Stock Annex: Sole (*Solea spp.)* in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Sole
Group Ecoregion (WGBIE)	Working Group for the Bay of Biscay and Iberian Waters
Created	Maria de Fatima Borges (WGBIE) May 2014
Last updated	March 2021
Last updated by	Maria Grazia Pennino and Catarina Maia

A. General

A.1. Stock definition

Solea Solea is a widely distributed species in Northeast Atlantic shelf waters with a range from southern Norway including North Sea and western Baltic and Mediterranean Sea, to the Northwest of Africa inhabiting sandy and muddy bottoms at depths near to 100 and 200 meters (Quero *et al.,* 1986). At present there is no information on stock unit definition for common sole in ICES subdivision 8.c and 9.a. It was considered that in the absence on specific information on stock structure, the subdivisions 8.c and 9.a may be used as a management unit.

A.2. Fishery

The unit management of the common sole stock in the Iberian Atlantic waters includes the ICES subdivisions 8.c and 9.a. where both the Portuguese and Spanish fleets operate. In this area common sole is target mainly by multispecies fleets using as main fishing gears trammel and gillnets. The minimum landing size of sole species is 24 cm. There are other regulations regarding the mesh size for trammel and trawl nets, fishing grounds and vessel’s size. Sole species are under the Landing Obligation in divisions 8.abde (all bottom trawls, mesh sizes between 70 mm and 100 mm, all beam trawls, mesh sizes between 70 mm and 100 mm and all trammel and gillnets, mesh size larger or equal to 100 mm) and in Division 9.a (all trammel nets and gillnets, mesh size larger or equal to 100 mm). In Portugal all catches of sole species from all gears and mesh sizes are under the Landing Obligation (more restrictively than required by European regulations).

The EU multiannual plan (MAP; EU, 2019) for stocks in the Western Waters and adjacent waters applies to this stock. The MAP stipulates that when the F_{MSY} ranges are not available, fishing opportunities should be based on the best available scientific advice.

A.3. Ecosystem aspects

The life cycle of common sole is complex and presents different ontogenetic migrations (Tanner *et al*., 2017). Common sole spawn in coastal waters at depths ranging from 30 to 100 m (van der Land, 1991). The spawning period is commonly between February and May, although it can occur in early winter in warmer areas. The development of the larvae is temperature-dependent and takes place in shallow waters (Tanner *et al*., 2017). It is during transport from spawning areas to coastal nurseries that the larvae metamorphose into benthic life (Marchand, 1991). Nursery areas are generally located within estuaries where juveniles of common sole spend up to two years in a residence phase before returning to the adult feeding and spawning areas on the continental shelf (e.g. Vasconcelos *et al*., 2010).

B. Data

B.1. Commercial catch

During the WGBIE2020, Portuguese's colleagues highlighted that catches from Portugal have a problem of misidentification in some ports with the three species (i.e. *Solea solea, Solea senegalensis, Pegusa lascaris* and *Solea* spp.) (Dinis *et al*., 2020).

For the WKWEST2021 benchmark, using data from the Data Collection Framework (DCF) sampling, Portuguese catches were proportionally divided by sole species applying the species weight proportion to the total weight of Soleidae in each year, landing port, and semester and using a simple random sampling estimator, following Figueiredo *et al*. (2020). Details on data available and catch estimation procedures can be found in Annex 2 of the working document Pennino et al. (2021). At the moment the new Portuguese catches are considered reliable.

In addition, from the WKWEST2021 data call, catches for *S. solea* were also reported by France and now are available in InterCatch from 2009 to 2019 (Figure 1). Information on discards indicates that discarding can be considered negligible (< 1%).

For the years 2009–2010, only catches from Spain and France are available, while for the other years (2011–2019) catches are available for the three countries (i.e. Portugal, Spain and France) (Figure 2).

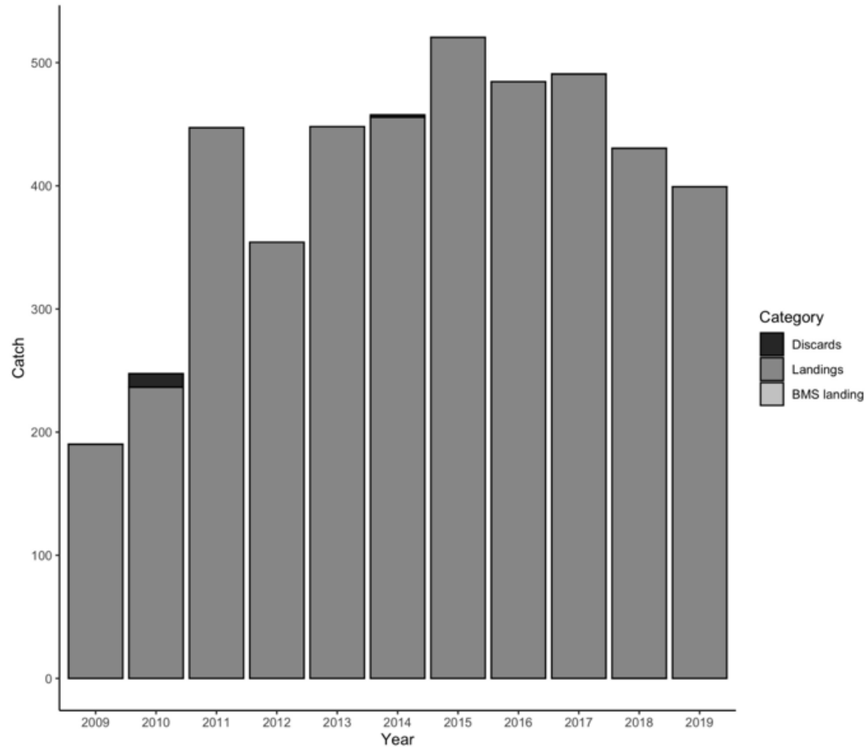

Figure 1: Catches for *Solea solea* by category (landings, discards and BMS landing) in the ICES divisions 8c9a for Portugal, Spain and France from 2009 to 2019. Source data: InterCatch.

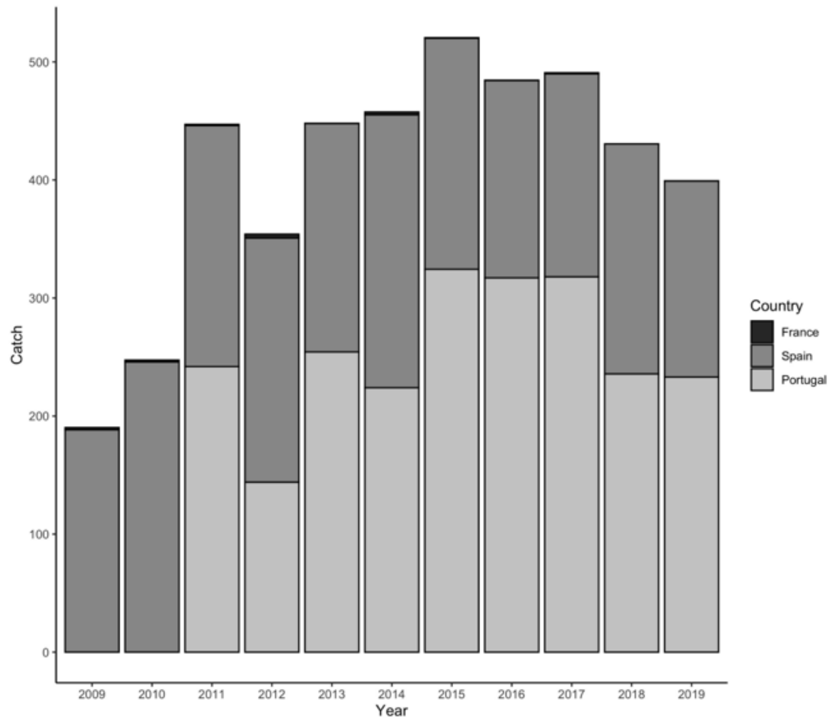

Figure 2: Catches for *Solea solea* in the ICES divisions 8c9a by country from 2009 to 2019. Source data: InterCatch.

When catches are analysed by division it is possible to see that the majority of them are in the ICES Division 9a and that, although different fleets fish this stock, the two main ones are the polyvalent fleet from Portugal (i.e. “MIS_MIS_0_0_0”) and the trammel net fleet from Spain (i.e. “GRT_DEF_60-79_0_0”) (Figure 3). The distribution of the catches is almost homogenous along the year for the two main countries (i.e. Portugal and Spain), as well as for the main fleets (Figure 4).

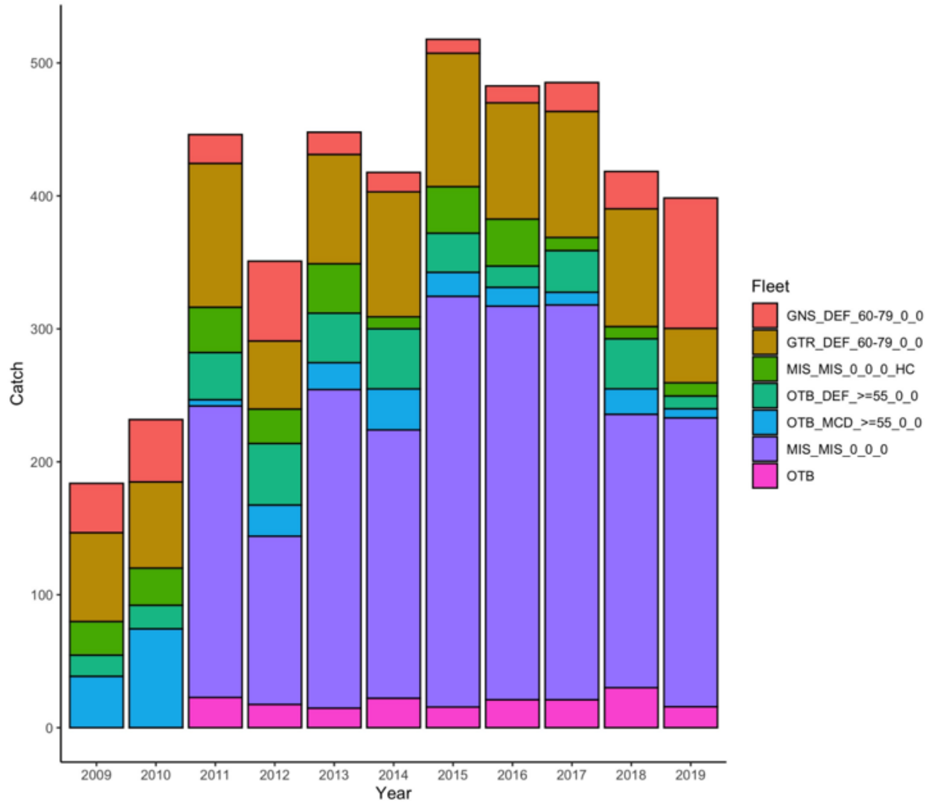

Figure 3: Catches for *Solea solea* by the main fleet in the ICES divisions 8c9a for Portugal, Spain and France from 2009 to 2019. Source data: InterCatch.

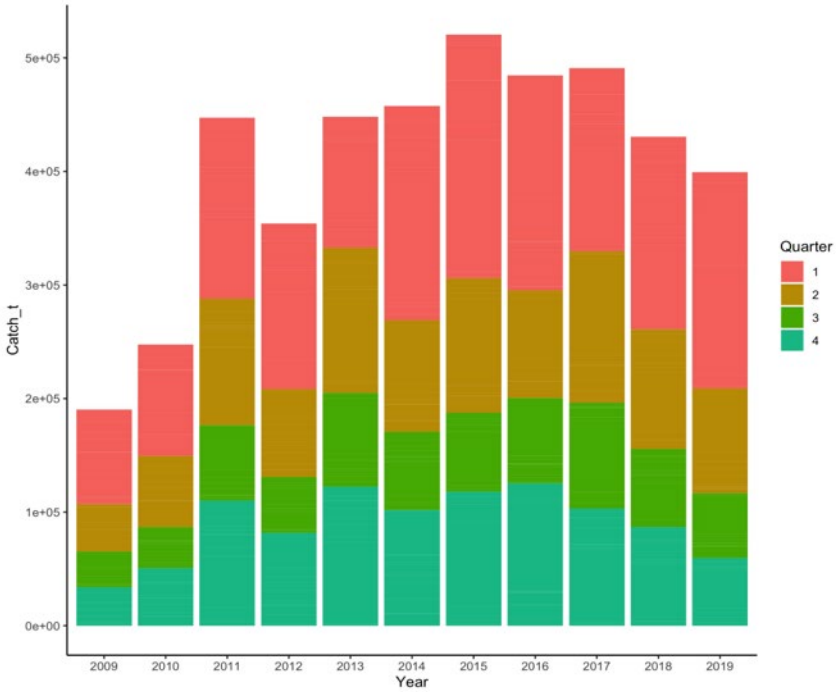

Figure 4: Catches for *Solea solea* by quarter in the ICES divisions 8c9a for Portugal, Spain and France from 2009 to 2019. Source data: InterCatch.

Length frequency distribution

In InterCatch, data on length frequency distribution are available for the years 2011–2019 (Figure 5). The majority of the data are of the polyvalent fleet (i.e. métier "MIS_MIS_0_0_0") from Portugal.

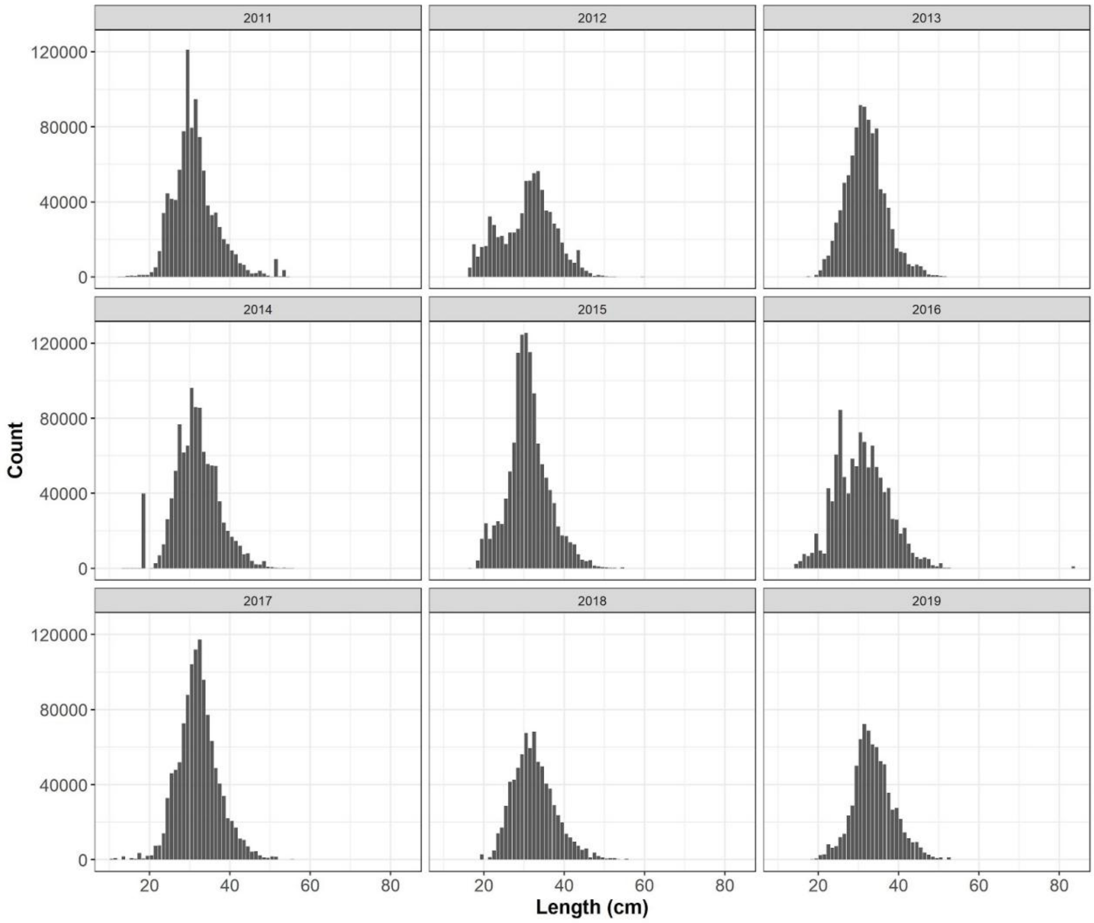

Figure 5: Length frequency distribution of catches for *Solea solea* in the ICES divisions 8c9a by year (from 2011 to 2019) for Portugal, Spain and France. Source data: InterCatch.

Other sole species

For the WKWEST21 an official data call was requested for this stock to get all the possible data, not only for the common sole (*S. Solea*) but also for the other sole species *Solea senegalensis*, *Pegusa lascaris* and *Solea spp*. (Figure 6).

For Portugal, *S. Senegalensis* and *P. lascaris* landings and length frequency distribution are available for the period 2011–2019. *Solea spp*. landings are also available for the period 2011–2019. For Spain, *S. Senegalensis*, *P. lascaris* and *Solea spp*. landings are available for the period 2009–2019. No French data on these species were available.

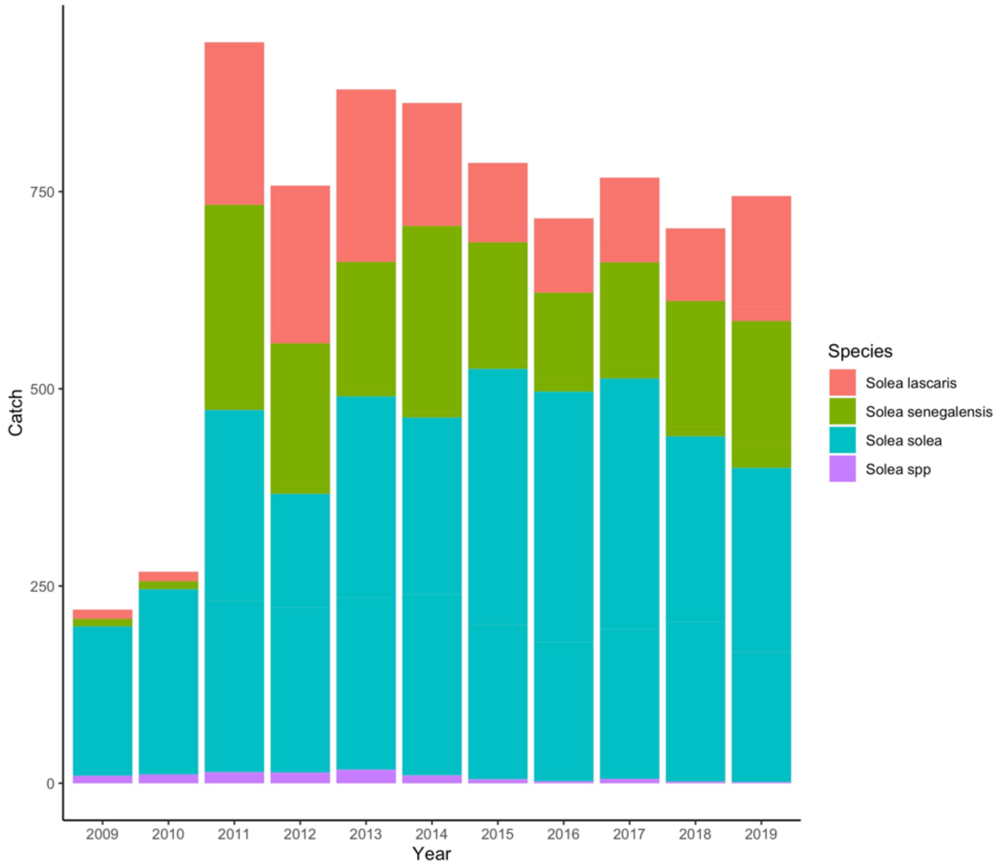

Figure 6: Sole species landings for the Division 8c9a. Data are from Spain and Portugal together.

B.2. Biological

Growth studies based on *S. solea* otolith readings in the Portuguese coast indicate L_{inf} 52.1 cm for and 45.7 cm for while the growth coefficient (k) estimate of females (K=0.23) was slightly higher than for males (k=0.21) and t_o estimates were -0.11 and 1.57 for females and males respectively (Teixeira and Cabral, 2010). Common sole length of first maturity was estimated as 25 cm for males and 27 cm for females (Jardim *et al*., 2011).

The natural mortality parameter M is not known for this stock but for the stock of common sole ICES Division 8a, is used a M of 0.2. A recent study of Cerim *et al*. (2020) defined the M of the common sole as M= 0.31 yr-1.

L_{95} is not known for this stock but for the common sole ICES Division 8a, b is 27.5 (see stock annex sol-bisc division 8a,b).

Bayesian length–weight: a=0.00759 (0.00629–0.00915), b=3.06 (3.00–3.12), in cm Total Length, based on LWR estimates for this species (Froese *et al*., 2014).

B.3. Surveys

Common sole data were collected during the scientific survey series SP-NSGFS Q4 performed by the Instituto Español de Oceanografía (IEO) in autumn (September and October) between 2000 and 2019. Surveys were conducted on the northern continental shelf of the Iberian Peninsula (ICES divisions 8c and the northern part of 9a) which has a total surface area of almost 18 000 km^2 (Figure 7).

Surveys were performed using a stratified sampling design based on depth with three bathymetric strata: 70–120 m, 121–200 m and 201–500 m. Sampling stations consisted of 30 minute trawling hauls located randomly within each stratum at the beginning of the design. The gear used is the baka 44/60 and the survey follow the protocol of the International Bottom Trawl Survey Working Group (IBTSWG) of ICES (ICES, 2017).

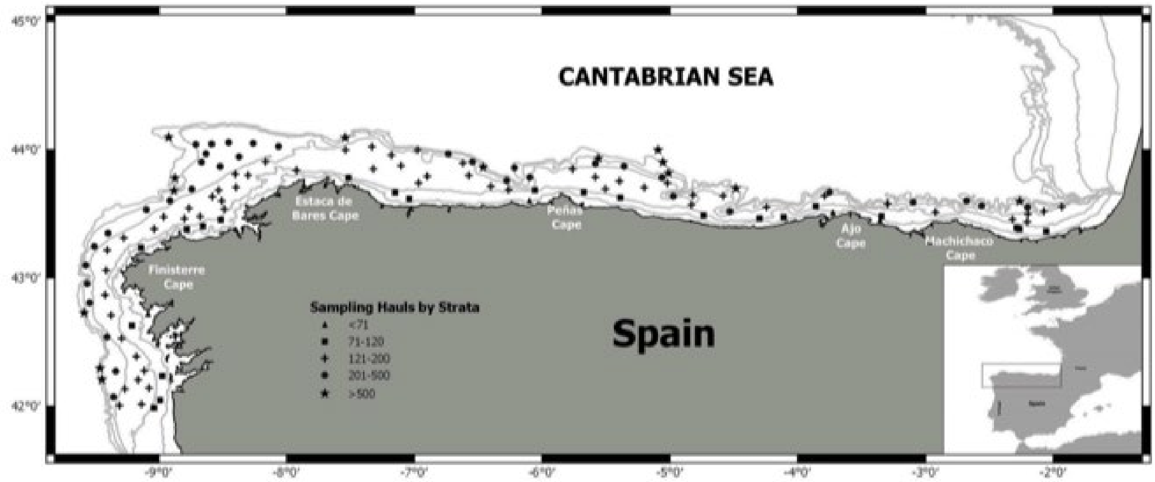

Figure 7: Map of the study area. Black dots represent annual sampling locations.

However, the common sole is a species with a biological bathymetric range between 0 and 200 meters in the Iberian Atlantic waters. The SP-NSGFS Q4 only covers partially the common sole bathymetric range and the resultant abundance index is probably underestimated. For this reason, and with the aim to correct this sampling bias, a hurdle Bayesian spatiotemporal was applied to this dataset.

Two response variables were analysed in order to characterize the spatiotemporal behaviour of common sole individuals. Firstly, a presence/absence variable was considered to measure the occurrence probability of the species. Secondly, the weight by haul (kg) was used as an indicator of the conditional-to-presence abundance of the species.

As environmental variable we used the bathymetry. Bathymetry values were retrieved from the European Marine Observation and Data Network (EMODnet, http://www.emodnet.eu/) with a spatial resolution of 0.02 x 0.02 decimal degrees (20 m).

Models were fitted using the integrated nested Laplace approximation approach INLA (Rue *et al*., 2009) in the R software (R Core Team, 2021). The spatial component was modelled using the spatial partial differential equations (SPDE) module (Lindgren *et al*., 2011) of INLA and implementing a multivariate Gaussian distribution with zero mean and a Matérn covariance matrix (Muñoz *et al*., 2013).

As spatiotemporal structure we used the progressive one (Paradinas *et al*., 2017; 2020), which contains an autoregressive ϱ parameter that controls the degree of autocorrelation between consecutive years. This ϱ parameter is bounded to [0, 1], where parameter values close to 0 represent more opportunistic behaviours and parameter values close to 1 represent more persistent distributions over time. In addition, an extra temporal effect g(t) was added using a second order random walk (RW2) prior to allow non-linear effects. In the presence of bathymetric and spatial autocorrelation terms, g(t) can be regarded as a spatially standardized stock size temporal trend.

Occurrence (Y_{st}) was modelled using a Bernoulli distribution and conditional-to-presence abundance (Z_{st}) using a gamma distribution, which is a probability distribution that captures the overdispersion of continuous data. The means of both variables were modelled through the logit and log link functions respectively to the bathymetric and spatiotemporal effects as:

$$Y_{st} \sim Ber(\pi_{st}) \qquad (1)$$

$$Z_{st} \sim Gamma(\mu_{st}, \phi)$$

$$logit(\pi_{st}) = \alpha(Y) + f(ds) + g(t) + U_{st}(Y)$$

$$log(\mu_{st}) = \alpha(Z) + \theta\, f(ds) + \eta\, g(t) + U_{st}(Z)$$

where π_{st} represents the probability of occurrence at location *s* at time *t* and μ_{st} and ϕ are the mean and dispersion of common sole conditional-to-presence abundance. The linear predictors, which contain the effects that link the parameters π_{st} and μ_{st}, include: $\alpha(Y)$ and $\alpha(Z)$, terms that represent the intercepts of each variable respectively; ds corresponds to the depth at location *s*, being f(ds) the bathymetric effect modelled as a second order random walk (RW2) smooth function parametrised as unknown values f = $(f_0, \ldots f_{i-1})_t$ at *i* = 14 equidistant values of ds, with hyperparameter σ representing the variance of the f(ds) model. In the same way, g(t) corresponds to the temporal trend fitted through a RW2 effect over the years. The terms f(ds) and g(t) are shared between both predictors and multiplied by θ and η in the conditional-to-presence abundance model to allow for differences in scales between both predictors (i.e. the logit transformed probability and the logarithm of the conditional-to-presence abundance); $U_{st}(Y)$ and $U_{st}(Z)$ refer to the progressive spatiotemporal structures of common sole occurrence and conditional-to-presence abundance respectively.

Following the Bayesian approach, penalised complexity priors (i.e. PC priors, weak informative priors; Simpson *et al.*, 2017) were assigned so that the probability of the spatial effect range being smaller than 0.5 degrees was 0.05, and the probability of the spatial effect variance being larger than 0.5 was 0.5. PC priors were also used for the variance of the bathymetric and the temporal trend RW2 effects. Specifically, the size of these effects was constrained by setting a 0.05 probability that sigma was greater than 0.5 and 1 respectively. Sensitivity analysis for the selection of priors was performed by testing different priors and verifying that the posterior distributions were consistent and concentrated comfortably within the support of the priors.

From this analysis, the most important results that we obtained were the predicted distribution of the species (Figure 8), and a new spatiotemporal abundance index (Figure 9).

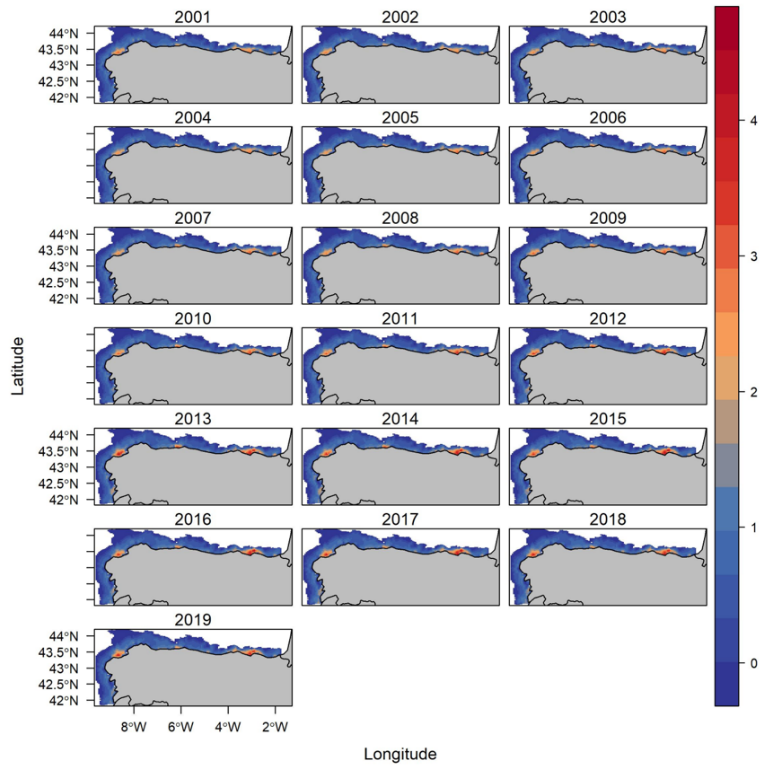

Figure 8: Prediction maps (2001–2019) of the common sole conditional-to-presence median abundance estimated by the hurdle Bayesian spatiotemporal model.

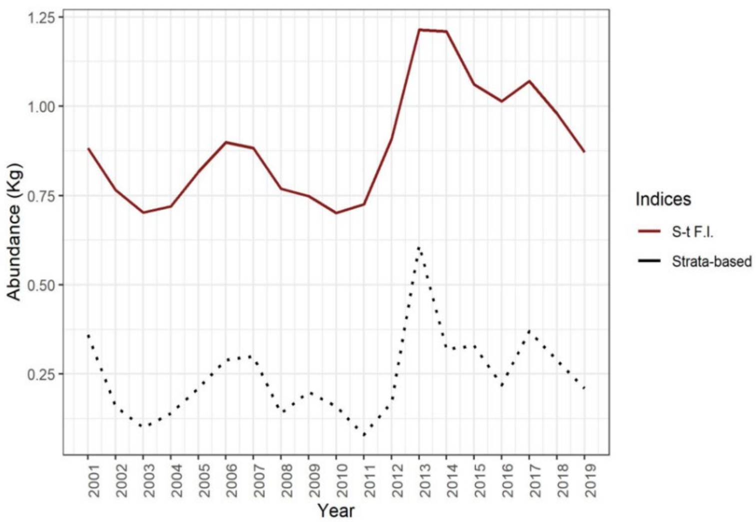

Figure 9: Temporal trend of the spatiotemporal abundance index (red) and the designed-based index for the SP-NSGFS Q4.

B.4. Commercial LPUE

Portuguese LPUE estimates relied on fishery-dependent data derived from the polyvalent fleet and are based on the estimated *S. solea* landed weight by fishing trip. The analysis was restricted to the most important landing ports in terms of *S. solea* landed weight: Viana do Castelo, Matosinhos, Aveiro, Peniche and Setúbal. The Portuguese polyvalent fleet segment comprises multi-gear/multispecies fisheries, usually licensed to operate with more than one fishing gear (most commonly gill and trammel nets, longlines and traps), that can be deployed in the same trip, targeting different species. The time period considered in the present study extends from 2011 to 2019.

The dataset was subset to trips with positive landings of the species. The LPUE standardization procedure was done via the adjustment of a General Linear Model (GLM) to the matrix data, where the response variable was the *S. solea* landed weight by trip (unit effort) and was fitted with a Gamma distribution. Several variables were evaluated as candidate to be included in the model: region, landing port, year, semester, quarter, month and vessel size group (<9 m and >9 m).

All the explanatory variables were considered as categorical variables. The function "bestglm" implemented in R software was used to select the best subset of explanatory variables (McLeod and Xu, 2010). The selection of the set explanatory variables to enter into the model is done following McLeod and Xu (2010) procedure, which is based on a variety of information criteria and their comparison following a simple exhaustive search algorithm (Morgan and Tatar, 1972). The diagnostic plots, distribution of residuals and the quantile-quantile (Q-Q) plots, were used to assess model fitting. Changes in deviance explained by the selected model and the proportions of deviance explained to the total explained deviance was determined and used as indicative of r2. Finally, annual estimates of LPUE and the corresponding standard error were determined using estimated marginal means (R package: emmeans).

The final model explained 87% of the variability and included as explanatory variables the year, the month, the landing port and the vessel size. Estimated effects of each explanatory variable, as well as, the residual graphical analysis for the best model selected are presented in Figures 10 and 11. The final LPUE index is presented in Figure 12. Finally, it worth to be mentioned that sensitivity tests were carried out to this dataset to assess the sensibility of the model to a possible increase or reduction of the weight per trip by 25% for data from 2019. Results highlighted that the model performed well and consequently obtained consistent outputs with the original dataset.

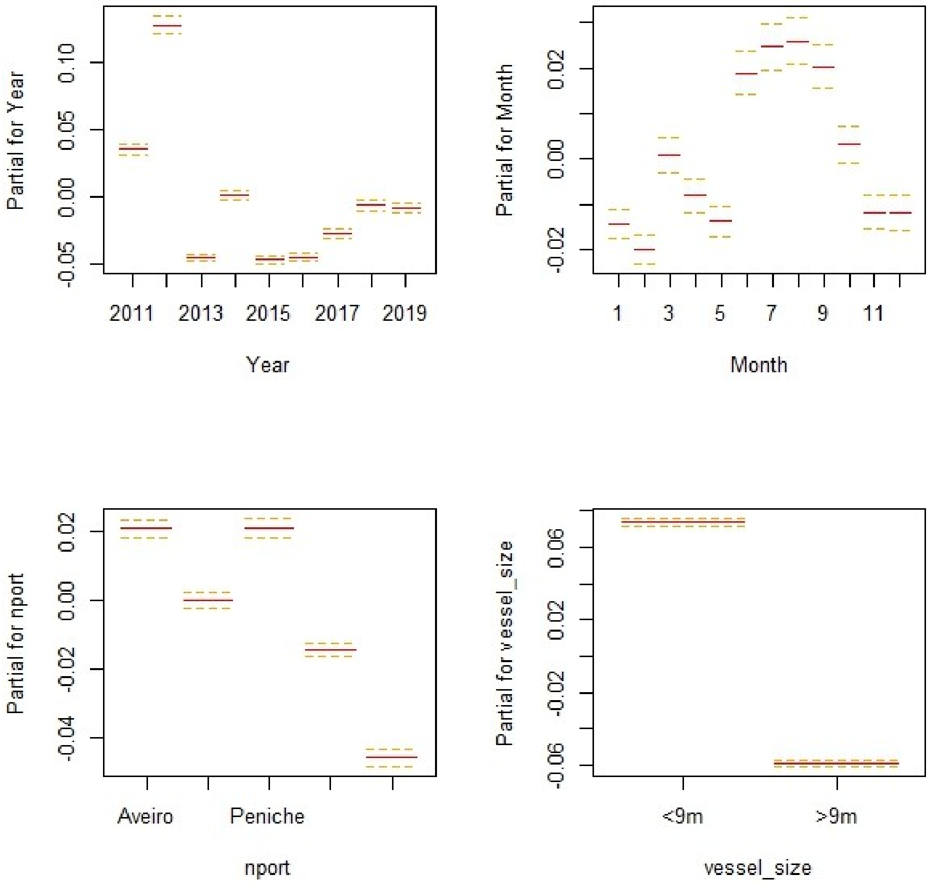

Figure 10. *Solea solea* in Portuguese waters (Division 9a). Effect of each explanatory variable included in the standardization of the LPUE for *S. solea* caught by the polyvalent segment in mainland Portugal (Division 9a): year, month, landing port (nport) and vessel size (vessel_size).

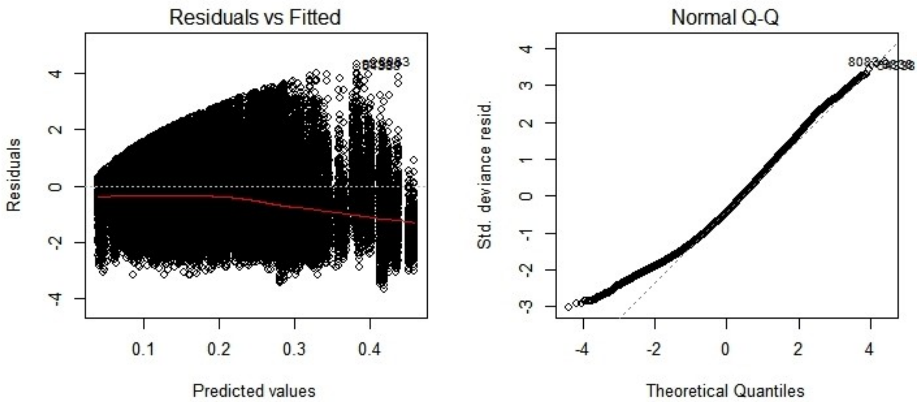

Figure 11. *Solea solea* in Portuguese waters (Division 9a). Residuals of the best GLM model fitted to the LPUE data for the Portuguese polyvalent fleet: (left) fitted vs. residuals (right) quantile-quantile (Q-Q) plot.

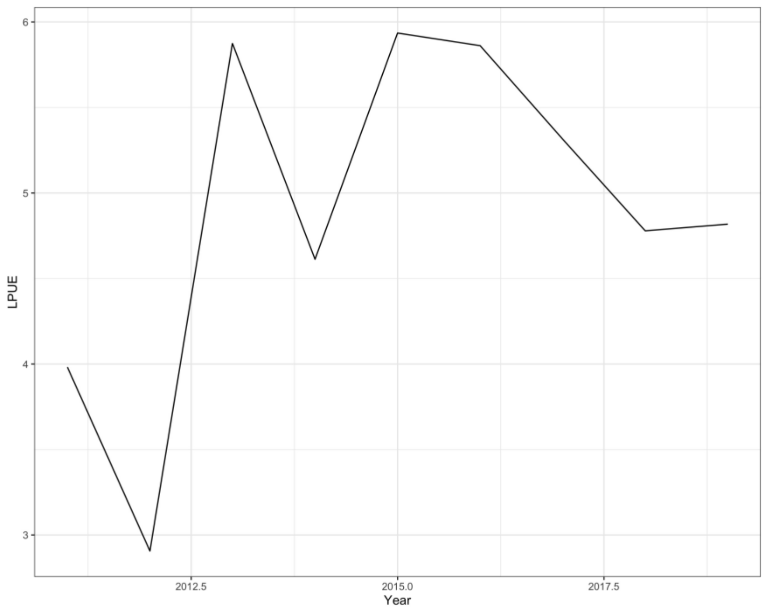

Figure 12. LPUE index by year of *Solea solea* in the in Portuguese waters (Division 9a).

B.5. Other relevant data

The Portuguese Groundfish Survey (PtGFS-WIBTS-Q4) dataset was analysed for this stock during the WKWEST2021 but due to the very few catches of this species and the low spatial coverage, the survey was not further considered. However, from December 2020 a new gear will be used in this survey that probably could have a better catchability of the common sole. These data need to be monitored in the future. Similarly, during the WKWEST2021, it was computed a commercial CPUE using data of observer on board the artisanal fleet that operate in the Galician waters (Spain). For the moment this CPUE was considered no representative for the stock but need to be monitored in future years.

C. Assessment: data and method

Before the WKWEST2021 benchmark, the common sole stock was considered as a data-limited stock and was classified as a category 5 stock, as only catch data were available. There was no analytical assessment for sole in this area. Since 2012, ICES provides scientific advice for this stock applying the precautionary approach. A precautionary buffer was applied in 2018 (≥20% reduction in catch relative to 2014–2016 average) and in 2019 (same catch value advised as 2018) with an advises that catches should be no more than 502 tonnes (2020–2021). The advice and assessment were provided only for common sole. The management of all sole species was provided under a unique combined Total Allowable Catch (TAC).

During the WKWEST2021 different data-poor methods were implemented, such as Length-based indicators (LBI), Length-based spawning potential ratio (LBSPR), Mean length-based mortality estimators (MLZ) and stochastic surplus production model in continuous time (SPiCT) (ICES, 2018a). Among them it was agreed that the LBI approach was currently the most adequate for this stock.

For the LBI implementation, life-history parameters considered were:

- M/K=1.41, derived from the M=0.31 (from Cerim *et al*., 2020), K=0.22 (from Teixeira and Cabral (2010) we have that K=0.23 for females and K=0.21 for males, then we consider the mean of both sexes).
- L_∞ =48.9 cm (from Teixeira and Cabral (2010) we have that L_{inf} = 52.1 cm for females and Linf = 45.7 cm for males, and hence we compute the mean of both sexes).
- L_{mat} =26 cm (from Jardim *et al*. (2011) we have that L_{mat} =25 cm for males and L_{mat} =27 cm for females, and then the mean of both sexes is computed).
- Length–weight relationship parameters a=0.00759 and b=3.06 (Bayesian length–weight model based on LWR estimates for this species Froese *et al*., 2014).

The LBI method was adjusted using the above values and defined as the reference model. A sensitivity analysis of the parameters L_∞, M/K and L_{mat} (around our literature/reference values) was also carried out overestimating and underestimating them by 5 and 10%.

From the reference model we can conclude that the stock is exploited at MSY level and the optimal yield is attained (Table 3 and Figure 13). The immatures are good preserved whereas the proportion of mega-spawners is low, although it has been increased in the last years.

Table 3: Traffic light indicator table for the LBI analysis.

	Conservation				Optimizing Yield	MSY
Year	L_c/L_{mat}	$L_{25\%}/L_{mat}$	$L_{max5\%}/L_{\infty}$	P_{mega}	L_{mean}/L_{opt}	$L_{mean}/L_{F=M}$
2011	1.10	1.10	0.94	0.13	1.00	0.99
2012	0.83	1.02	0.90	0.17	0.96	1.12
2013	1.02	1.10	0.89	0.14	0.99	1.01
2014	1.02	1.10	0.91	0.15	0.99	1.02
2015	1.06	1.10	0.88	0.12	0.98	0.98
2016	0.87	0.98	0.93	0.17	0.95	1.08
2017	1.10	1.13	0.91	0.15	1.02	1.00
2018	1.02	1.10	0.93	0.18	1.00	1.03
2019	1.13	1.17	0.94	0.23	1.05	1.01

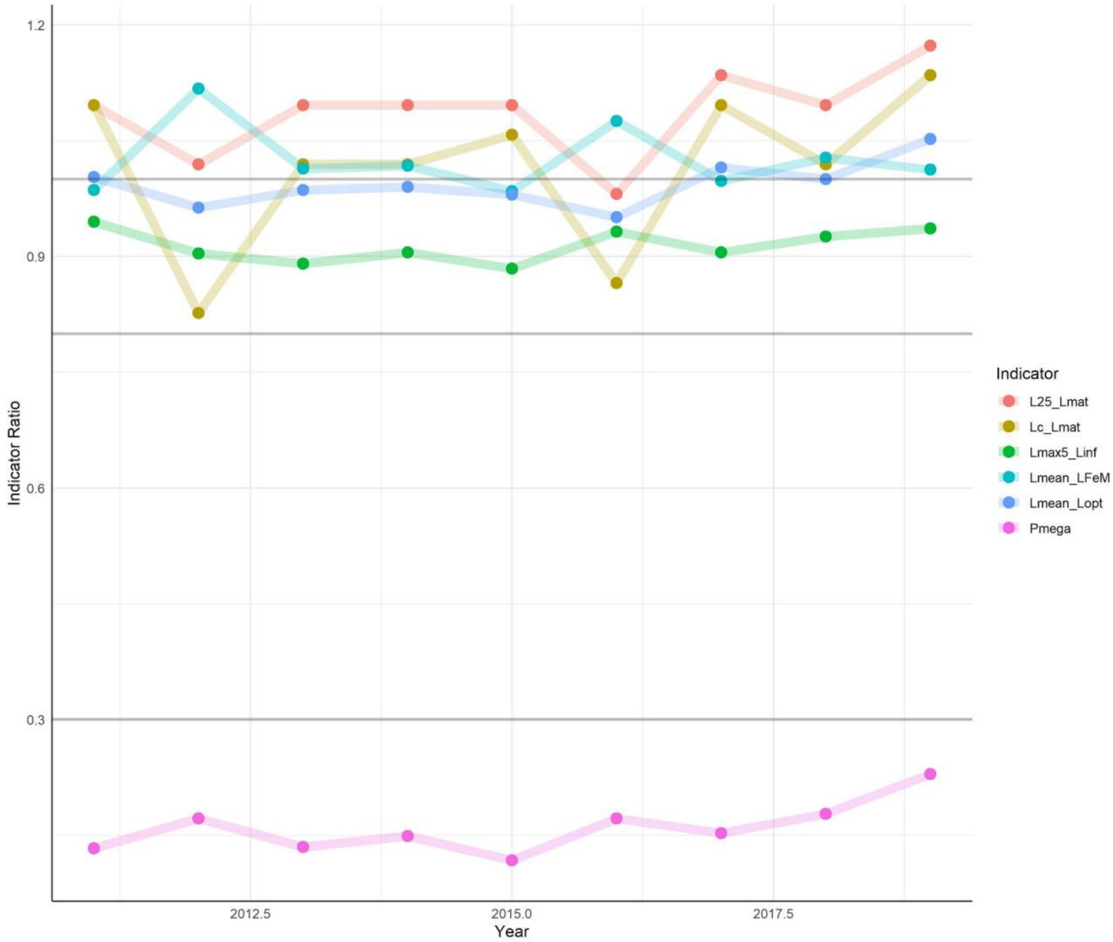

Figure 13: Temporal trends of the indicator ratios estimates.

Finally, the sensitivity analysis (Figure 14) shows that:

- L_{inf}: overestimation of this parameter leads to a decrease in the proportion of mega-spawners and also affects the MSY indicator, although this indicator is in red for some years it is not worrisome since its values are close to 1. Underestimation leads to the opposite situation, the proportion of mega-spawners increased attaining values above the threshold of 0.3.
- M/K: the conclusions are similar to the ones derived from the reference model (although of course under overestimation the proportion of mega-spawners increased and was larger or close to the threshold of 0.3).
- L_{mat}: overestimation leads to a decrease in the values of the indicators related to the conservation of immatures, in spite of this the conclusion derived from the last year still maintain that conservation is correct.

From the above explanations we conclude that the stock status is good but attention to the conservation of mega-spawners is required.

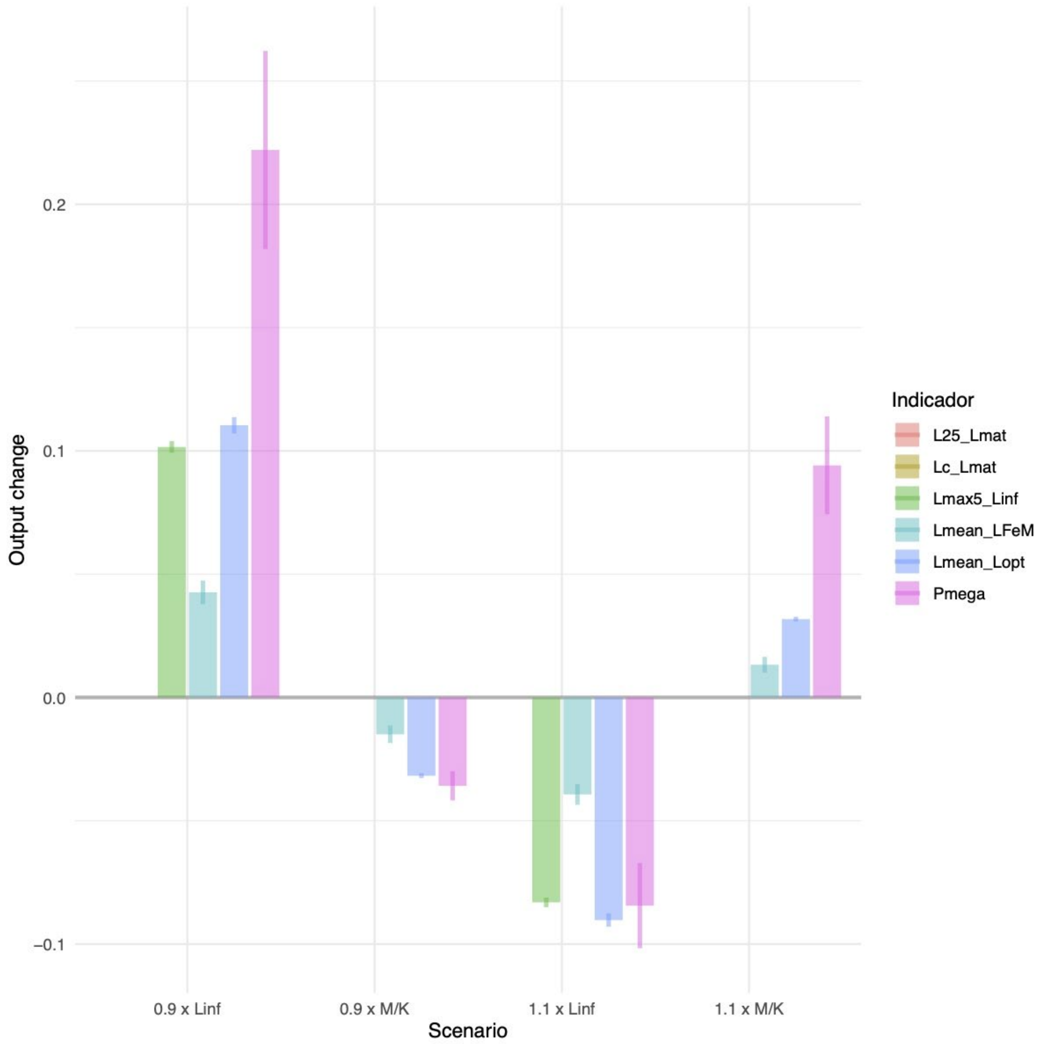

Figure 14: Sensitive analysis of the parameters L∞ and M/K (around our reference model), overestimating and underestimating them by 5 and 10%.

Advice rules for harvest control rules for length-based approaches

During the WKWEST2021 benchmark, it was decided that the LBI was the best suited to reflect the status of the stock. Using this method as basis, the catch advise will be provided with the 2-over-3 HCR (Method 2.1, Annex III, WKLIFE VIII, ICES 2018b). As for the 2-over-3 HCR an index of biomass is required, among the all possible options it was agreed to use a weighted sum of the Portuguese LPUE and the Spanish Bayesian survey index with weights varying by year according to the percentage of catches of each of the countries (i.e. Spain and Portugal). In this setting the two indices are standardized before their application:

$$Index_{year} = ½ * [S\text{-}BayesianIndex_{year}/mean(S\text{-}BayesianIndex) + P\text{-}LPUE_{year}/(mean(P\text{-}LPUE)]$$

In this scenario the catch advise was of 309.9102 t.

D. Short-term projection

No fishing possibilities can be projected.

E. Medium-term projections

No medium-Term projections can be projected.

F. Long-term projections

No long-term projections can be projected.

G. Biological Reference Points

No biological references points were available.

H. Other Issues

I. References

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