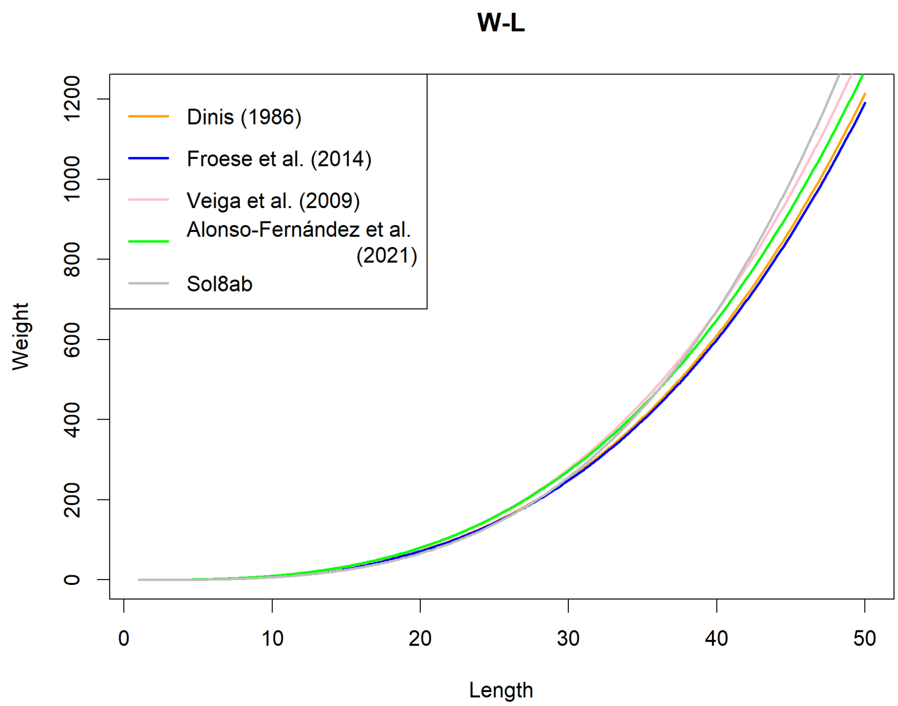

Figure 4: Comparison of L-W curves.

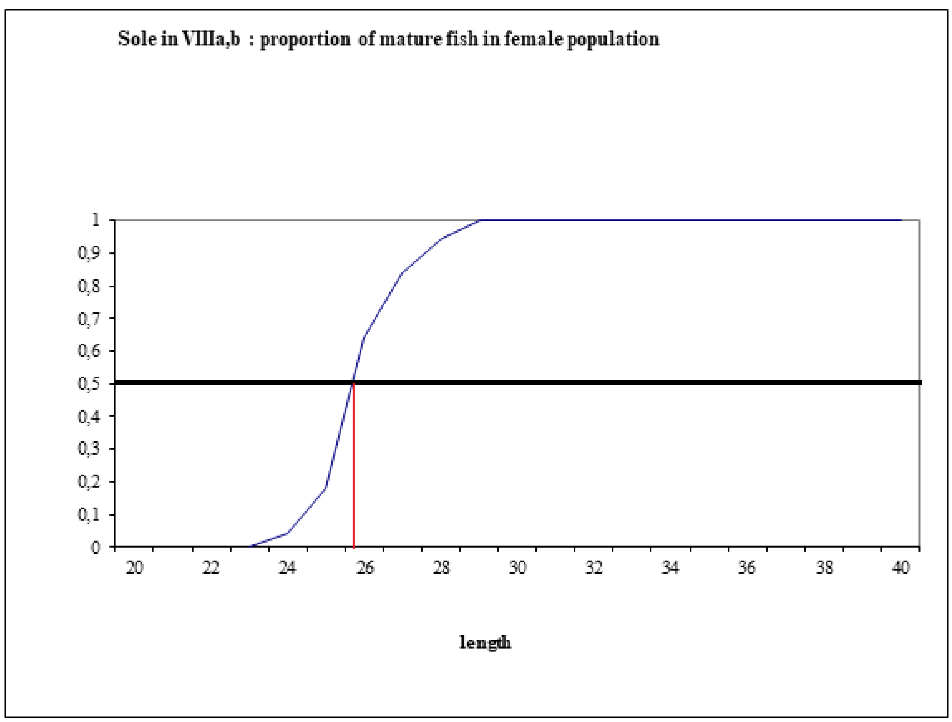

Figure 5: Maturity for common sole stock in Bay of Biscay (sol.27.8ab).

common sole in divisions 8.a and 9.a (see logistic curve in Figure 7). The selectivity curve is converted to age-based selectivity for use in the R FLife package in the creation of the OMs. The alternative growth curve is dome-shaped, defined so that the right-hand side of the curve follows the logistic form of the baseline OM selectivity, while the left-hand side slopes down to a value of 0.6 after the peak.

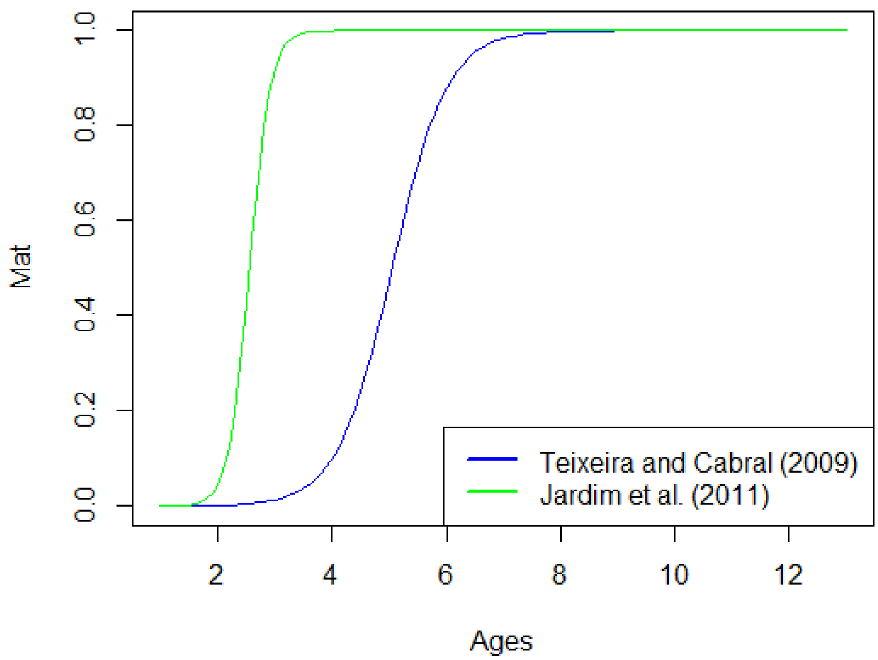

Figure 6: Maturity curves.

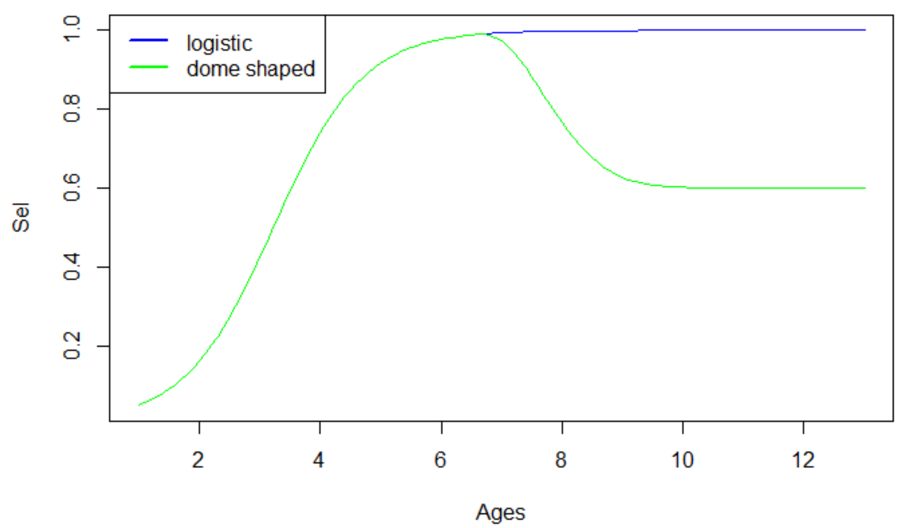

Figure 7: Logistic and dome-shaped selectivity for commercial fleet.

2.7 Interactions between OMs

It is important to clarify that selectivity, natural mortality and maximum age calculated using the baseline OM information are not recalculated if the value of other life history parameters are changed due to a change to an alternative OM. For example, in OM 5, where an alternative growth curve is used, the values for natural mortality, selectivity and maximum age are not recalculated using this new curve. Instead, the estimates derived from the baseline OM are retained.

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