Institut Català de Recerca per a la Governança del Mar

State of fisheries in Catalonia 2023, Part 2:

Stock assessment

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This report presents the state of fisheries in Catalonia in 2023 and is the second volume to State of fisheries in Catalonia 2023, Part 2: stock assessment.

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Section 1 and section 2 (Mireia G. Mingote),
References (Marta Blanco).

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Glossary

B_{curr}: Biomass current, in the period of time analysed.

BKfrac: Ratio between biomass in the initial year relative to K. Stock depletion level at the begging of the time series.

B_{lim}: Biomass limit, defined as the lowest biomass from which a recovery has been confirmed. 30% of Bmsy.

B_{th}: Biomass threshold. 50% of B_{msy}.

B_{msy}: Biomass target.

CPUE: Catch per unit of effort.

DCF: Data Collection Framework.

F: Fishing mortality.

F_{msy}: Fishing mortality at a maximum sustainable yield.

F/M: relative fishing mortality.

F_{tgt}: Fishing mortality target.

F_{curr}: Fishing mortality current, in the period of time analysed.

GNS: Set gillnet.

GSA: Geographic Sub-Area.

k: Growth rate (Von Bertalanffy Growth Function).

LBSPR: Length-Based Spawning Potential Ratio.

LFD: Length Frequency Distribution.

L_{inf}: Length infinity or asymptotic length at which growth is zero (Von Bertalanffy Growth Function).

LLS: Set longline.

LLD: Drifted long liner.

L_{mat50}: Length where 50% of individuals are mature.

L_{mat95}: Length where 95% of individuals are mature.

M: Natural mortality.

OTB: Bottom otter trawl.

PS: Purse seiner.

SL_{50}: Length where 50% of individuals are caught.

SPR: Spawning Potential Ratio of a stock is defined as the proportion of the unfished reproductive potential left at any given level of fishing pressure.

SPR_{lim}: limit spawning potential ratio. Define as 10% of SPR, below this value the population will not recover.

SPR_{tgt}: target spawning potential ratio. Define as 40% of SPR remained in the sea to achieve maximum sustainable yield

SPiCT: Stochastic Production model in Continuous Time.

t_0: age at which the organisms would have had zero size (Von Bertalanffy Growth Function).

Executive summary

This report presents the stock assessment results obtained by ICATMAR. For the data-resource limited (length-based) model (i.e. LBSPR), the data used corresponds to the continuous monitoring from ICATMAR in Catalonia (North GSA6). For the surplus production model (i.e. SPiCT), the report also uses official data from the Data Collection Framework (DCF), the EU fleet register and the Spanish Government from the whole GSA6. Priority demersal species (i.e. red mullet, hake, deep-water rose shrimp, Norway lobster and blue and red shrimp) and small pelagic species (i.e. European sardine and anchovy) were evaluated using both models. ICATMAR data was available from 2019 to 2023, but for SPiCT, the final scenarios only use data until 2022 because the biomass index (i.e. MEDITS for demersal, and MEDIAS for small pelagic) was not yet available.

Each model provides different indicators; LBSPR estimates the Spawning Potential Ratio (SPR) whereas SPiCT estimates Biomass and Fishing mortality, both showing different perceptions of the stock status in most cases. For LBSPR, the results estimate that the SPR in 2023 for hake, red mullet, and blue and red shrimp is under SPR_{lim}, but for deep-water rose shrimp, the SPR is on SPR_{lim}. In contrast, for Norway lobster and European sardine, the estimated SPR is above SPR_{lim}. Finally, for anchovy, the estimated SPR is nearby the SPR_{tgt} (Figure 1, Figure 2). For SPiCT, in 2022, the estimated biomass for red mullet, hake, and Norway lobster is above the B_{thr}. The estimated biomass for deep-water rose shrimp, blue and red shrimp, and anchovy is above B_{msy} (Figure 3b). However, the biomass estimate for European sardine is below B_{lim} (Figure 4b). In terms of fishing mortality, red mullet, hake, blue and red shrimp, and anchovy have F below F_{msy} (Figure 3a), indicating a fishing mortality levels whereas F for deep-water rose shrimp, Norway lobster, and European sardine is higher than F_{msy} (Figure 4a)

For each demersal species, the trends for the period evaluated with LBSPR are the following: For the stock status of red mullet, SPR remains stable. For hake, there seems to be a positive trend in the SPR estimates, but the values from 2023 remained similar to 2019. The deep-water rose shrimp improved its SPR from the previous years, achieving the highest value out of the five years evaluated. The Norway lobster SPR has been decreasing but it is relatively stable in the last three years. For the blue and red shrimp, the estimates of SPR have a decreasing trend until 2022, but 2023 has higher values than the previous year assessed (Figure 1).

For each demersal species, the results for the period evaluated with SPiCT are the following: the red mullet biomass was below B_{lim} at the beginning of the time series but, in the recent years, the biomass has been increasing and it is currently above B_{thr}. Regarding fishing mortality, at the beginning of the time series, the estimates were above F_{msy}. However, the stock improved its status being, currently, below F_{msy} (Figure 5a). The hake biomass is currently around B_{thr}. As for fishing mortality, the biomass has been oscillating above and below F_{msy} and, recently, it is around F_{msy} (Figure 5b). The biomass for the deep-water rose shrimp had an increasing trend for most of the studied time series, changing towards a decreasing trend over the last three years. At the same time, fishing mortality has been continuously rising throughout most of the time series (Figure 5c). The Norway lobster population was below the target biomass (B_{msy}) at the beginning of the studied period, and it is now located near B_{thr}. The estimated fishing mortality values consistently remain at F_{msy} throughout the time series. However, the model struggles to accurately track this parameter (Figure 5d). In the early part of the time series, the biomass of blue and red shrimp was close to B_{thr}, but it has increased since the early 2000s. For fishing mortality, the parameter seems to be more stable in the middle years of the studied period, but it has been decreasing in the last years (Figure 5e).

For each small pelagic species, the results for the period evaluated with LBSPR are the following: European sardine SPR estimates fluctuate within similar values with no clear trend but they are above the SPR_{lim} (Figure 2). Similarly, anchovy does not have a clear trend, but SPR estimates are closer to SPR_{tgt} (Figure 2).

For each small pelagic species, the results for the period evaluated with SPiCT are the following: European sardine is below B_{lim} and F_{msy} throughout the evaluated time series (Figure 4). On the contrary, anchovy biomass was below B_{msy}, but in the middle of the time series, the biomass switched to a positive trend, reaching values above B_{msy} in recent years (Figure 4b). Accordingly, fishing mortality is below F_{msy} in recent years (Figure 4a).

Figure 1. Spawning potential ratio (SPR) per year (2019, 2020, 2021, 2022 and 2023) for the five demersal stocks evaluated with LBSPR model. MUT: red mullet, HKE: hake, DPS: deep-water rose shrimp, NEP: Norway lobster, ARA: blue and red shrimp, LBSPR: Length-Based Spawning Potential Ratio, SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. The scenario selected for each species is explained in the corresponding section. The grey shade shows the standard deviation.

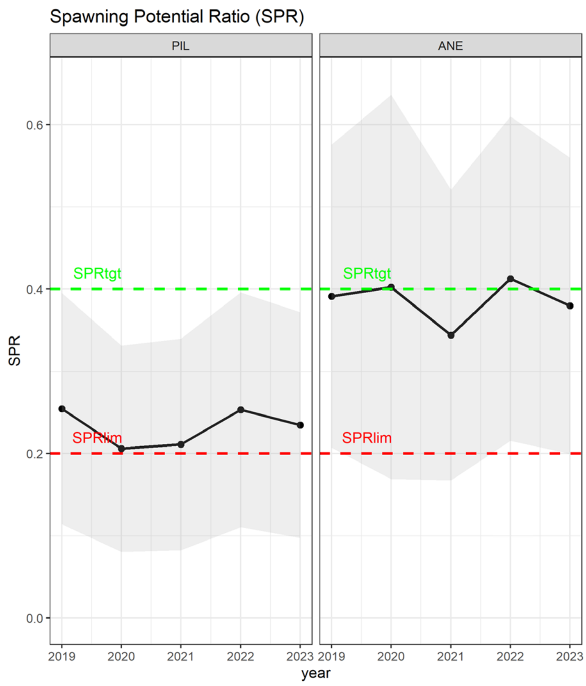


Figure 2. Spawning potential ratio (SPR) per year (2019, 2020, 2021, 2022 and 2023) for the two small pelagic stocks evaluated with LBSPR model. PIL: European sardine, ANE: anchovy, LBSPR: Length-Based Spawning Potential Ratio, SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. The scenario selected for each species is explained in the corresponding section. The grey shade shows the standard deviation.

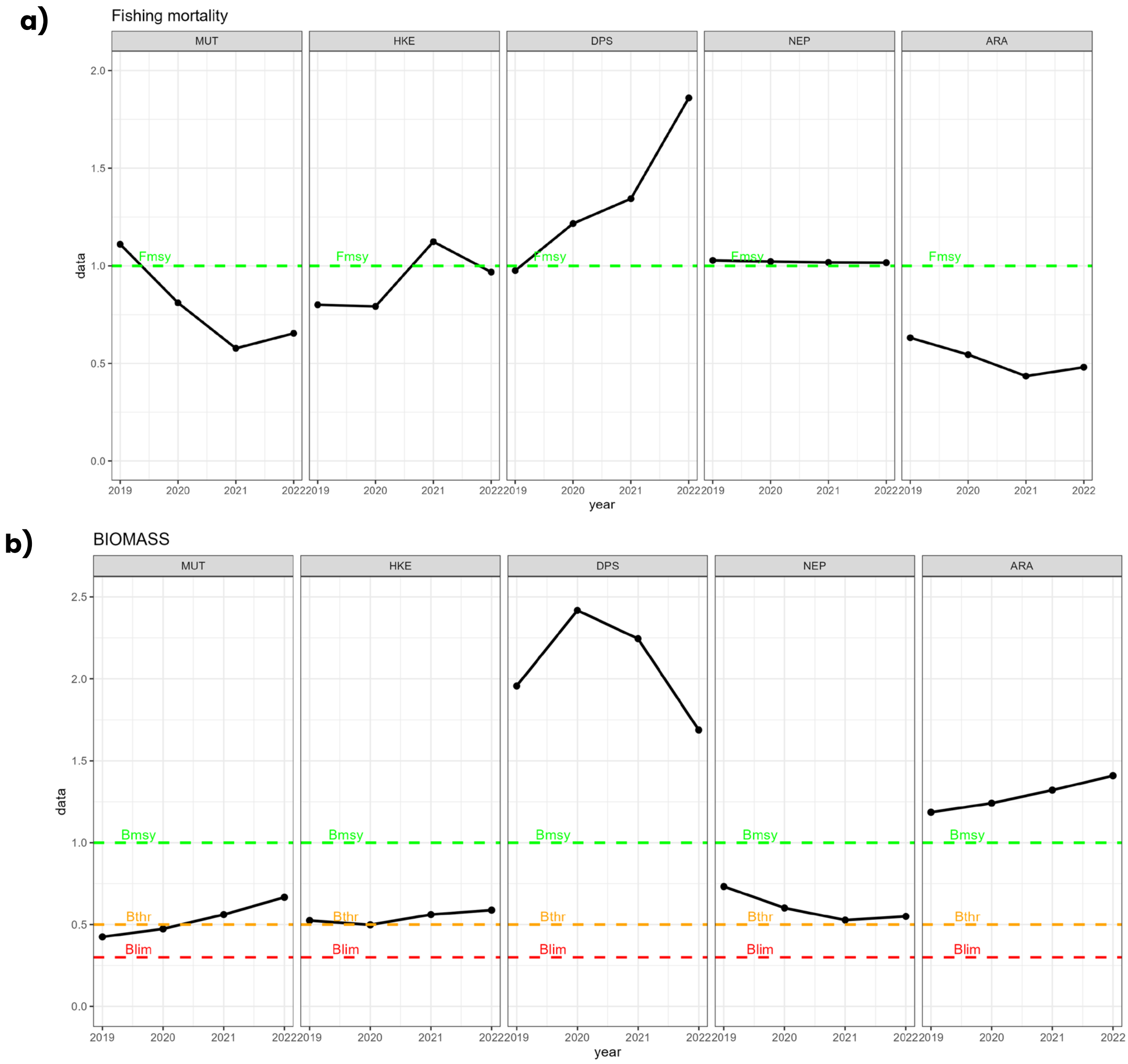


Figure 3. (a) Relative fishing mortality (F_{curr}/F_{msy}) and (b) relative biomass (B_{curr}/B_{msy}) per year (2019, 2020, 2021, 2022) for the five demersal stocks evaluated with SPiCT model. MUT: red mullet, HKE: hake, DPS: deep-water rose shrimp, NEP: Norway lobster, ARA: blue and red shrimp. SPiCT: Stochastic Production model in Continuous Time. F_{msy}: Fishing mortality at a maximum sustainable yield, B_{lim}: Biomass limit, B_{thr}: Biomass threshold, B_{msy}: Biomass target.

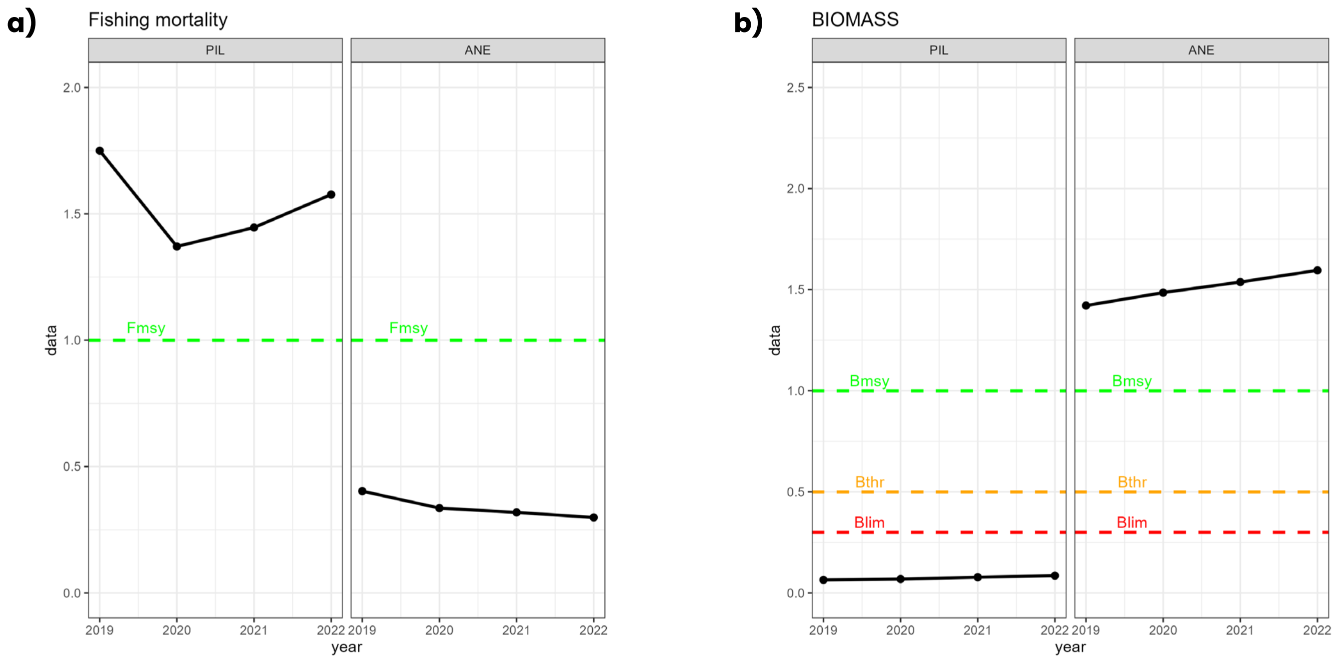


Figure 4. (a) Relative fishing mortality (F_{curr}/F_{msy}) and (b) relative biomass (B_{curr}/B_{msy}) per year (2019, 2020, 2021, 2022) for the two small pelagic stocks evaluated with SPiCT model. PIL: European sardine, ANE: anchovy. SPiCT: Stochastic Production model in Continuous Time. F_{msy}: Fishing mortality at a maximum sustainable yield, B_{lim}: Biomass limit, B_{thr}: Biomass threshold, B_{msy}: Biomass target.

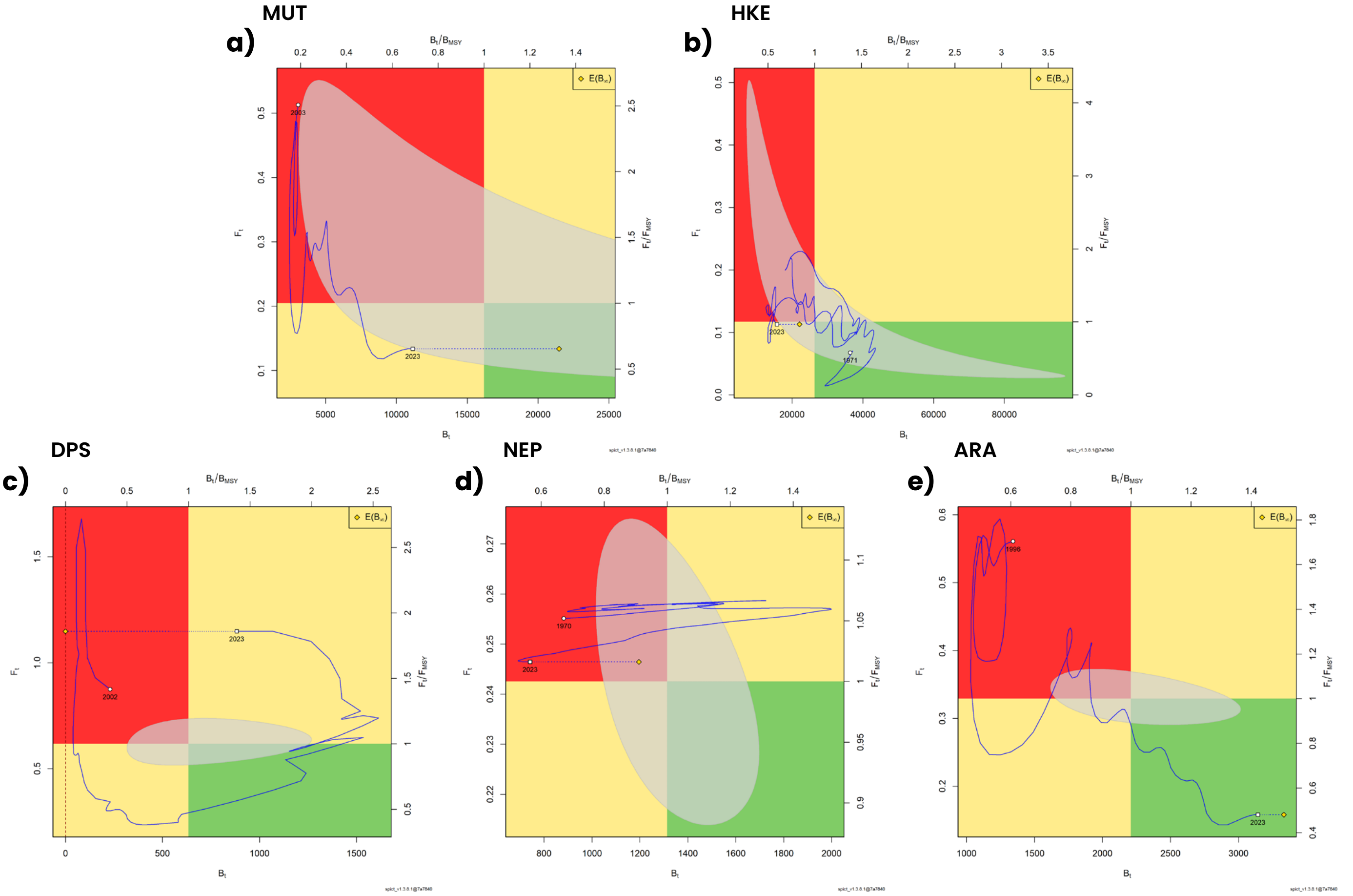


Figure 5. Kobe plots for the five demersal stocks evaluated with SPiCT showing the results forthe final scenarios. MUT: red mullet, HKE: hake, DPS: deep-water rose shrimp, NEP: Norway lobster, ARA: blue and red shrimp. SPiCT: Stochastic Production model in Continuous Time. F_{msy}: Fishing mortality at a maximum sustainable yield, B_{lim}: Biomass limit, B_{thr}: Biomass threshold and B_{msy}: Biomass target. The grey shade shows the incertainity.

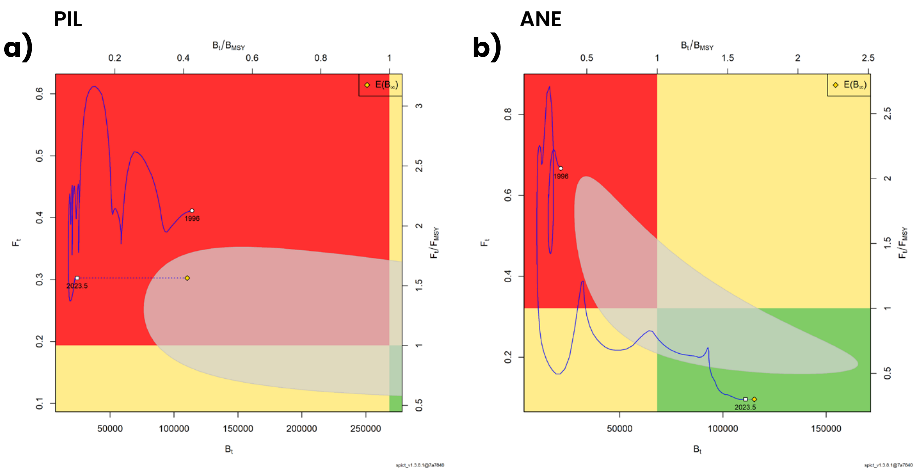


Figure 6. Kobe plots for the two small pelagic stocks evaluated with the SPiCT model. a) PIL: European sardine and b) ANE: anchovy. SPiCT: Stochastic Production model in Continuous Time. F_{msy}: Fishing mortality at a maximum sustainable yield, B_{lim}: biomass limit, B_{thr}: biomass threshold, and B_{msy}: biomass target. The grey shade shows the incertainity.

The advice drawn from these models should be considered as qualitative in all cases. Moreover, there are some discrepancies between models. For example, results for red mullet seem contradictory. Whereas LBSPR indicates that the SPR is much below the recommended limit (Figure 1), SPiCT estimates that the biomass is improving while the fishing mortality decreases (Figure 3). This second prediction seems to be more in agreement with our observations from the monitoring program and also with landings and MEDITS (Figure 17), highlighting that one model may not be suitable for evaluating the stocks of all species. Some models are more sensitive to different biological parameters and the lack of information for some species could produce misleading results.

Summary table by stock

A summary Table 1 is provided to understand, in a glance, the results obtained from the stock assessment models (i.e. LBSPR and SPiCT). LBSPR results are from Catalonia in 2023, the SPiCT results are from GSA6 in 2022 because the biomass index is not available for 2023. The species analysed are red mullet, hake, deep-water rose shrimp, Norway lobster, blue and red shrimp, European sardine and anchovy.

Table 1. Stock assessment outputs from LBSPR (Length-Based Spawning Potential Ratio) and SPiCT (Stochastic Production model in Continuous Time) models. LBSPR results are from Catalonia in 2023, but the SPiCT results are from GSA6 in 2022 because the biomass index is not available for 2023. MUT: red mullet, HKE: hake, DPS: deep-water rose shrimp, NEP: Norway lobster, ARA: blue and red shrimp, PIL: European sardine, ANE: anchovy, SPR: Spawning Potential Ratio, SPR0.4: SPR at 40%, Bcurr: Biomass for the current year, Bmsy: Biomass at maximum sustainable yield, Fcurr: Fishing mortality for the current year, Fmsy: Fishing mortality at at maximum sustainable yield.

Area	Method	Ref. Year	Species	SPR/SPR0.4	Bcurr/Bmsy	Fcurr/Fmsy
CAT	LBSPR	2023	MUT	0.13	-	-
			HKE	0.12	-	-
			DPS	0.51	-	-
			NEP	0.65	-	-
			ARA	0.17	-	-
			PIL	0.59	-	-
			ANE	0.95	-	-
GSA6	SPiCT	2022	MUT	-	0.67	0.65
			HKE	-	0.59	0.97
			DPS	-	1.69	1.86
			NEP	-	0.55	1.02
			ARA	-	1.41	0.48
			PIL	-	0.09	1.58
			ANE	-	1.60	0.30

SECTION 1
Introduction

Introduction

The European Union Data Collection Framework (DCF) establishes that the member states must collect, manage and annually report biological, environmental and socioeconomic data from fisheries to use as a base for scientific advice in management strategies (EU 2017/1004). In the Mediterranean and Black Seas, Geographical Sub-Areas (GSAs), as defined by the General Fisheries Commission for the Mediterranean (GFCM, Resolution GFCM/33/2009/2), are used to structure the data collection. The GSA6 (Northern Spain) comprises the Spanish Mediterranean coast from Cartagena to the Spanish-French border.

The European Common Fisheries Policy (CFP) aims to ensure long-term sustainability for fisheries and regulates Mediterranean fisheries controlling fishing effort (fishing days) which, combined with specific technical measures such as gear regulation (Resolution GFCM/33/2009/2), the establishment of a minimum conservation reference size (EU Reg. 2019/1241) and the implementation of closure areas and closed seasons (EU Reg. 2022/1614), are the main management strategies adopted in the western Mediterranean Sea. Then, the CFP manages all fishing modalities including bottom trawling and purse seine. The bottom trawling fleet is currently regulated under the Western Mediterranean Multiannual Plan (WMMAP, EU reg. 2019/1022), which establishes a series of management measures. The bottom trawlers from the Spanish Mediterranean are allowed to fish between 50 and 800 m depth or 3 miles far from shore when the seabed is shallow and five days per week with a maximum of 12 labour hours per day. The maximum power of the vessel may not exceed 500 hp and the vessel length is limited to a range between 12 and 24 meters (Real Decreto 1440/1999). In addition, the Ministry of Agriculture and Fisheries, Food and Environment may limit, by regulation, the number of days per year that a vessel may fish to regulate the total effort exerted in each of the fishing areas (EU Reg, 2019/1022). The purse seine fleet is regulated by the order (APA/1127/2023) approved by the Spanish Ministry of Agriculture, Fisheries and Food to comply with the CFP. This order aims to regulate the stocks for sardine and anchovy through spatial, temporal and catch fishing restrictions, including the increase of the minimum reference conservation size for both species.

Since 2000, the EU Member States have been collecting fisheries data to support CFPthrough fisheries-dependent and -independent methods. The fisheries-dependent samplings come from on-board samplings and occur monthly in some specific ports by on-board observers, whereas the fisheries-independent data is gathered once a year from the Mediterranean Trawl Survey (MEDITS). With the goal to obtain a more exhaustive data set to better manage marine resources, the monitoring program established by the DCF is complemented with a dataset obtained by the Institut Català de Recerca per a la Governança del Mar (ICATMAR). ICATMAR, promoted by the Directorate-General for Fisheries and Maritime Affairs of the Government of Catalonia and the Institut de Ciències del Mar (ICM-CSIC), is an autonomous organization whose main goal is to generate scientific advice for management purposes in the blue economy field. Since 2019, ICATMAR has developed and implemented a fisheries monitoring program in Catalonia, which constitutes the northern part of the GSA6 (from the French border to the south of the Ebre delta). This program uses fisheries-dependent methods that also allow the collection of biological and stock parameters. The goal is to monitor the main target species of the Catalan commercial fleet of different fishing modalities, including bottom trawling and purse seining. In detail, bottom trawling is, economically, the most important fishing modality with a revenue of 51.23 M€ in 2023 (ICATMAR, 24-03). Moreover, bottom trawlers target demersal species, such as those defined by the WMMAP including red mullet, hake, deep-water rose shrimp, Norway lobster, and blue and red shrimp (EU reg. 2019/1022). Purse seine is the fishing modality that accounts for the highest biomass in catches, with a total value of 7.67 t in 2023 (ICATMAR, 24-03) and targets sardine and anchovy, species of special interest to manage for the CFP.

To provide scientific advice for management purposes in the northern GSA 6, two different models were used for stock assessment evaluations for the five demersal species regulated by WMMAP and the two small pelagic fishes targeted by purse seine (Figure 7). First, a length-based model (LBSPR) with data gathered by ICATMAR during 2019, 2020, 2021, 2022 and 2023 was used for stock assessment evaluations in the northern GSA6. Second, a surplus production model (SPiCT), was applied to test the influence of a long-term data series, such as landings and biomass index, for the species selected in the whole GSA6. Both models are based on different assumptions and use different input data, giving different perspectives of stock status and types of advice (Reference points for LBSPR: SPR, for SPiCT: B_{msy} and F_{msy}). SPiCT reference points are comparable with the ones used for age-structured models (i.e., a4a) or integrated models (i.e., SS3).

The long-term data collection from ICATMAR continuous and exhaustive monitoring program will allow, in the following years, the use of more complex models, e.g. Stock Synthesis (SS3), which integrates species life-history and catch at length information with the time series of catch and fisheries-independent data.

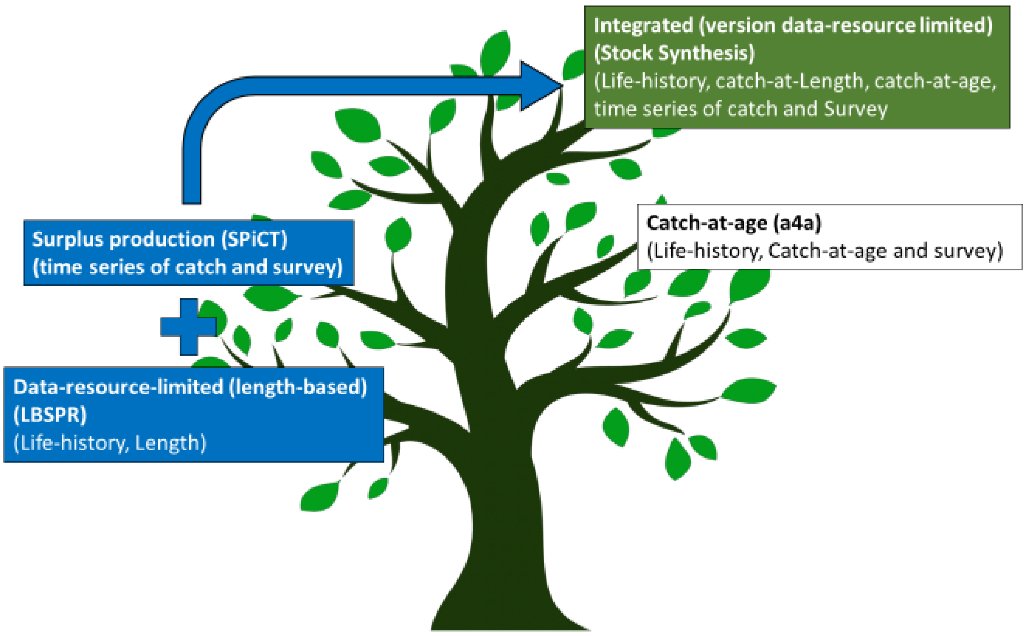


Figure 7. Different models used for fisheries stock assessment, LBSPR is a data-resource-limited model, SPiCT is a Surplus production model, a4a is a catch-at-age model, and Stock Synthesis (SS3) is an integrated stock assessment model.

SECTION 2
Material and Methods

Machine learning for *métiers* assignation

As explained in a previous report (ICATMAR, 22-04), the fishing fleet activity is defined by *métiers*. In short, a *métier* is defined as a "group of fishing operations targeting a similar assemblage of species, using similar gear, during the same period of the year and/or within the same area and which are characterized by a similar exploitation pattern" (Reg. (EC) N° 949/2008 and Commission Decision 2010/93/UE). In this study area, the daily fishing landings of a vessel correspond to one effective fishing day, as vessels land their catch daily. Therefore, as each sampling haul is allocated to a specific *métier*, the sampled length frequencies can be weighed and extrapolated to the fishing landings by *métier*.

7 *métiers* are defined performing dendrograms and cluster analysis for the Catalan bottom trawling fleet (OTB). These *métiers* are related to different depths, areas and catch composition. All daily landings from 2002 to 2021 were classified according to these *métiers*.

For the for 2022 onwards, machine learning algorithms have been used to assign the corresponding *métier* to each daily trip (vessel + day). Machine learning is a branch of artificial intelligence that focuses on the training of algorithms and models to predict results based on data. In this case, random forests were the machine learning algorithms used because they are more suitable to classify the fishing trips in each different *métier*.

The applied process is described below:

Data preparation:

Landings data from 2021 were selected, but only trips from 2021 had *métiers* assigned. The species considered for the analyses are those which biomasses contribute to the 95% of the daily trip. This filter allows to eliminate the species that rarely appear and have barely any influence on the *métier* assignation. The data were transformed to have one row per daily trip, area, *métier* and a column for each species that was caught with its percentage of biomass contribution to the daily trip.

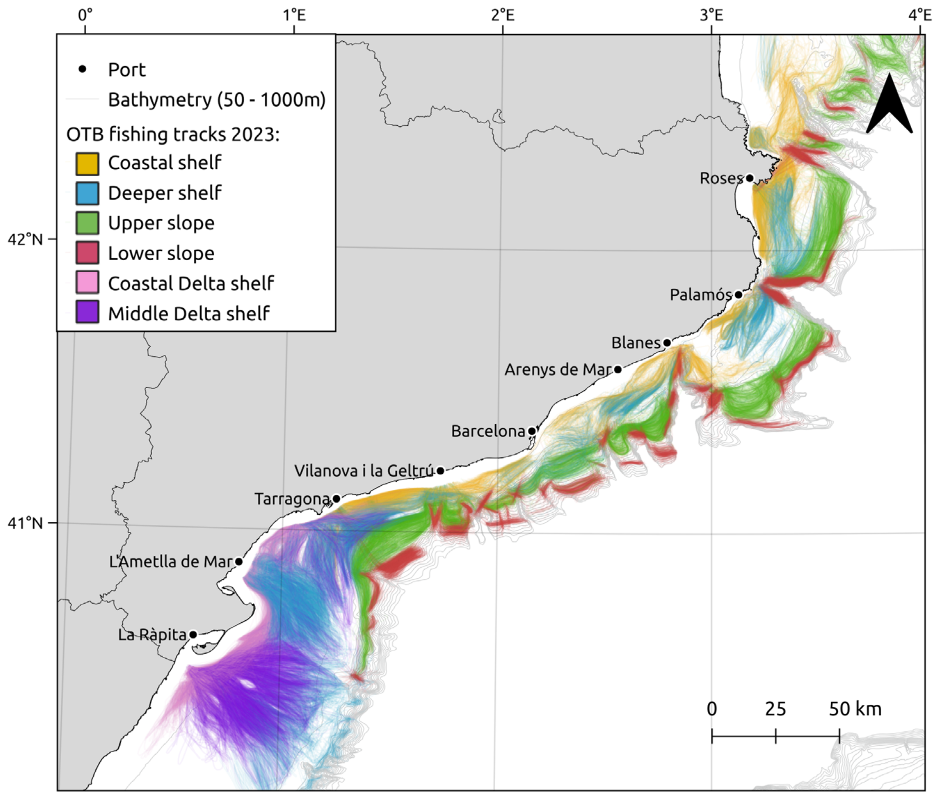


Figure 8. Spatial distribution of the bottom trawl fishery (OTB) tracks. Colours represent the different OTB *métiers* identified for the Catalan fishery in 2023.

Model execution:

A process of model tuning was applied to test different combinations of the parameters and ways to split the data to find the most suitable model. For that, 80% of the classified data from 2021 were used for model training and 20% for model validation. The model has a 95% of accuracy, which is obtained executing the model with the validation data. The trained model is used to predict the *métier* assignation for non-classified data for 2022 onwards. Besides the model execution with the validation data, the predicted *métiers* are combined with their corresponding VMS track to generate a map and perform a visual validation (Figure 8). Finally, the predicted *métiers* for 2022 onwards are imported to the database for the extrapolation of the data.

Data extrapolation

To estimate the annual length-frequency distributions (LFD) of the target species in Catalonia (N GSA6), data from the ICATMAR monitoring program (trawling and purse seine) and from EU-DCF (GSA6, artisanal fisheries) were used. A three-step process was followed: 1) Raising of monitoring data, 2) inclusion of artisanal fisheries catch, and 3) validation of the estimated LFD using the sum of products (SOP) approach.

Raising of the monitoring data

Bottom trawling

The basic unit for the data raising were the fishing hauls, which were previously assigned to a *métier* according to its catch composition. The calculations for each area (North, Center, and Ebre delta) were made separately to keep the spatial resolution of the sampling and, within each area, fishing hauls were separated by port. Starting from this spatial aggrupation, the data raising also considered seasonal variations in catch, calculated according to the following steps:

Monthly LFD (sampled ports, by area, *métier* and month)

Seasonal LFD (sampled ports, by area, *métier* and season)

Seasonal LFD (all fleet, by area, *métier* and season)

Annual LFD (total for Catalonia)

This process is described below for each fraction of the catch (landed and discarded) and calculated independently for each target species. Note that the LFD were grouped by intervals of 1 cm for fish species and 1 mm for crustaceans. The extrapolation used two ICATMAR databases: monitoring data and commercial fishing landings.

Raising process for the landed catch

Monthly LFD (sampled ports, by area, *métier* and month)

For every fishing haul, the LFD and its total weight were extracted from the monitoring database. A ratio was calculated dividing the monthly landings by the total weight of each haul. The resulting monthly LFD was determined by multiplying the LFD of each fishing haul by the corresponding ratio.

Seasonal LFD (sampled ports, by area, *métier* and season)

In this step, the previous procedure is replicated, but now starting with the monthly LFD. The ratio was calculated dividing the seasonal landings of each port and *métier* by the corresponding monthly landings. The seasonal LFD was obtained by multiplying this ratio with the monthly size distribution.

Seasonal LFD (all fleet, by area, *métier* and season)

The previously calculated LFD of the sampled ports corresponding to the same season and *métier* were summed. The ratio was calculated dividing the total landings (considering all ports of each area) by the weight from the sum of the LFD of the sampled ports. The total LFD by area, season, and *métier* were obtained by the product of the LFD of the sampled ports by its ratio.

Annual LFD by area and totals for Catalonia

The annual LFD by area was obtained by the sum of the LFD of the different seasons and *métiers*. This process must be repeated for each year and area to obtain the estimated annual LFD of the landed individuals from the target species corresponding to all the trawling fishing fleet in Catalonia.

Raising process for the discarded catch

The raising of discards LFD follows the same structure as the raising of landings. The proportion of discards within the total catch was estimated from the monitoring database. This proportion was calculated for each year, area, season and *métier*. For those months when no sampling was available, the annual discard ratio was used. Then, the steps explained for landed size distributions can be replicated, considering that the commercial landings must be multiplied by the discard ratio beforehand.

Purse seine

The raising process of the purse seine sampling requires a simplified version of the method for trawling. In this case the spatial structure (area – port) is maintained but in the raising process only month and season were considered, as no *métiers* were available for purse seine.

Inclusion of the artisanal fisheries catch data for modelling

Our sampling includes both bottom trawling and purse seine. However, it does not include artisanal fisheries despite their catch may be important to be considered, especially for hake and red mullet. Then, for these two species, we employed data from the EU-DCF (GSA6) in order to obtain the LFD for our target species in Catalonia and add these data to our bottom trawling monitoring data. The ratio from the artisanal fisheries was calculated by dividing the catches from Catalonia by the total catches in the GSA6. The product of this ratio with the LFD of the GSA6 provides an estimate of the LFD corresponding to Catalonia. These LFD can be summed to the trawling (landing + discards) extrapolation to get the annual LFD for Catalonia considering all fishing gears.

SOP validation

The sum of products (SOP) is computed by summing the number of individuals at each length class of the LFD multiplied by their corresponding weight, estimated with the species' growth parameters:

$$\sum_{i=\min(length\ class)}^{\max(length\ class)} \text{number of individuals i} * \text{calculated weight of length class i}$$

The results of the SOP validation for the landed catch must be similar to the reported landings.

Models settings

Length-Based Spawning Potential Ratio (LBSPR)

LBSPR is classified as a data-limited stock assessment model which relies on a number of assumptions. In particular, the LBSPR models are equilibrium-based and assume that the length composition data is representative of the exploited population at a steady state. Also, selectivity is assumed to follow a logistic function.

To fit the model the best, some facts should be considered such as:

The length structure of the harvested population raised by considering the main factors (time: monthly and annual catches; sample size; ports, fleets/gears and/or depth).

Local estimates of life-history parameters, including von Bertalanffy growth parameters, length of maturity (L_{mat50} and L_{mat95}) and M.

Information on the input data and methods used to estimate life history.

Sensitivity analysis

Different scenarios were carried out by stock to test the sensitivity of the model. In general, scenarios were chosen based on STECF or GFCM data inputs, available bibliography and ICATMAR data.

Uncertainty in life history parameters

To include uncertainty in the model computation, the following settings were applied for each stock and scenario (Table 2):

The main output of the model is the Spawning Potential Ratio (SPR) which is defined as a proportion of the unfished reproductive potential left in the population at any given level of fishing pressure.

The referent points were proposed for the length-based methods approach as: SPR_{tgt}=0.4, SPR_{pa}=0.2 and SPR_{lim}=0.1. Due to the model's instability regarding the stock's live history, the FM estimator is not considered a reference point.

Table 2. Settings used for model LBSPR computation uncertainty.

Number of random draws: nits=1000	
CVL_{inf}lower <- 0.075 CVL_{inf}upper <- 0.3 CVL_{inf}mid <- 0.15 CVL_{inf}vec <- rtriangle(nits, CVLinflower, CVLinfupper, CVLinfmid)	MKlower <- (M/K) *0.75 MKupper <- (M/K) *1.25 MKmid <- M/K MKvec <- rtriangle(nits, MKlower, MKupper, MKmid)

L_{inf}lower <- L_{inf}*0.75
L_{inf}upper <- L_{inf} *1.25
L_{inf}mid <- L_{inf}
L_{inf}vec <- rtriangle(nits, L_{inf}lower, L_{inf}upper, L_{inf}mid)
	L_{mat50}vec <- L_{inf}vec * (Lmat50/L_{inf}) # Assume constant Lmat50/L_{inf} ratio
	LHpars <- MyPars
	L_{mat95}vec <- L_{mat50}vec + (LHpars@L_{mat95} - LHpars@L_{mat50}) # assume constant L_{mat95}-L_{mat50}

Stochastic Production model in Continuous Time (SPiCT)

Model assumptions and input data

SPiCT is classified as a data-moderate stock assessment model. To perform surplus production models for a certain stock, it is needed to have information on the time series of landings, effort, CPUE (ideally standardized), and/or fishery-independent biomass index. The catch data should be representative of both landings and bycatch. It is also possible to use a time series of landings, but the interpretation of the results varies in this case. When available, seasonal catches should be also used as input.

Stock size indices should be provided in terms of biomass and should be representative of the exploitable stock biomass. Given that the surplus production models require the comparison between the same fraction of the stock, to build the biomass index there should only be considered the range of lengths that are observed in the catches.

Biomass indices are assumed to be snapshots on given time points. Therefore, the timing of survey indices has to be given as decimal year, corresponding to the timing of the survey in the vector. Commercial CPUE indices should be associated to the midpoint of the interval of the corresponding catches, i.e. when CPUE indices are based on yearly aggregated catches and effort, the value in the mid-year should be considered.

The SPiCT model can reference points with uncertainties and includes observation error and process errors.

SECTION 3
Results by stock

Demersal species

Stock assessment results for species in the GSA6

Red mullet (*Mullus barbatus*) MUT

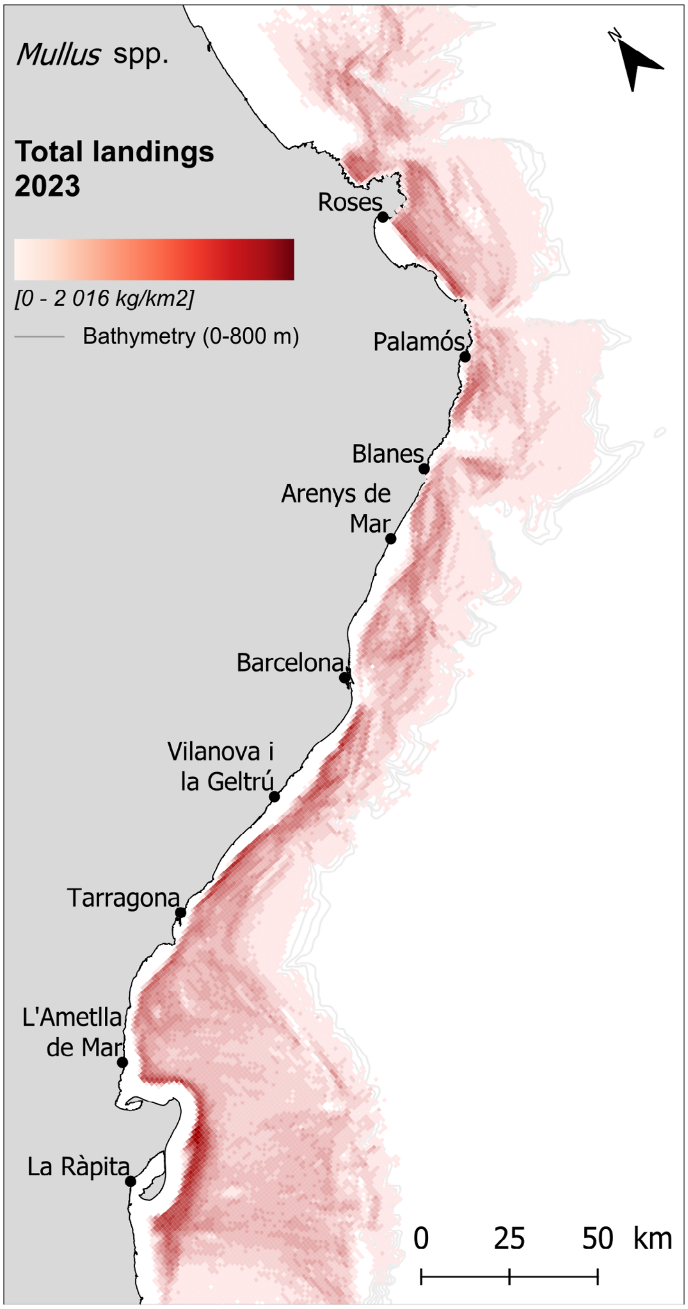


Figure 9. Spatial distribution of landings per unit of effort (LPUE) for red mullet (*Mullus spp.*) in the Catalan fishing grounds (North GSA6) in the year analysed.

The spawning area for red mullet is the continental shelf but the nursery zone is located on coastal areas. The recruitment season is between October and December (Lombarte et al. 2000).

Input data

The spatial distribution of total landings for red mullet in the Catalan fishing grounds (Figure 9) is located, mainly, in coastal areas considering bathymetry. However, in terms of total landings, red mullets are more abundant in the central and southern areas.

Historical red mullet landings in Catalonia since 2002 are shown in Figure 10. Landings increased throughout the time series until 2016, when the highest value was observed. Thereafter, landings were relatively stable.

Figure 11 shows red mullet landing distribution by *métier* from 2019 to 2023. Bottom trawlers have the highest landings for coastal delta shelf and the coastal shelf *métiers*. Lower landings are observed in the middle delta and deeper shelf *métier*. Artisanal fisheries only have residual landings in all years.

Annual LFD

After raising the length frequencies obtained with the monitoring program (Table 3), and considering discards and small-scale fisheries length frequency, the annual length frequency of red mullet in Catalonia is plotted in Figure 12. The shape of the plots varies among them, indicating different length-frequency distributions in time. There was an increase in small-length classes in 2021 and 2022, but not in 2023. Finally, the largest individuals are mainly caught with small-scale fisheries.

Length-Based Spawning Potential Ratio (LBSPR)

Model setting and results

Scenarios

Four different scenarios were applied for the sensitivity analysis for red mullet (Table 4). The first scenario used growth parameters, natural mortality and maturity from STECF and GFCM stock assessment. The second one used growth parameters and natural mortality from literature (Demestre et al., 1996) and the same maturity as scenario one. The third scenario used the same parameters as scenario 1 but a preliminary length at first maturity from ICATMAR data. Finally, scenario four used the same growth parameters as scenario 1, 2 and 3, but length at first maturity from Kokokiris et al., 2014

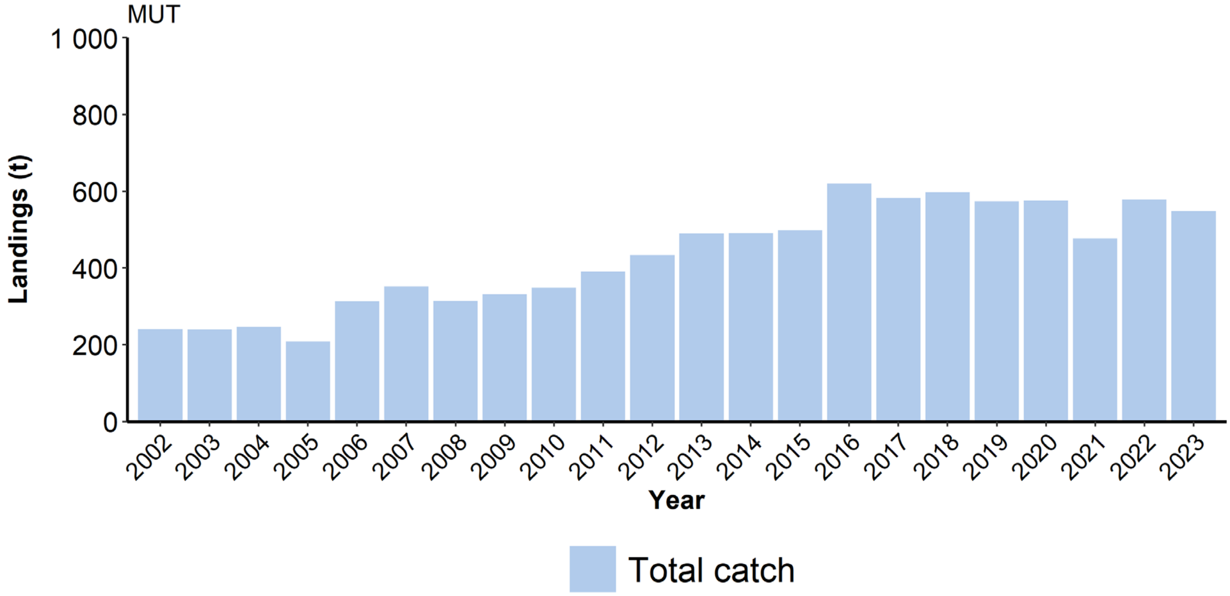


Figure 10. Historical landings (t) for red mullet in Catalonia.

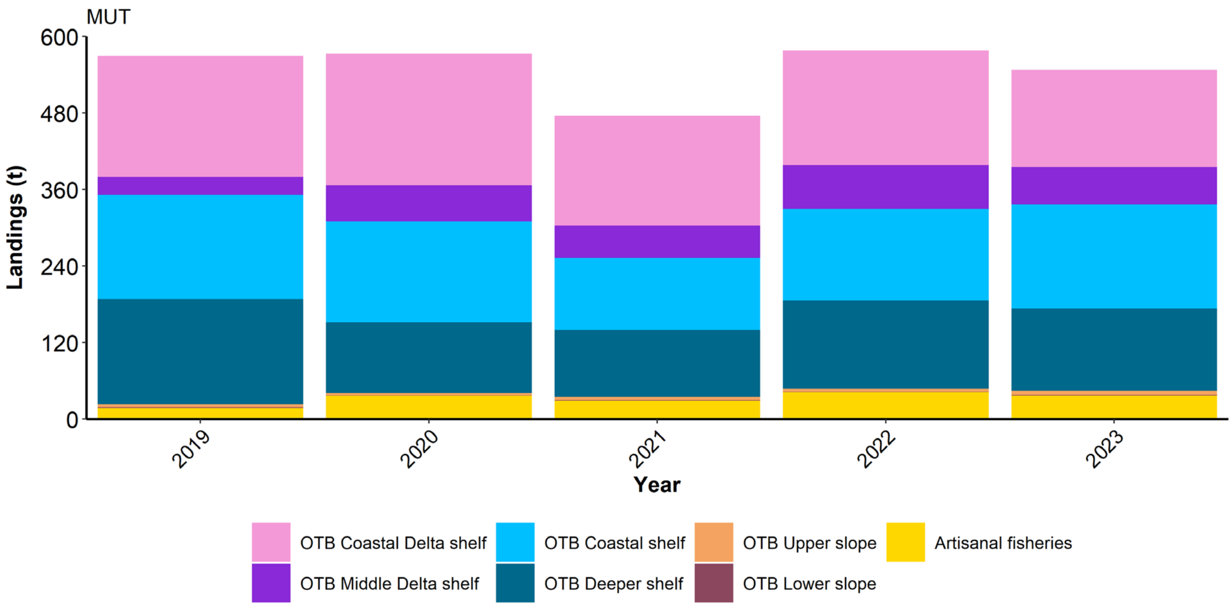


Figure 11. Landings (t) for red mullet by métier and fishing gear. OTB: bottom trawling.

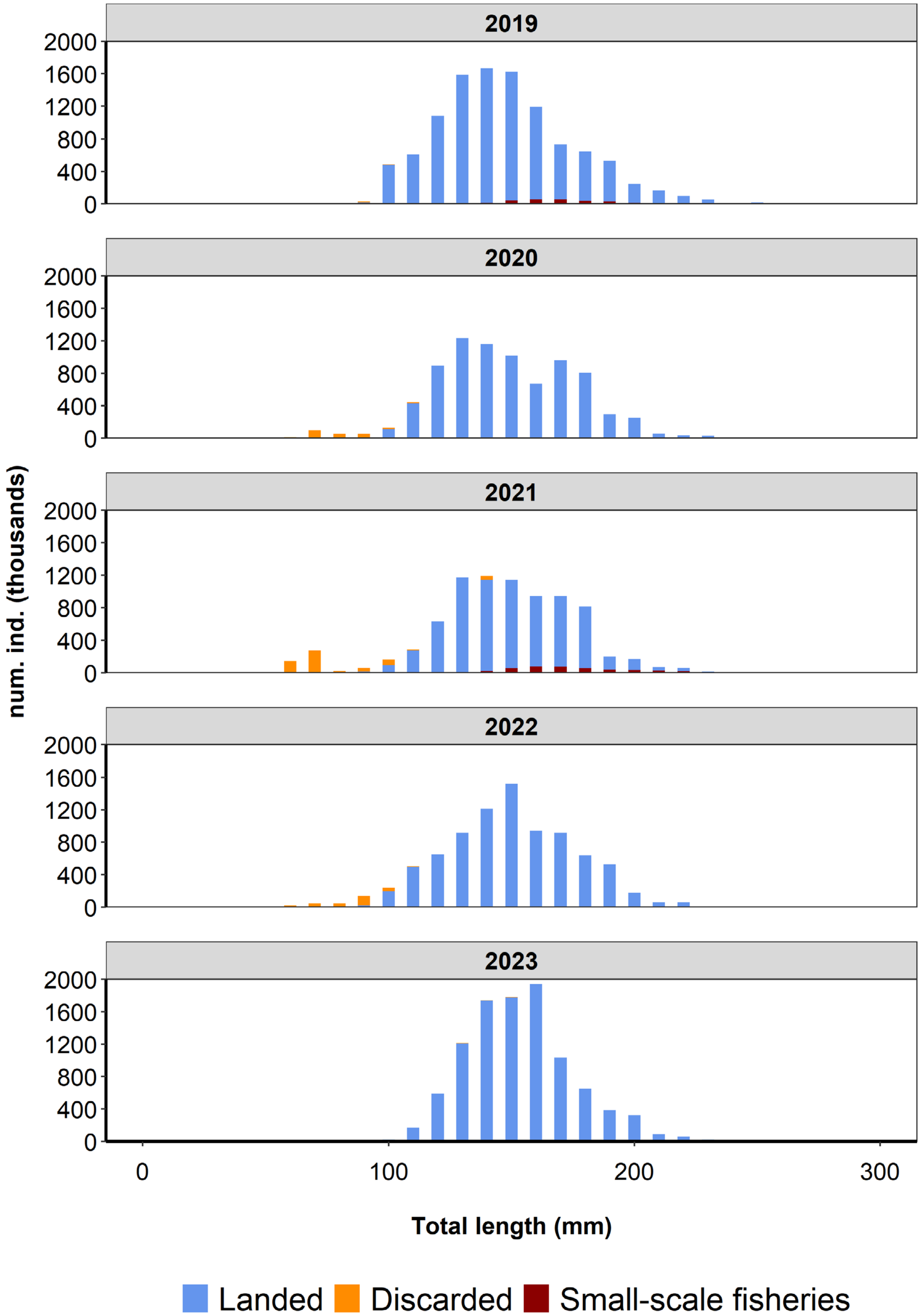


Figure 12. Annual length frequency distributions of red mullet from bottom trawling and small-scale fisheries. The data from bottom trawling is raised from ICATMAR data and details landed and discarded red mullet. The data from small-scale fisheries is obtained from DCF (Data Collection Framework) dataset.

Table 3. Number of red mullet individuals sampled by zone and season from ICATMAR monitoring data used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N hauls
			Number individuals sampled				
Bottom trawl	2019	North	70	415	159	116	19
Bottom trawl	2019	Center	82	119	50	83	17
Bottom trawl	2019	South	301	217	206	391	25
Bottom trawl	2020	North	43	102	58	237	15
Bottom trawl	2020	Center	145	76	64	102	11
Bottom trawl	2020	South	114	67	264	142	18
Bottom trawl	2021	North	261	88	125	60	18
Bottom trawl	2021	Center	123	135	91	49	11
Bottom trawl	2021	South	33	46	221	211	20
Bottom trawl	2022	North	111	97	99	162	16
Bottom trawl	2022	Center	122	64	141	134	11
Bottom trawl	2022	South	88	188	272	359	21
Bottom trawl	2023	North	303	240	272	339	24
Bottom trawl	2023	Center	297	207	252	188	12
Bottom trawl	2023	South	297	141	285	122	20

Fitted data

The length frequency distribution fit per year is shown in Figure 13. The model generally follows the mode for all years, slightly underestimating the number of individuals for some length classes, mostly in 2020, 2021, 2022 and 2023.

Selectivity

The outputs of the model for the selectivity of the fishery are shown for each scenario in Table 5. The outputs are also plotted together with L_{mat50} and SL_{50} in Figure 14. For the different scenarios, the model outputs reveal that the fishery is fishing similar to or above L_{mat50} in all scenarios.

Table 4. Biological parameters used in the different LBSPR scenarios for red mullet (MUT). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Species	Scenario	L_{inf} (mm)	M/k	L_{mat50} (mm)	L_{mat95} (mm)
MUT	1	345	1.235	137	150.7
MUT	2	330	1.132	137	150.7
MUT	3	345	1.235	133	146.3
MUT	4	345	1.235	114	155.0

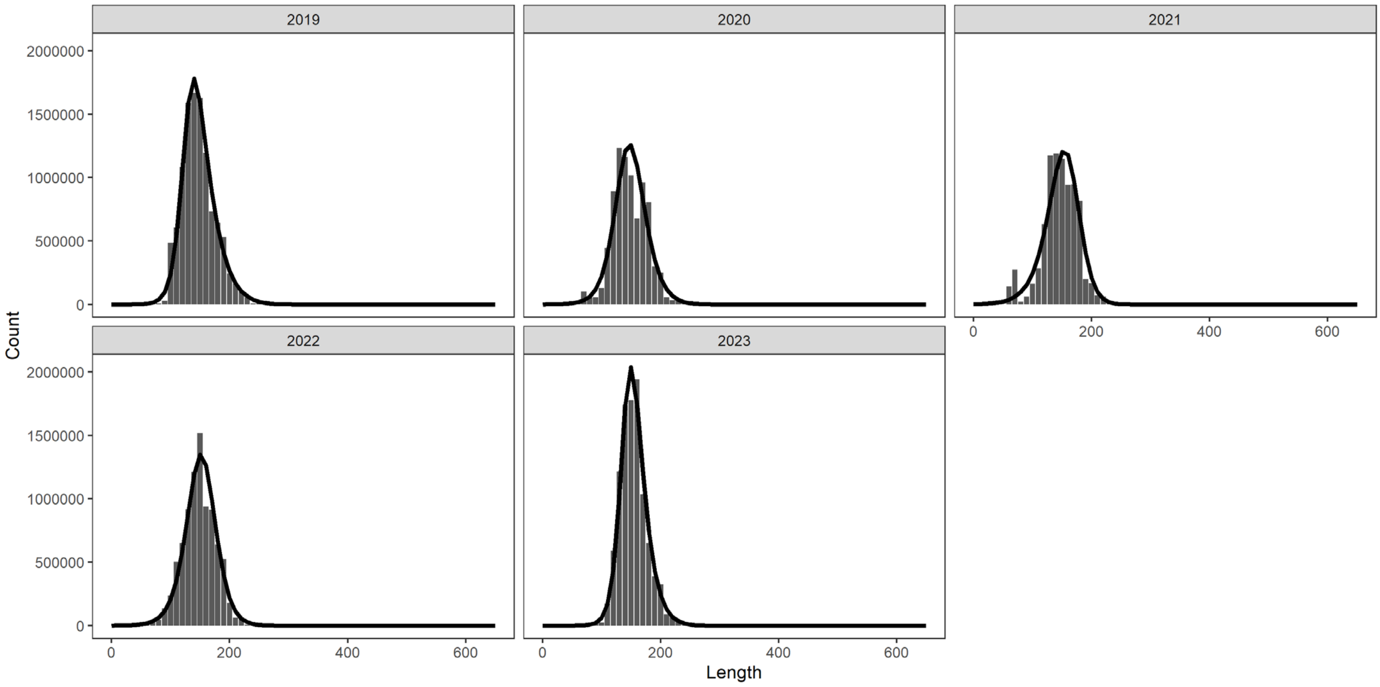


Figure 13. Fit of the data using the LBSPR model for red mullet for each studied year. Grey columns indicate length frequencies. Black lines indicate the fit of the model.

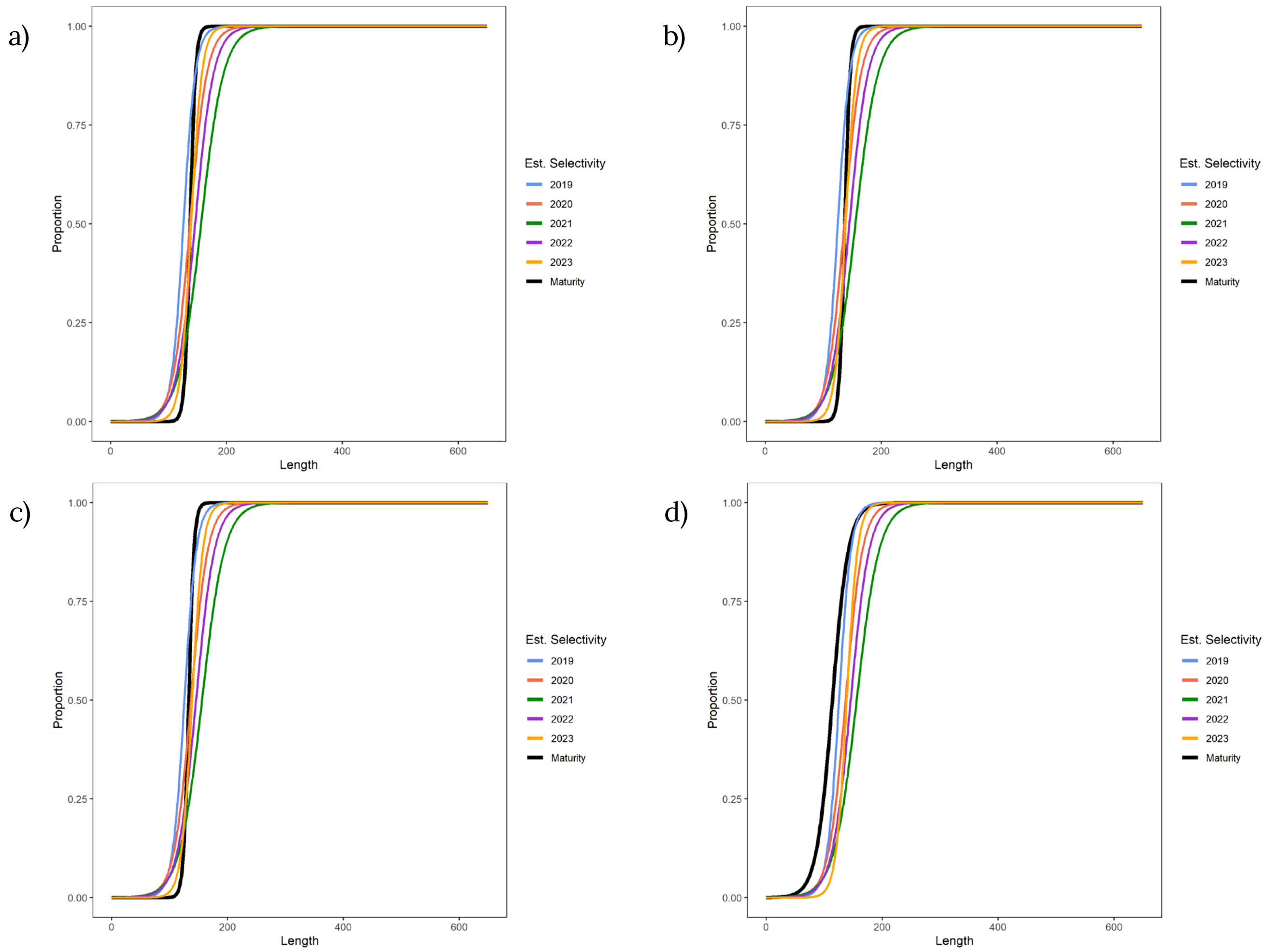


Figure 14. Length curves for red mullet. Black line shows the length curve at maturity. Colour lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (a), scenario 2 (b) scenario 3 (c) and (d) scenario 4.

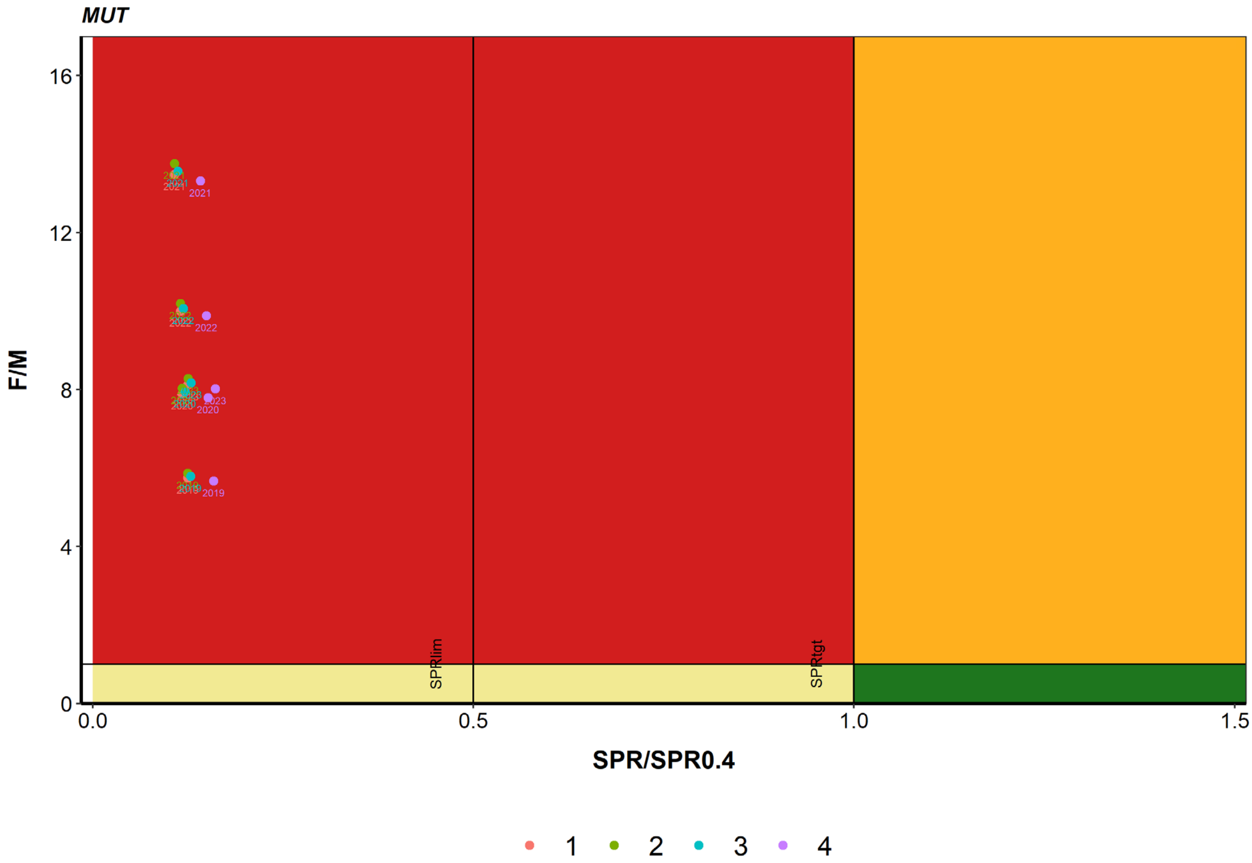


Figure 15. Kobe plot for red mullet by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

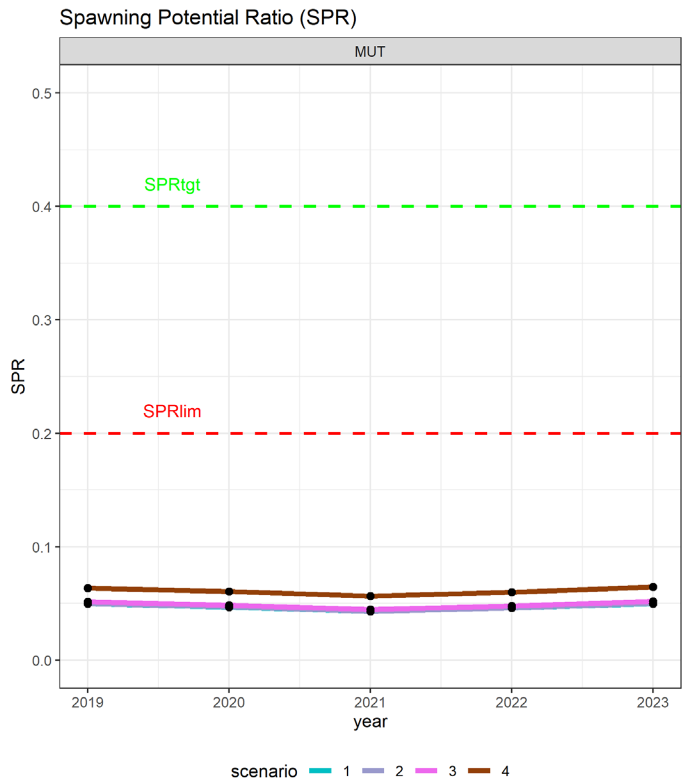


Figure 16. Spawning potential ratio (SPR) per year analysed for red mullet evaluated with LBSPR model. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. Coloured lines show the results for each scenario.

Reference points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is below SPR_{lim} (=0.1) in all the scenarios (Table 5 and Figure 16). The Kobe plot for red mullet (Figure 15) shows the stock status throughout the different years, with a negative trend. The stock is, in all cases, located in the red zone meaning that it is overfished and under overfishing.

Final scenario

As LFD and L_{mat} originated from ICATMAR data, scenario three was selected to provide final advice for the LBSPR model.

Table 5. LBSPR model results for red mullet with the different scenarios tested for each year analysed. SL_{50}: Length where 50% of individuals are caught, SPR: spawning potential ratio and FM: fishing mortality. SD is the standard deviation calculated for each indicator.

Species	Scenario	Year	SL_{50}	SD	SPR	SD	FM	SD
MUT	**1**	**2019**	127.53	1.70	0.05	0.03	5.75	1.51
MUT	**1**	**2020**	140.69	3.13	0.05	0.03	7.90	2.19
MUT	**1**	**2021**	160.43	3.00	0.04	0.03	13.48	3.63
MUT	**1**	**2022**	149.49	2.80	0.05	0.03	10.00	2.69
MUT	**1**	**2023**	140.66	1.43	0.05	0.03	8.12	2.06
MUT	**2**	**2019**	127.21	1.83	0.05	0.03	5.86	1.59
MUT	**2**	**2020**	140.29	3.37	0.05	0.03	8.04	2.35
MUT	**2**	**2021**	160.31	3.24	0.04	0.03	13.76	3.94
MUT	**2**	**2022**	149.23	3.03	0.05	0.03	10.19	2.90
MUT	**2**	**2023**	140.49	1.53	0.05	0.03	8.28	2.18
MUT	**3**	**2019**	127.46	1.70	0.05	0.03	5.79	1.56
MUT	**3**	**2020**	140.57	3.15	0.05	0.03	7.95	2.30
MUT	**3**	**2021**	160.31	3.03	0.04	0.03	13.56	3.86
MUT	**3**	**2022**	149.38	2.82	0.05	0.03	10.07	2.84
MUT	**3**	**2023**	140.59	1.43	0.05	0.03	8.17	2.14
MUT	**4**	**2019**	127.48	1.79	0.06	0.04	5.67	1.58
MUT	**4**	**2020**	140.62	3.28	0.06	0.04	7.80	2.32
MUT	**4**	**2021**	160.37	3.14	0.06	0.03	13.32	3.87
MUT	**4**	**2022**	149.43	2.94	0.06	0.03	9.88	2.86
MUT	**4**	**2023**	140.63	1.50	0.06	0.04	8.02	2.16

Stochastic Production model in Continuous Time (SPiCT)

For red mullet, data was taken from EU fleet register provided by the European Commission (Reg. EU 2017/218), GSA6 daily commercial fishing landings provided by the Spanish Ministry of Agriculture, Fisheries and Food, DCF and GFCM Stock Assessment Form (SAF) for MUT in GSA6 RY2022 (Figure 17)

Landings from 2002 to 2022 (Tons)

OTB CPUE data from 2004 to 2022 (kg/vessel/day)

Index: MEDITS survey data from 2004 to 2022 (Biomass, kg/km2)

To compare input data, a double axis plot was presented in Figure 18. Both indexes had an increasing trend since 2010. Catches and CPUE follow similar trends, but this is not the case for the MEDITS index. Considering the data available, three scenarios were defined as follows:

Scenario 1: MEDITS + CPUE OTB

Scenario 2: MEDITS

Scenario 3: CPUE OTB

All the final scenarios end in 2022 because no MEDITS data for 2023 was available. Further work will be needed regarding the longest time series and standardized CPUE for set gillnet (GNS).

Settings for all final scenarios selected:

Catches from 2003 to 2022.

dat$stdevfacC = rep(1, length(dat$obsC))

ce = 0.05

dat$priors$logsdc <- c(log(ce), 0.3, 1)

lh.hke = flmvn_traits(Genus =”mullus”, Species =”barbatus barbatus”, Plot = F)

dat$priors$logr <- c(log(r.pr1[1]), r.pr1[2], 1)

bk.pr = c(0.5,0.5,1)

dat$priors$logbkfrac <- c(log(bk.pr[1]) - bk.pr[2]^2/2, bk.pr[2], bk.pr[3])

datinilogn <- log(2)

dat$phases$logn <- -1

pe = c(0.1, 0.5, 1)

dat$priors$logsdb <- c(log(pe[1]) - 0.5*pe[2]^2, pe[2], pe[3])

fdevs = c(4, 0.5, 1)

dat$priors$logsdf <- c(log(fdevs[1]) - 0.5*fdevs[2]^2, fdevs[[2]], fdevs[3])

dat$priors$logalpha <- c(0, 0, 0)

dat$priors$logbeta <- c(0, 0, 0)

dat$dteuler = ¼

<u>Scenario 1 MEDITS + CPUE OTB</u>

The input data (Figure 19) consisted of a landings time series from 2003 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 2004 and CPUE for OTB.

Indices were added considering the specific month when each survey per year was carried out. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value of 0.1 was set for BK frac.

Observation error for MEDITS survey and CPUE: SE = 0.3 and a CV = 0.3.

Figure 46 shows a summary of the scenario 1 fit. For the whole time series, the relative biomass was below 1. The estimated fishing mortality was above 1. It is important to consider the estimates’ high uncertainty.

Scenario 2 MEDITS

The input data (Figure 21) consisted of a landings time series from 2003 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 2004.

Indices were added considering the specific month each survey was carried out per year. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value of 0.5 was set for BK frac.

The observation error for MEDITS is SE=0.5, with CV = 0.3.

Figure 22 shows a summary of the scenario 2 fit. For the whole time series, the relative biomass was below 1. The estimated fishing mortality has been below 1 since 2020. It is important to consider the estimates' uncertainty.

Scenario 3 CPUE OTB

The input data (Figure 23) consisted of a landings time series from 2003 onwards and a biomass index to tune the model. The biomass index data were derived from CPUE for OTB from 2004.

For this scenario, a final value of 0.2 was set for BK frac.

The observation error for CPUE, SE = 0.3, with CV = 0.3.

Figure 24 shows a summary of the scenario 2 fit. For the whole time series, the relative biomass was below 1. The estimated fishing mortality is below 1 since 2020. It is important to consider the high estimates of uncertainty.

Finally, Figure 25 compares the three final scenarios. It is important to highlight the different perceptions of the stock status depending on the input data.

Scenario 2 was selected as the final one since the CPUE OTB index did not give contrast to the model.

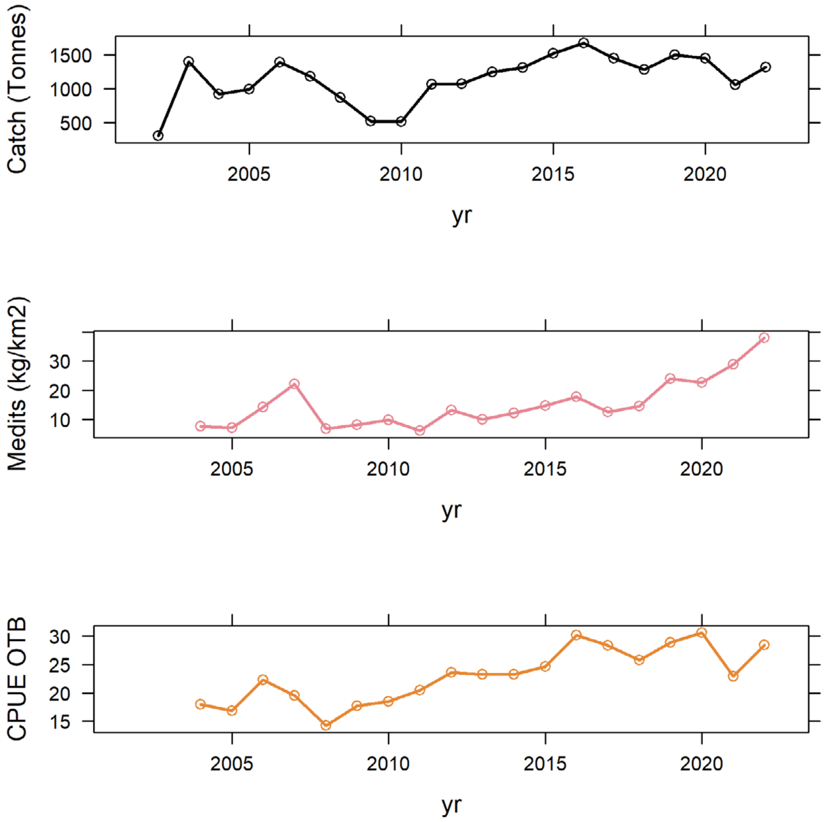


Figure 17. Data available for the assessment for red mullet in GSA6 to run SPiCT model. Top: catch data from 2002 to 2022. Centre: Medits survey data since 2004 to 2022. Bottom: CPUE OTB data since 2004 to 2022.

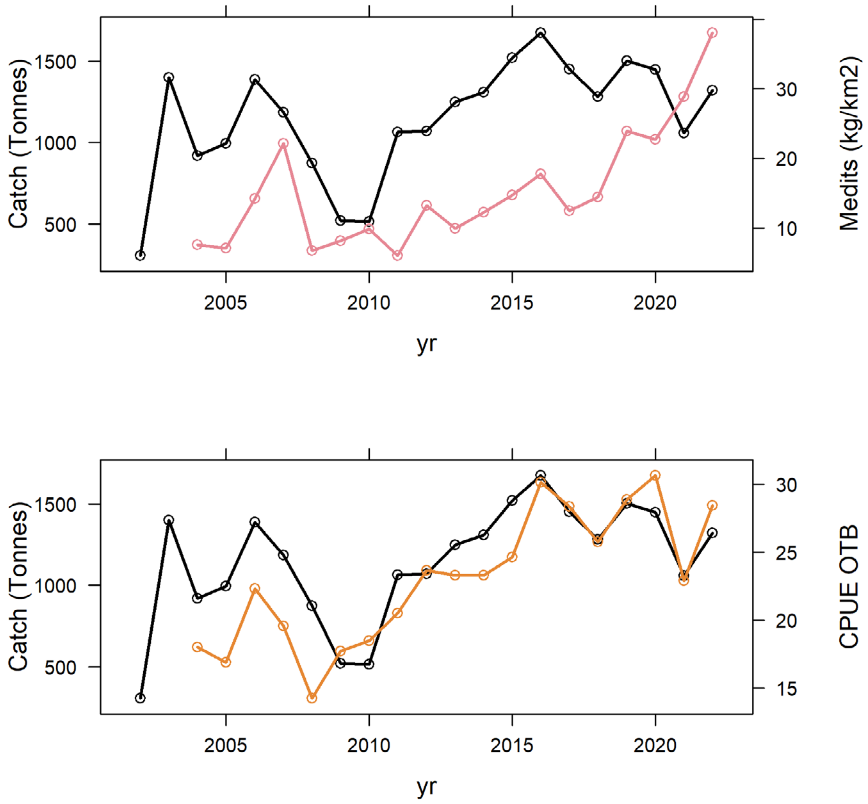


Figure 18. Double axis plot to compare trends between catch and Medits index (top) and catch and CPUE OTB (bottom) for red mullet.

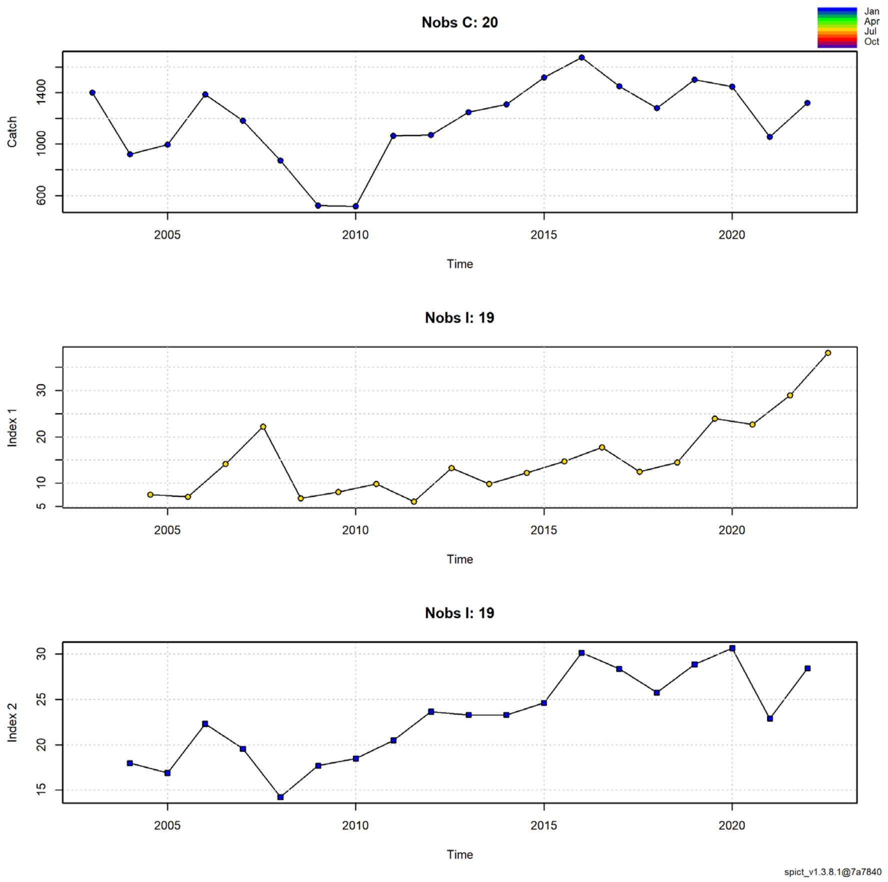


Figure 19. Input data for SPiCT model for red mullet in GSA6 for scenario 1. Top: catch in tones per year since 2003, centre: index data of biomass derived from MEDITS since 2004, and bottom: CPUE for OTB data since 2004 to 2022.

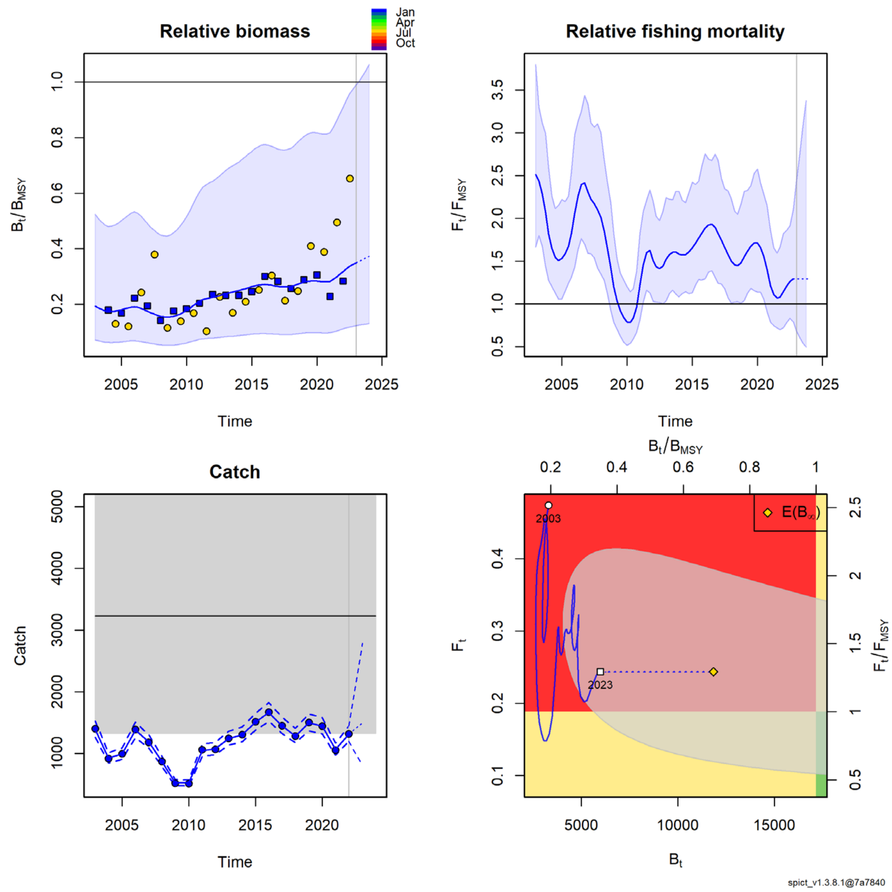


Figure 20. Stock assessment summary for SPiCT model for red mullet in GSA6 for scenario 1.

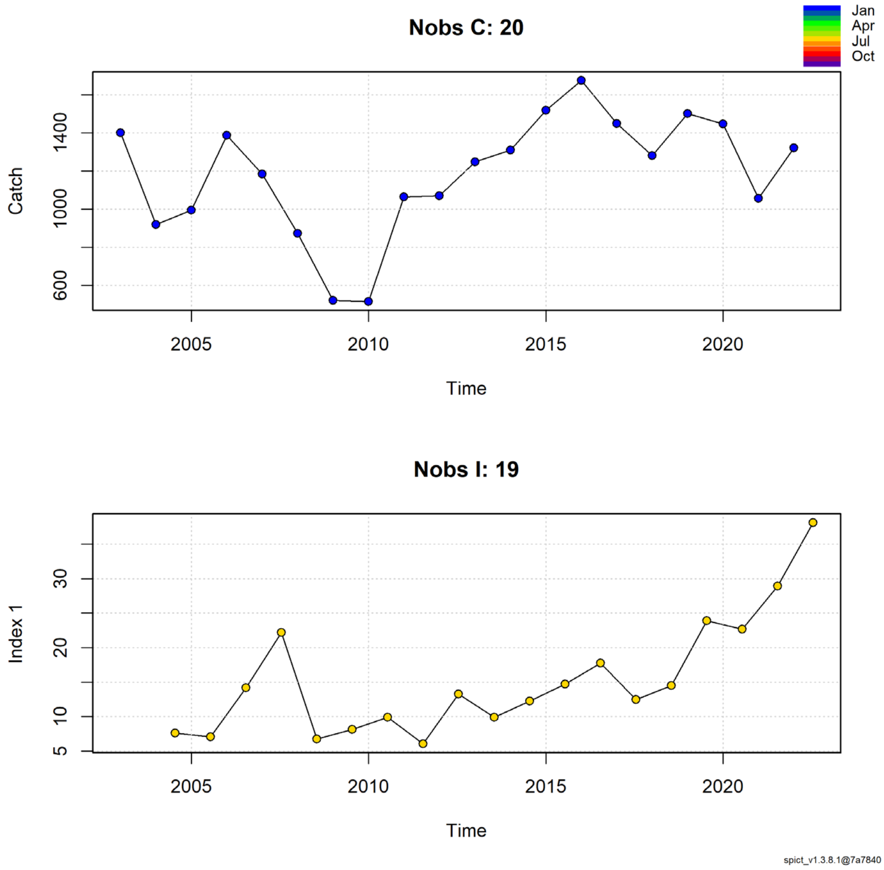


Figure 21. Input data for SPiCT model for red mullet in GSA6 for scenario 2. Top: catch in tones per year since 2003 and bottom: index data of biomass derived from MEDITS since 2004.

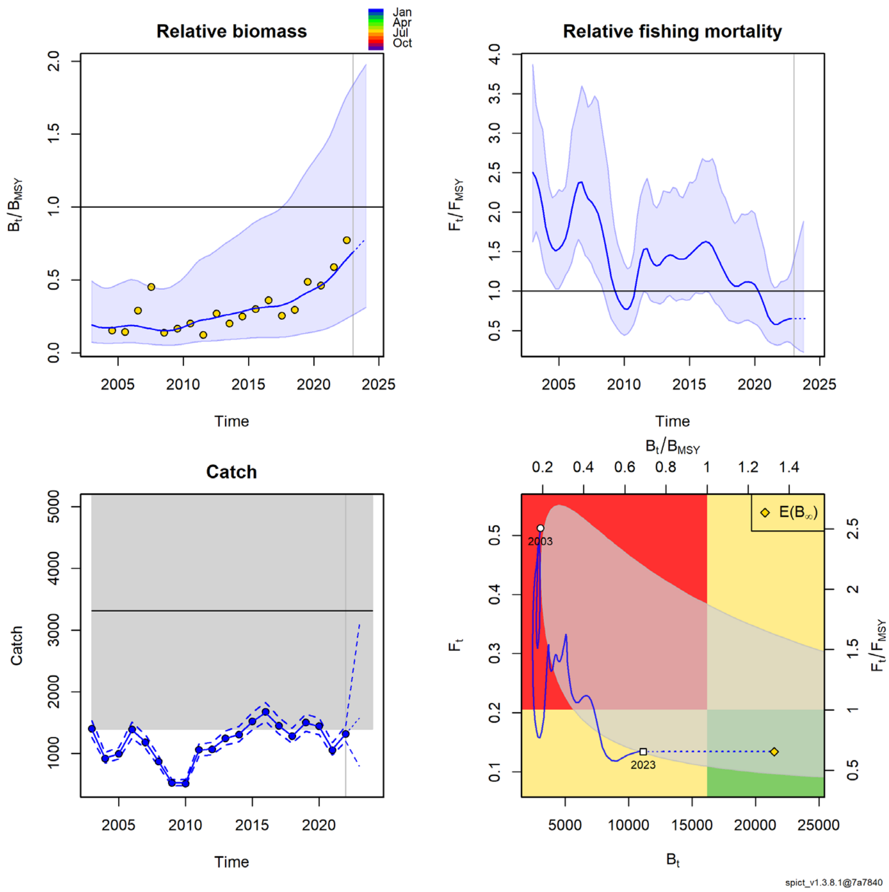


Figure 22. Stock assessment summary for SPiCT model for red mullet in GSA6 for scenario 2.

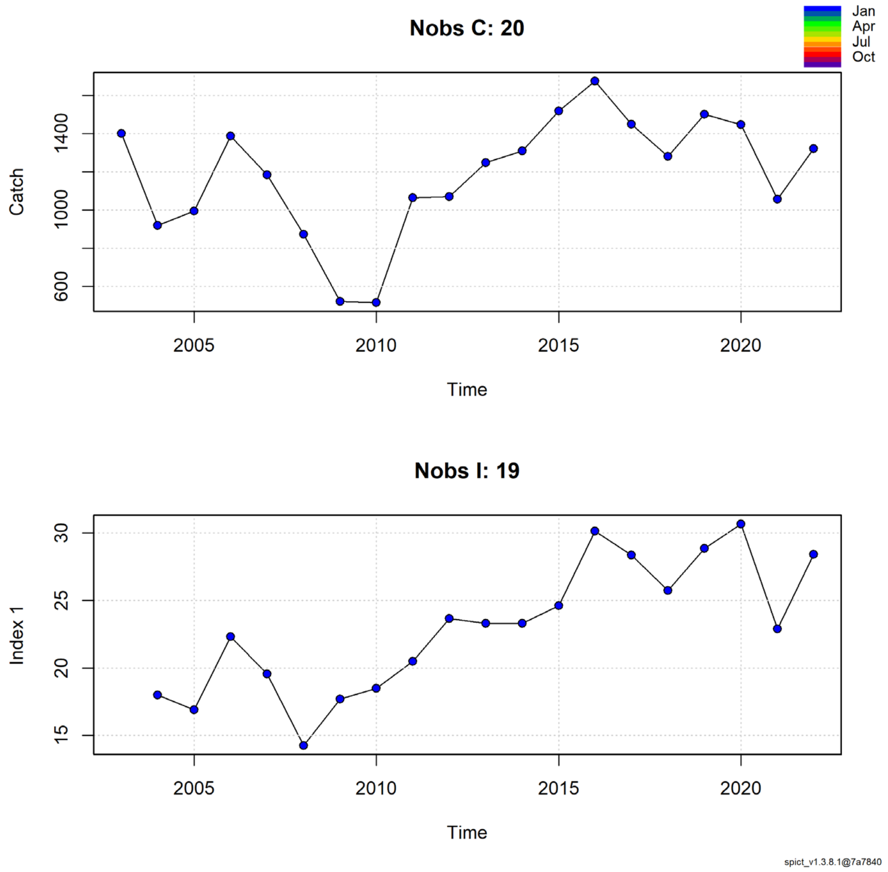


Figure 23. Input data for SPiCT model for red mullet in GSA6 for scenario 3. Top: catch in tones per year since 2003, bottom: CPUE for OTB data since 2004 to 2022.

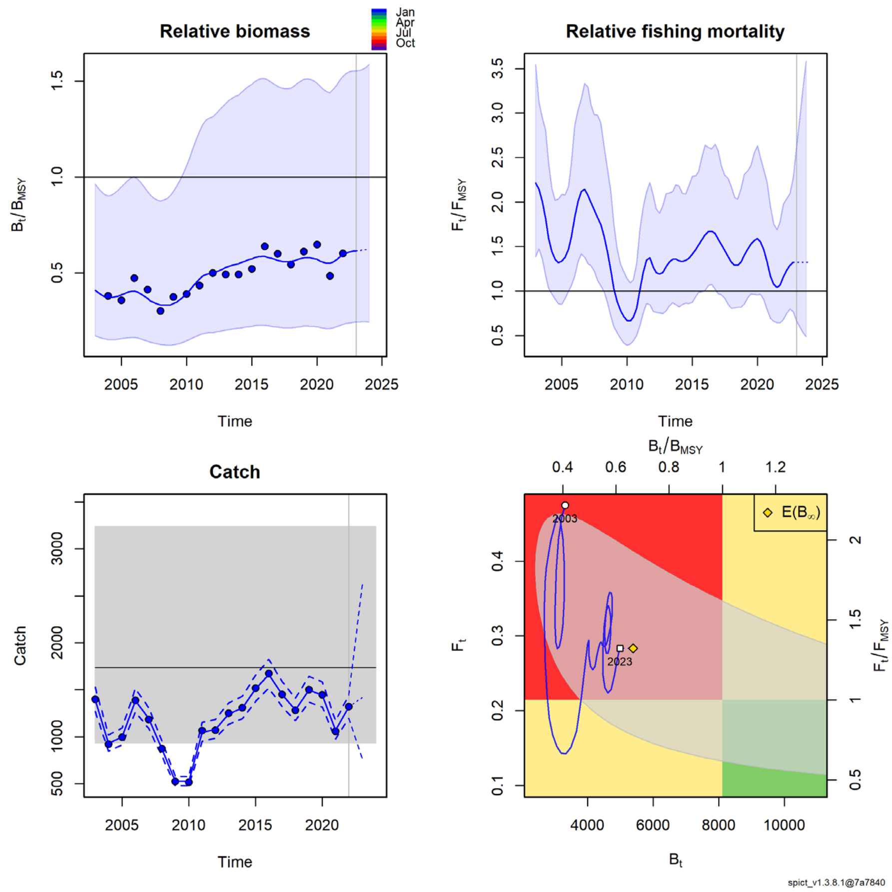


Figure 24. Stock assessment summary for SPiCT model for red mullet in GSA6 for scenario 3.

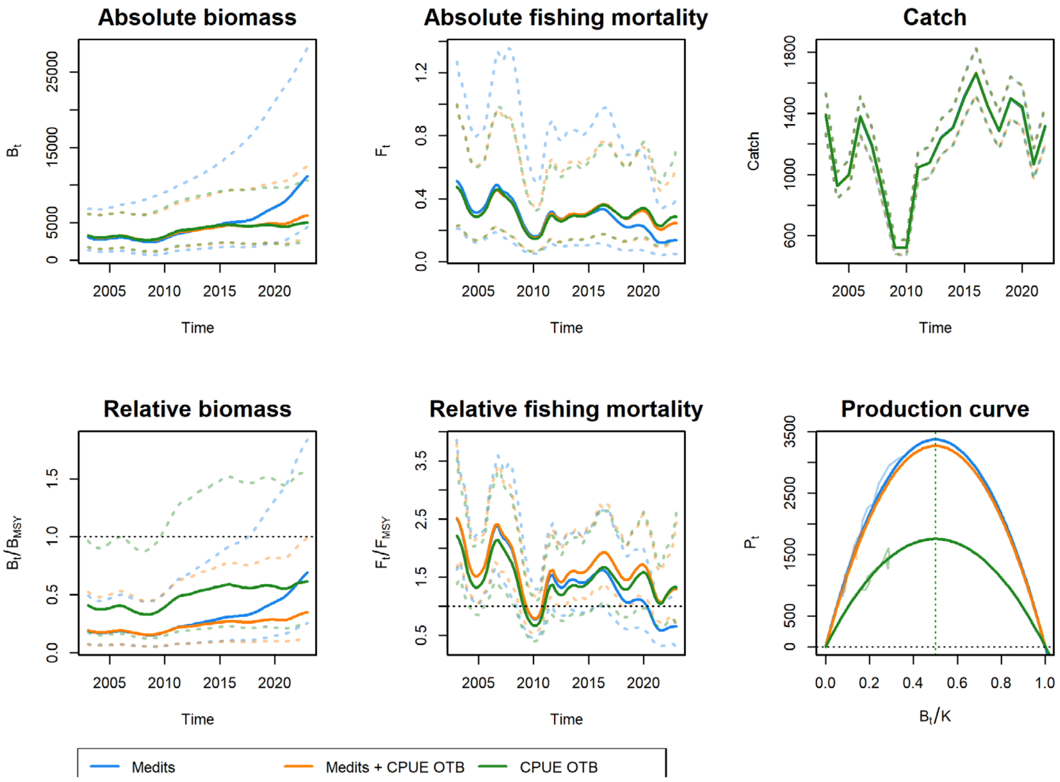


Figure 25. Scenarios comparison for red mullet in GSA6.

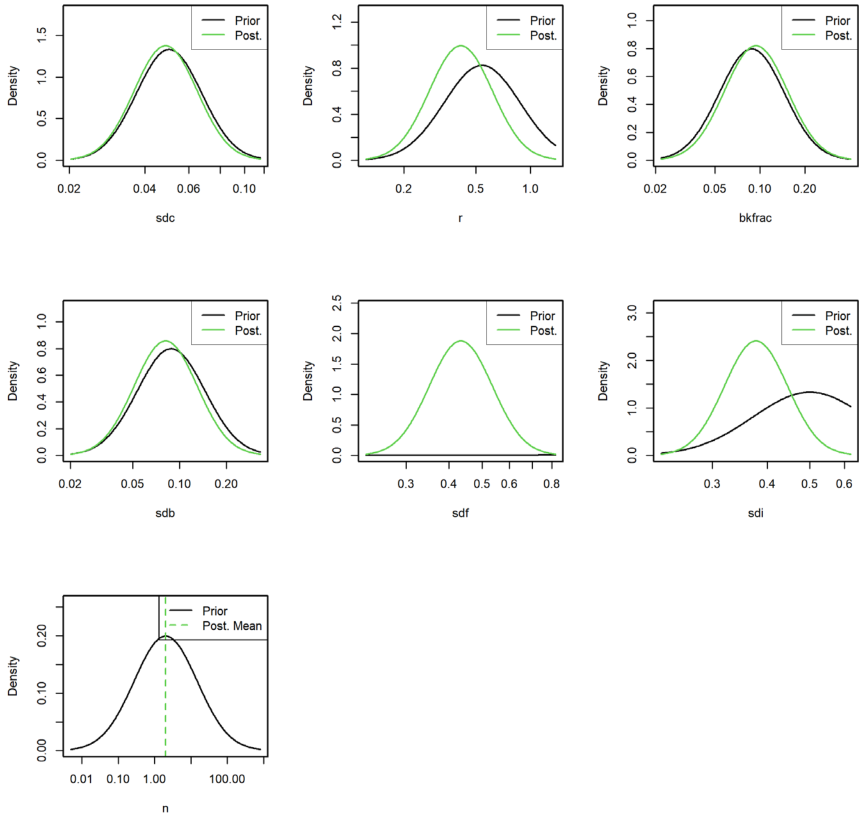


Figure 26. Estimated priors and posteriors for the updated assessment for red mullet in GSA6 for scenario 2.

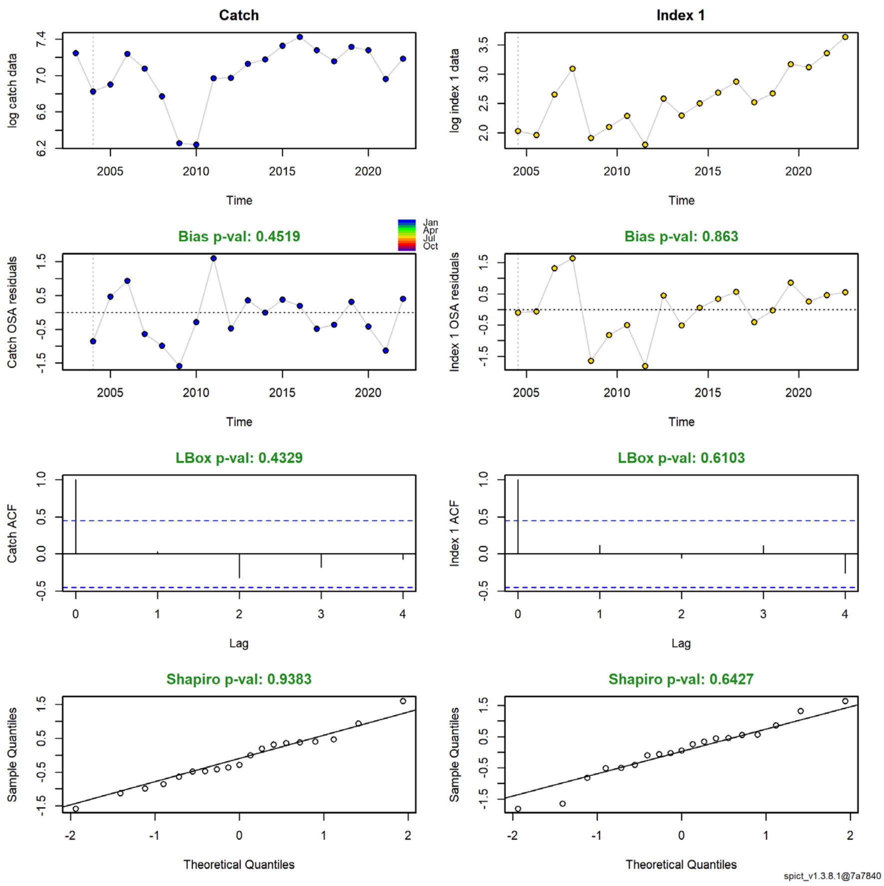


Figure 27. One-step-ahead residuals for the model for red mullet in GSA6 for scenario 2.

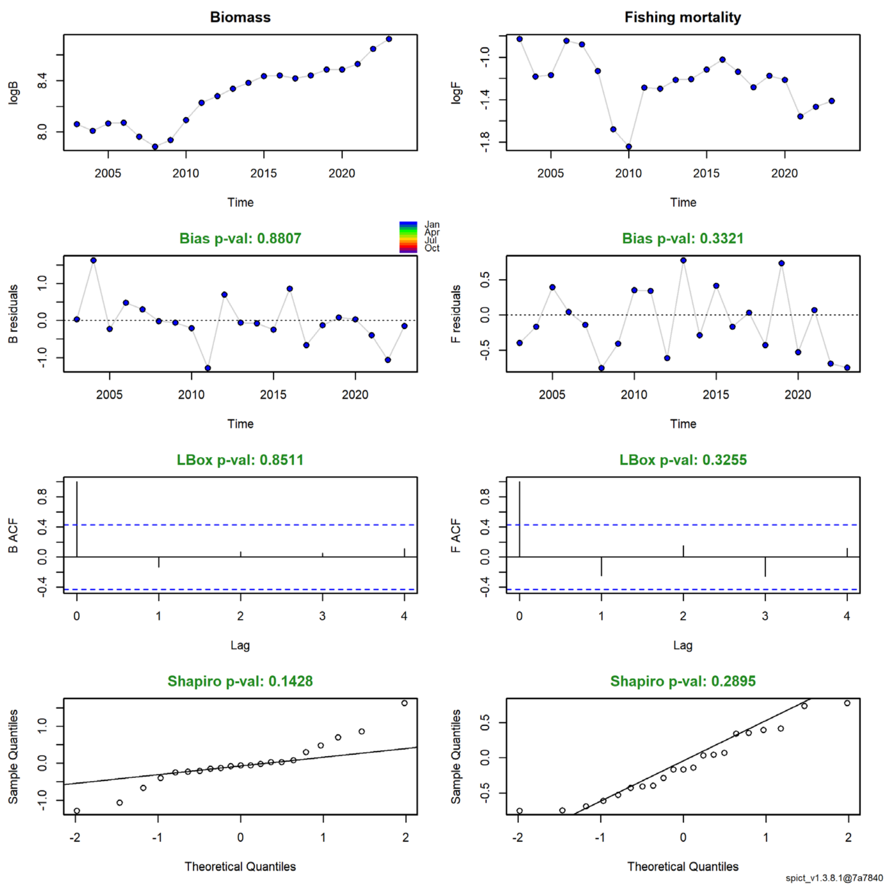


Figure 28. Process error deviations for the model for red mullet in GSA6 for scenario 2.

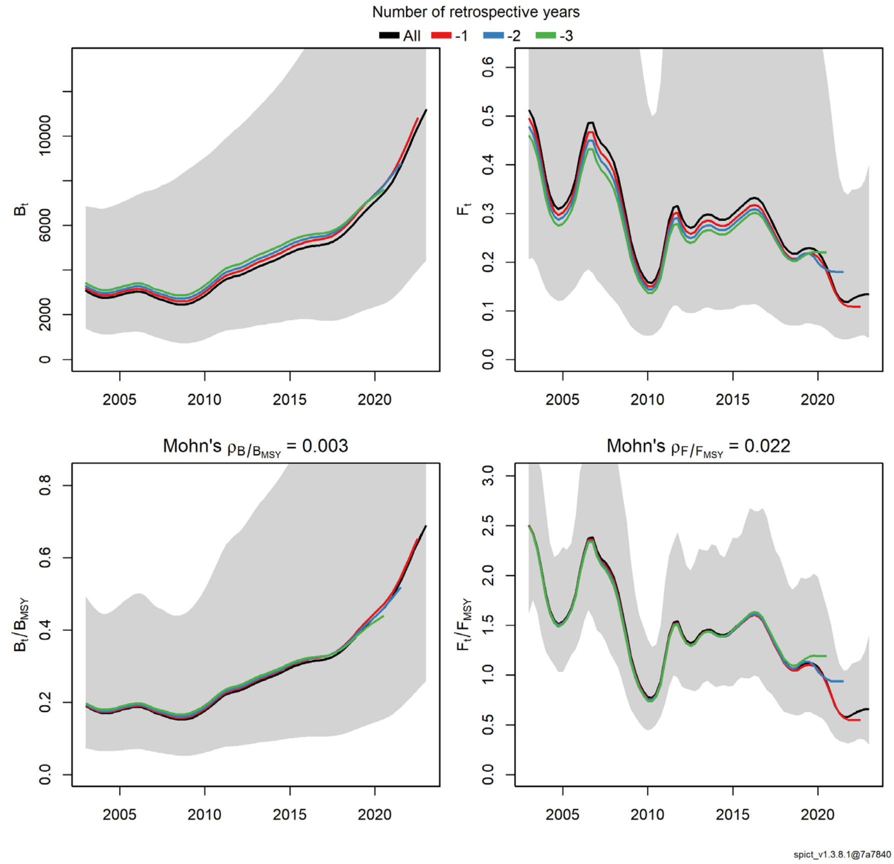


Figure 29. Retrospective analysis for red mullet in GSA6 for scenario 2.

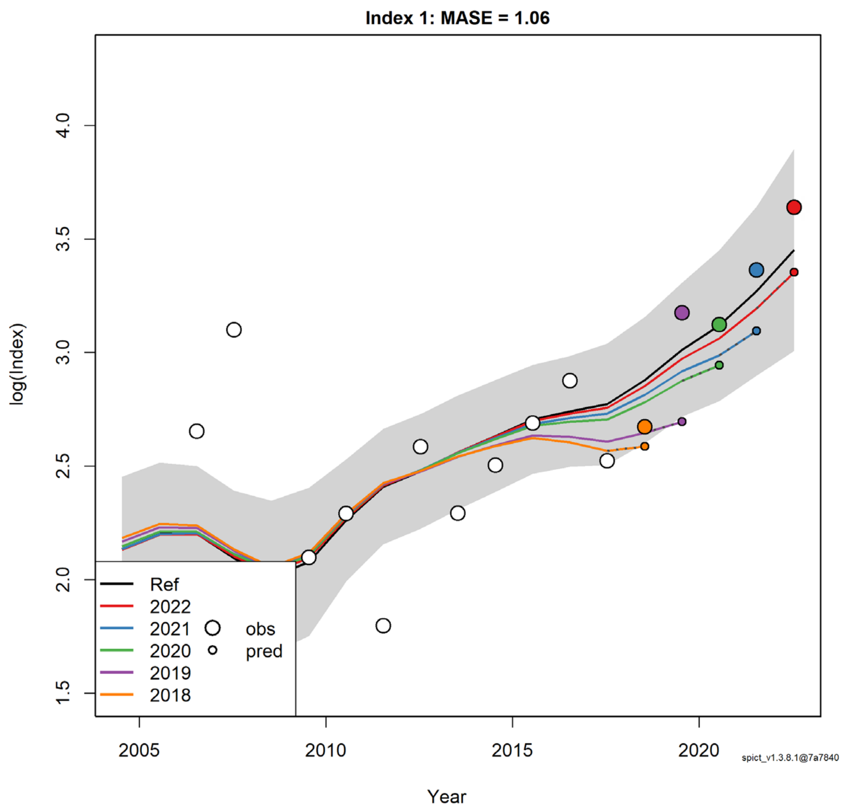


Figure 30. Hindcasting for the model for red mullet in GSA6 for scenario 2.

Figure 31. Advice for scenario 2 for red mullet in GSA6: Historical and current stock status regarding F_{msy}, B_{msy} and B_{lim}.

Table 6. Indicators in 2022 from SPiCT for red mullet in GSA6.

Species	Year	Catch (t)	FFmsy	BBmsy	BBpa	BBlim
MUT	**2022**	1317.75	0.65	0.67	1.33	2.22

Final scenarios diagnostics

Diagnostics for the final scenario selected (i.e., Scenario 2) are shown below (Figure 26, Figure 27, Figure 28, Figure 29, Figure 30). The chosen scenario met most of the model diagnostics and provided good retrospective analysis and hind-casting diagnostics.

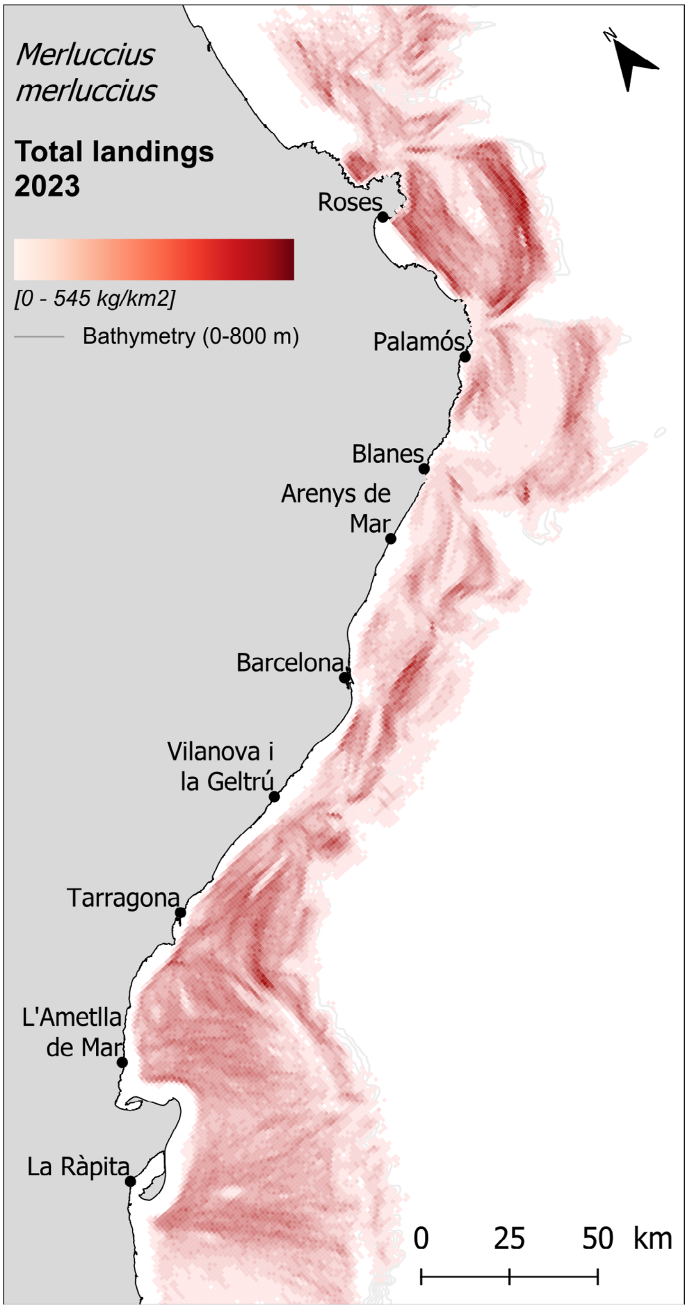
The annexes contain all the diagnostics for scenario 1 (Annex 1, Annex 2, Annex 3, Annex 4, Annex 5) and scenario 3 (Annex 6, Annex 7, Annex 8, Annex 9, Annex 10).

Also, a sensitivity analysis for scenario 2 was performed, testing r prior (Annex 11), bkfrac (Annex 12), process error (Annex 13), and observation error (Annex 14) to see how robust the model is within these priors.

Final scenarios advice

Figure 31 represents the stock assessment for the final scenario (i.e., scenario 2) (advice framework) using MEDITS as a biomass index. Table 6 shows indicators in 2022 for scenario 2 for red mullet in GSA6.

Hake (*Merluccius merluccius*) HKE



The spawning area for European hake is the continental shelf and upper slope but the nursery area is only on the continental shelf. Recruitment occurs all year round but peaks in winter and spring (Recasens *et al.* 2008, ICATMAR, 23-07).

Input data

The spatial distribution of total landings for hake in the Catalan fishing ground is presented in

Figure 32 is more or less homogeneous considering bathymetry. However, in terms of total landings, the northern and southern areas have higher landings per km^2.

Historical hake landings in Catalonia, from 2002 to 2023, are shown in Figure 33. Landings decrease throughout the whole time series until 2020, when the lowest value was observed. Later on, in 2021 and 2022, landings have an increasing trend. However, in 2023 hake landings decrease.

Figure 34 shows hake landings distribution by *métier* from 2019 to 2023. Bottom trawlers have the highest landings, especially for coastal *métiers* and upper slopes. Artisanal fisheries and set longliners have fewer landings.

Figure 32. Spatial distribution of landings per unit of effort (LPUE) for hake in the Catalan fishing grounds (North GSA6) in the year analysed.

Annual LFD

After raising the length frequencies obtained with the monitoring program (Table 7), and considering discards and small-scale fisheries length frequencies, the annual length frequency of hake in Catalonia is plotted in Figure 35. An important increase in small-length classes is observed, with more individuals in the discard fraction than the commercial fraction in 2021. These data may be indicating an increase on the species' recruitment. It is worth noting that the biggest individuals are mainly caught with small-scale fisheries.

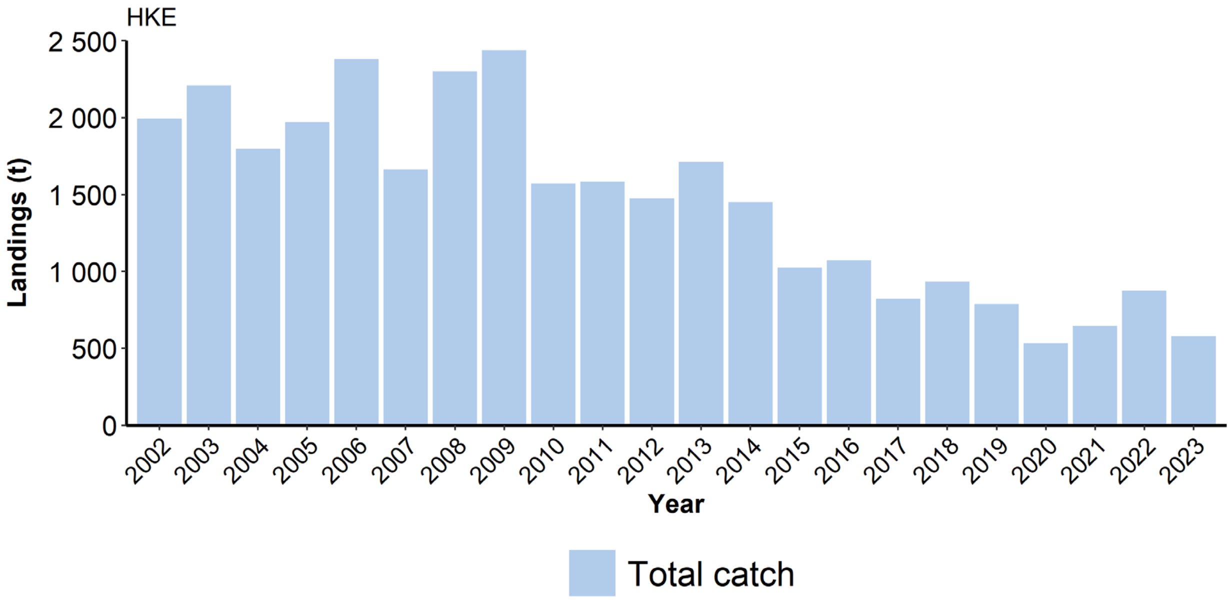


Figure 33. Historical landings (t) for hake in Catalonia.

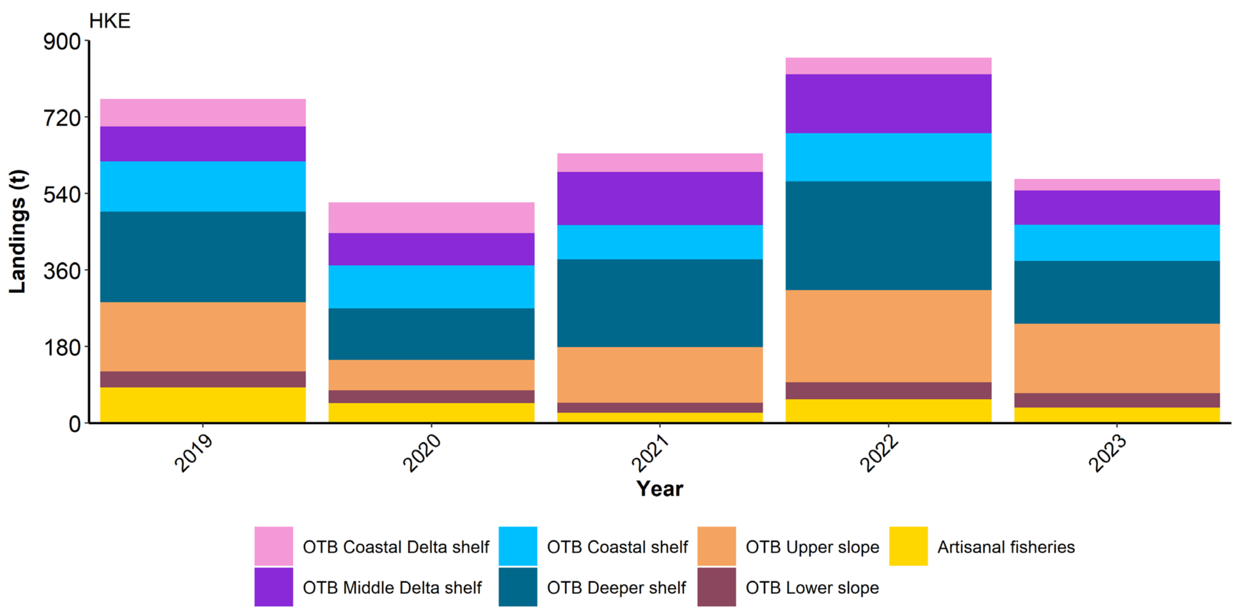


Figure 34. Landings (t) for hake by métier and fishing gear. OTB: bottom trawling.

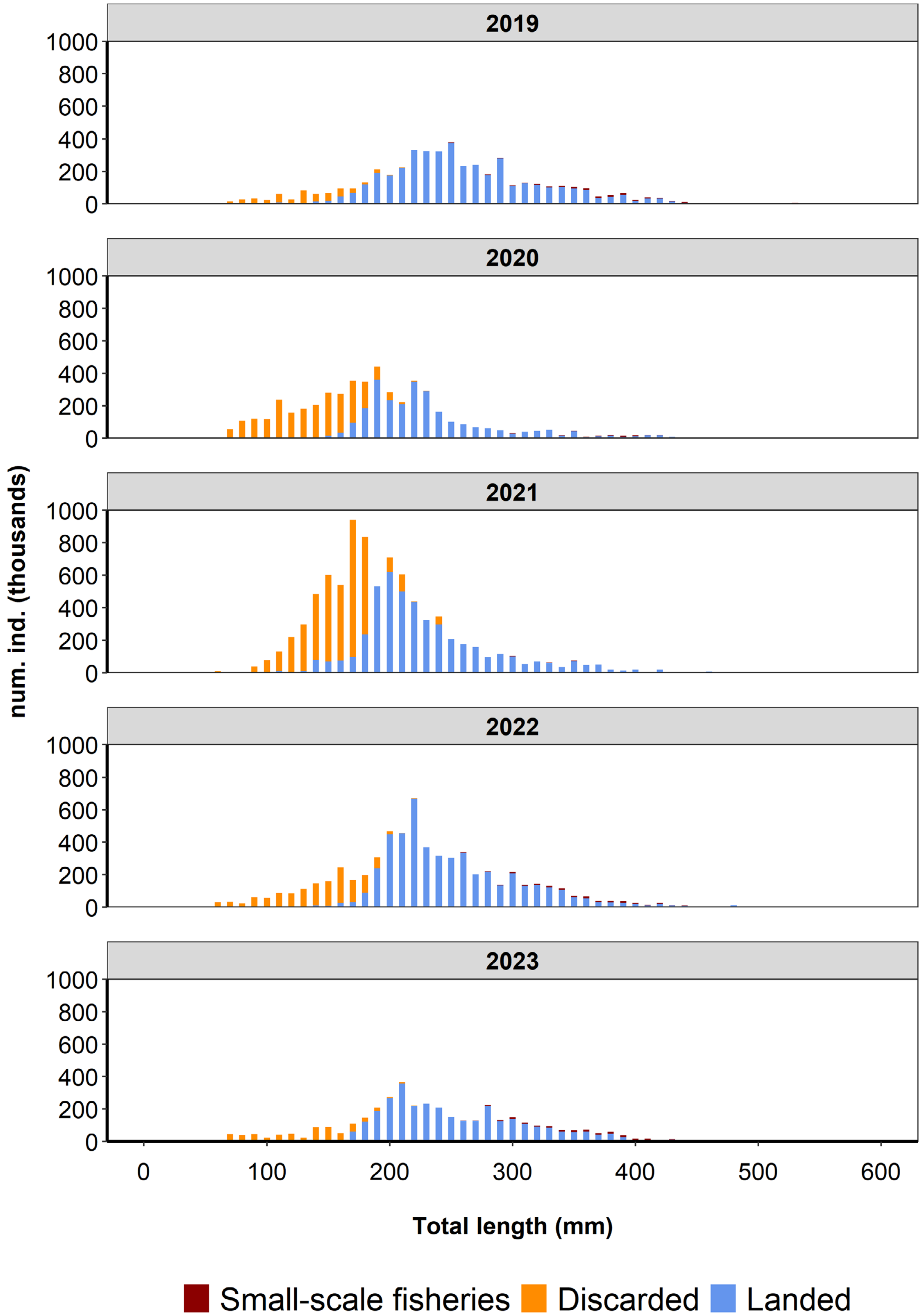


Figure 35. Annual length frequency distributions of hake from bottom trawling and small-scale fisheries. The data from bottom trawling is raised from ICATMAR data and details landed and discarded hake. The data from small-scale fisheries is obtained from DCF (Data Collection Framework) dataset.

Table 7. Number of hake individuals sampled by zone and season from ICATMAR monitoring data used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N hauls
			Number individuals sampled				
Artisanal fisheries	2019	Center	0	3	0	0	1
Artisanal fisheries	2022	Center	0	2	0	0	1
Artisanal fisheries	2023	Center	23	0	0	0	1
Bottom trawl	2019	North	70	415	159	116	19
Bottom trawl	2019	Center	82	119	50	83	17
Bottom trawl	2019	South	301	217	206	391	25
Bottom trawl	2020	North	43	102	58	237	15
Bottom trawl	2020	Center	145	76	64	102	11
Bottom trawl	2020	South	114	67	264	142	18
Bottom trawl	2021	North	261	88	125	60	18
Bottom trawl	2021	Center	123	135	91	49	11
Bottom trawl	2021	South	33	46	221	211	20
Bottom trawl	2022	North	111	97	99	162	16
Bottom trawl	2022	Center	122	64	141	134	11
Bottom trawl	2022	South	88	188	272	359	21
Bottom trawl	2023	North	303	240	272	339	24
Bottom trawl	2023	Center	297	207	252	188	12
Bottom trawl	2023	South	297	141	285	122	20

Length-Based Spawning Potential Ratio (LBSPR)

Model setting and results

Scenarios

Three different scenarios were applied for the sensitivity analysis for hake (Table 8). The first scenario used growth parameters, natural mortality and maturity data from STECF and GFCM stock assessment. The second one used the same parameters and included length at first maturity from ICAMAR data. Finally, the third scenario used growth parameters and natural mortality from the literature (Aldebert et al., 1993) and the same maturity as scenario two.

Table 8. Biological parameters used in the different LBSPR scenarios for hake (HKE). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Species	Scenario	L_{inf} (mm)	M/k	L_{mat50} (mm)	L_{mat95} (mm)
HKE	1	1100	2.247	260	309.4
HKE	2	1100	2.247	282	335.6
HKE	3	802	2.247	282	335.6

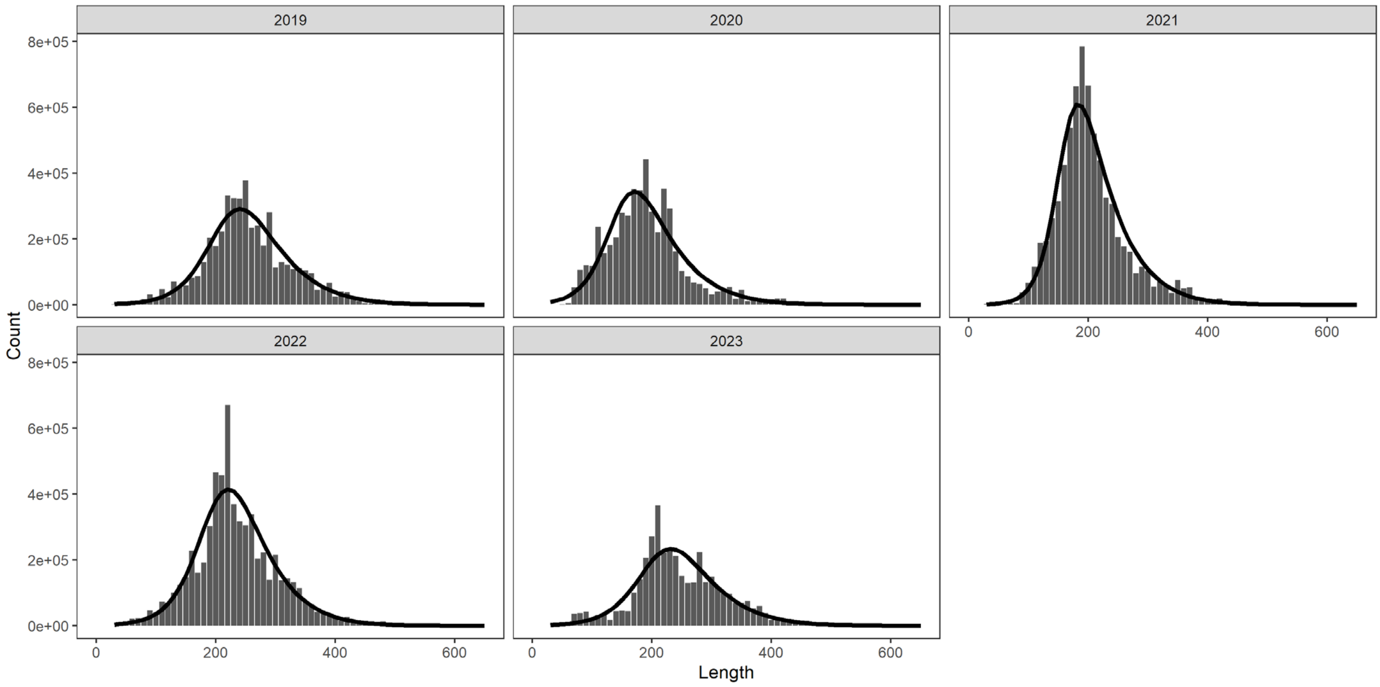


Figure 36. Fit of the data using the LBSPR model for hake for each studied year. Grey columns indicate length frequencies. Black lines indicate the fit of the model.

Fitted data

The length frequency distribution fit per year is shown in Figure 36. The model generally follows the mode for all years, but tends to overestimate or underestimate the number of individuals in the middle-length classes.

Selectivity

The outputs of the model for the selectivity of the fishery are shown for each scenario in Table 9. The outputs are also plotted together with L_{mat50} and SL_{50} in Figure 37. For the different scenarios, the model outputs reveal that the fishery is fishing below the SL_{50}.

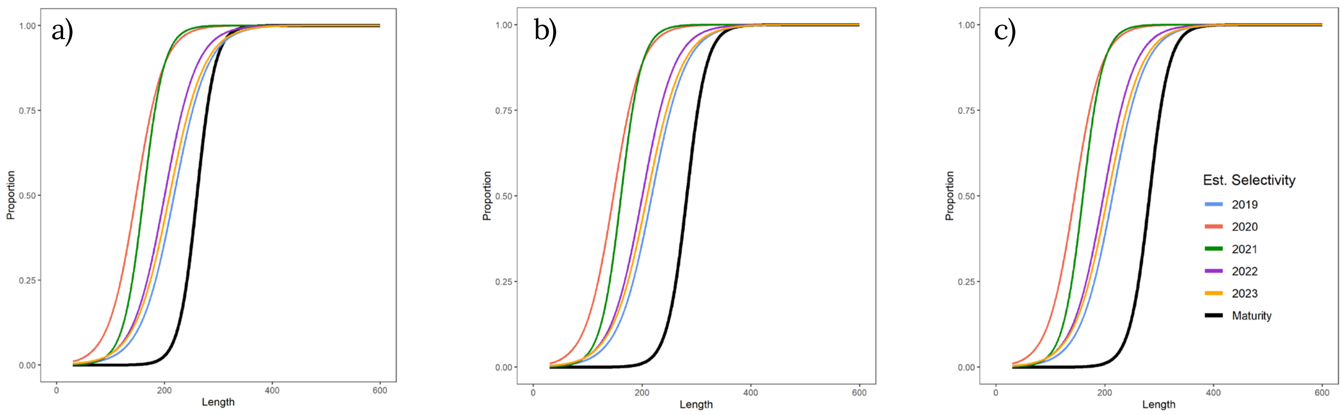


Figure 37. Length curves for hake. Black line shows the length curve at maturity. Colour lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (a), scenario 2 (b) and scenario 3 (c).

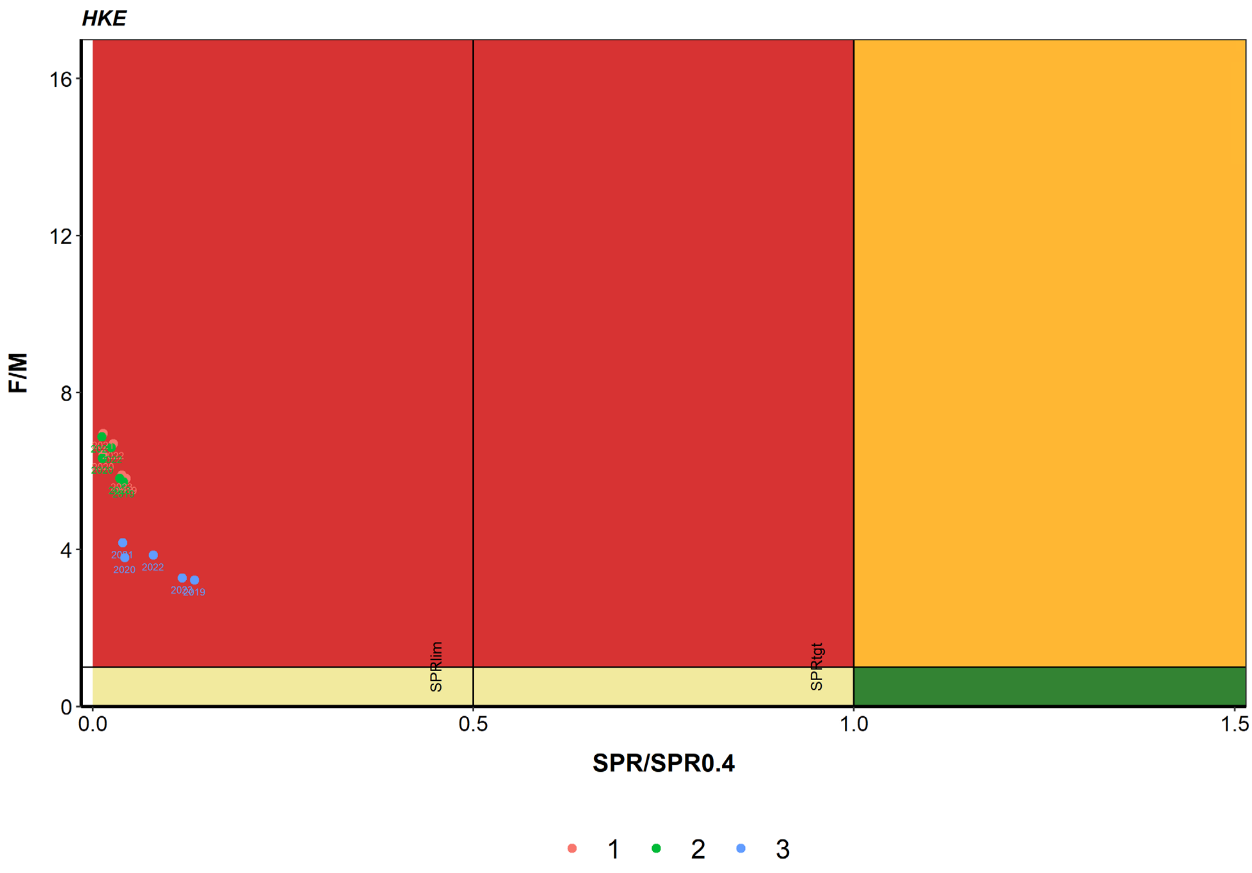
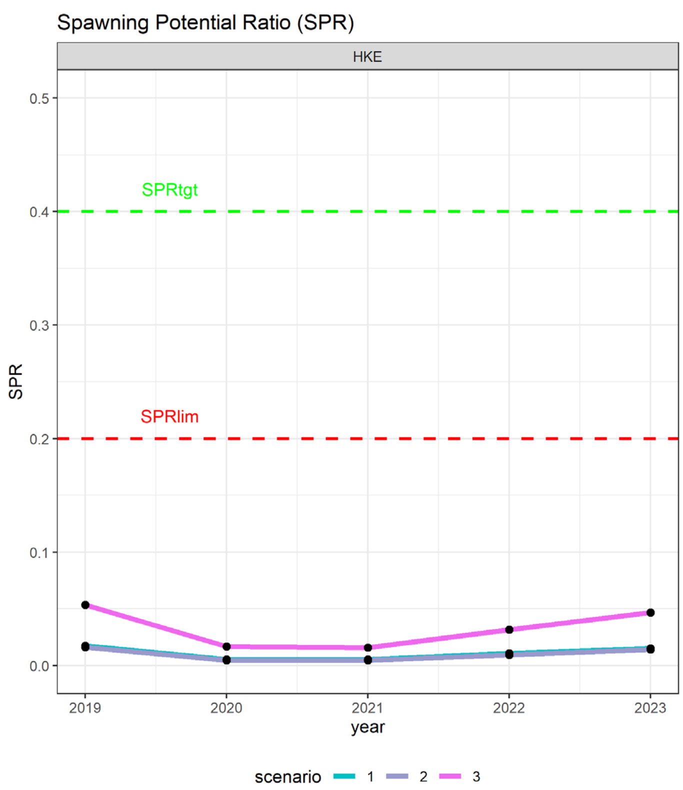


Figure 38. Kobe plot for hake by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.



Reference points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is below SPR_{lim} (=0.1) in all the scenarios (Table 9 and Figure 39). The Kobe plot for hake (Figure 38) shows the stock status throughout the different years, with no clear trend. However, the stock is, in all cases, located in the red zone meaning that it is overfished and under overfishing.

Figure 39. Spawning potential ratio (SPR) per year analysed for hake evaluated with LBSPR model. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. Coloured lines show the results for each scenario.

Table 9. LBSPR model results for hake with the different scenarios tested for each year analysed. SL_{50}: Length where 50% of individuals are caught, SPR: spawning potential ratio and FM: relative fishing mortality. SD is the standard deviation calculated for each indicator.

Species	Scenario	Year	SL_{50}	SD	SPR	SD	FM	SD
HKE	**1**	**2019**	221.09	2.63	0.02	0.01	5.81	1.23
HKE	**1**	**2020**	150.26	2.33	<0.01	<0.01	6.42	1.28
HKE	**1**	**2021**	162.98	1.40	<0.01	<0.01	6.96	1.36
HKE	**1**	**2022**	203.32	2.32	0.01	<0.01	6.70	1.37
HKE	**1**	**2023**	212.74	2.75	0.02	0.01	5.90	1.25
HKE	**2**	**2019**	220.96	2.67	0.02	0.01	5.72	1.23
HKE	**2**	**2020**	150.15	2.37	<0.01	<0.01	6.34	1.27
HKE	**2**	**2021**	162.92	1.42	<0.01	<0.01	6.87	1.35
HKE	**2**	**2022**	203.21	2.36	<0.01	<0.01	6.61	1.36
HKE	**2**	**2023**	212.59	2.79	0.01	<0.01	5.81	1.25
HKE	**3**	**2019**	218.45	3.37	0.05	0.04	3.22	0.85
HKE	**3**	**2020**	147.98	2.90	0.02	0.01	3.80	0.89
HKE	**3**	**2021**	161.86	1.70	0.02	0.01	4.18	0.94
HKE	**3**	**2022**	201.17	2.89	0.03	0.02	3.86	0.95
HKE	**3**	**2023**	209.57	3.44	0.05	0.03	3.28	0.86

Final scenario

As LFD and L_{mat} originated from ICATMAR data, scenario three was selected to provide final advice for the LBSPR model.

Stochastic Production model in Continuous Time (SPiCT)

For hake, an extra effort was made due to its historical importance in the area. Twelve scenarios were tested considering different time series, biomass index and CPUE information, which can be historical or obtained from DCF. Different selectivity periods of the fishery were considered to better understand the stock behaviour since 1971. Finally, the best diagnostics and the best informative input data were selected for the final scenario, which considers biomass index and CPUE standardized for long-liners. With this extended analysis, it is important to highlight the different perceptions of the model depending on the input data, being more or less optimistic about the stock status.

Data available for hake in GSA6:

Landings, vessel characteristics and fishing days for GSA6 (by CAT, VAL and MUR) by year are available:

Catch from 1971 to 2023 were estimated as follows:

1971-1987 (CAT+VAL) (Martín, 1991)

1987-1994 (CAT *1.82 factor to GSA06) based on Laura Recasens data

1995-2009 (GSA6 - Landings=catch) DCF data

2010-2023 (GSA6 - Catch) DCF data

CPUE:

From 1990 to 2024: vessel data (EU fleet register provided by the European Commission (Reg. EU 2017/218))

From 2004 to 2023: GSA6 daily commercial fishing landings provided by the Spanish Ministry of Agriculture, Fisheries and Food

Nominal CPUE (kg/day & kg/vessel)

Standardized CPUE (based on Henning Winker (GFCM) & Hoyle et al., 2024)

Survey data:

MEDITS data (1994-2022) DCF data

1994-1996 -> High uncertainty Codend mesh size is 20 mm (stretched mesh) In this scenario, it was assumed that MEDITS covers the same area as a commercial fleet and that the LFD removed by the MEDITS survey is the same as a commercial fleet.

However, the MEDITS survey uses experimental, non-selective fishing gear (can capture smaller individuals – 20 mm codend mesh size).

1990 biomass estimation assumes comparable to MEDITS survey (Bas Peired, C., 2005)

Explore input data:

To explore the input data, landings, vessels, and fishing days were plotted by year and gear (refer to Figure 40). OTB, LLS, and GNS are the most important gear harvesting hake. In general, all gears show a negative trend, indicating a reduction in effort over the years.

For OTB, LLS, and GNS, data normalization was performed to compare kg/day and kg/vessel (Figure 41). For LLS and GNS, kg/day values were significantly higher than kg/vessel at the beginning of the series. In recent years, values have been much closer when comparing kg/day and kg/vessel. Considering CPUE per vessel underestimates the kg captured per unit effort. Per day, the capture increased each time they went fishing. Per vessel, the significance of kg capture over time is not apparent. Over time, capture per day and per vessel became more similar. For OTB similar trends for kg/days and kg/vessel were observed.

Index data for the assessment

After comparing the trend between catches and nominal CPUE and the MEDITS biomass index long liners (LLS) and MEDITS were selected as biomass indexes for the biggest and smaller to medium individuals, respectively (Figure 42). The results from the CPUE standardization were used for the final scenarios (Figure 43). OTB CPUE is not informative for the model because the trend is similar to catches. Further analysis for GNS (i.e., Standardized CPUE) will be necessary to consider this fishing gear properly.

Catch data for the assessment

Catch Commercial data: the length structure removed by the commercial fishery from 1971 to 2009 assumes representing catches. Since 2010, discards have been quantified, accounting for 10% on average of the total catch because the mesh size was changed from diamond to square 40 mm. Since 2010, hake's minimum conservation reference size (MCRS) is 20 cm (Figure 44).

1971-1994: Diamond codend mesh size 35

1994-2009: Diamond codend mesh size 40

2010-2023: Square codend mesh size 40 + MRSC>20cm

Different scenarios

Different scenarios were tested:

The first group was based on MEDITS survey data plus nominal CPUE for all gears (from 1 to 4).

The second group was based only on nominal CPUE for all gears (from 5 to 7).

Scenario 8 tests the impact of the estimated biomass due to selectivity changes as an index for the assessment.

Scenario 9 (nominal CPUE LLS) and 10 (nominal CPUE LLS + MEDITS data) test the impact of using this biomass as a catch (scenario 8) to test how the stock status will be without selectivity changes.

Scenario 11 and 12 use as an index CPUE LLS standardized with or without MEDITS respectively. For CPUE std from 2004 to 2009 and 2023, SE = 2 and from 2010 to 2022, SE = 1.

Final scenarios selected and presented in detail:

Scenario 2: MEDITS (+1990)

Scenario 11: MEDITS (+1990) + Standardized CPUE LLS (kg/day)

Scenario 12: Standardized CPUE LLS (kg/day)

All the final scenarios end in 2022 because no MEDITS data for 2023 was available.

Settings for all final scenarios selected:

<u>Catches:</u>

From 1971 to 2022.

<u>Observation error catch:</u>

SPiCT use a two-step approach to specify observation errors.

• stdevfacC vector for interannual variability scaled to 1

• logsdc prior for the average observation error Estimating the standard deviation of logsdc is often confounded with process error, F deviations and observation error of the indices.

To substantially improve model stability and convergence, it may therefore be desirable to admit changes of catch error over time but not to estimate the additional uncertainty about this catch error. This is particularly important in cases where the catch time series is longer than the index.

<u>Interannual variability in catch</u>

dat$stdevfacC = rep(1,length(dat$obsC))

Then compute the average observation error over the time series and fix the logsdc by assuming a moderate CV = 0.3.

ce = 0.05

dat$priors$logsdc <- c(log(ce), 0.3, 1)

<u>Retrieve life-history traits from metadata</u>

Population growth r estimate is retrieved from the meta-analysis performed by FishLife package

lh.hke = flmvn_traits(Genus=”Merluccius”,Species=”merluccius”,Plot=F)

r.pr1 = as.numeric(lh.hke$traits[10,c(“mu.sp”,”cv.sp”)])

r.pr1

[1] 0.1656 0.8164

dat$priors$logr <- c(log(r.pr1[1]),r.pr1[2],1)

<u>Depletion prior (BKfrac)</u>

A prior for BKfrac is included because we already know that fisheries occurred before the beginning of the time series. A moderate depletion of 0.5 was tested. Finally, 0.7 is adopted.

bk.pr=c(0.7,0.5,1)

dat$priors$logbkfrac <- c(log(bk.pr[1])-bk.pr[2]^2/2,bk.pr[2],bk.pr[3])

<u>Shape of the production curve</u>

Determining the shape of the production curve: Fixing n to resemble the Schaefer production model

datinilogn <- log(2)

dat$phases$logn <- -1

<u>Process error</u>

Additional process variance error fairly high and vague is informed

pe = c(0.1,0.5,1)

dat$priors$logsdb <- c(log(pe[1])-0.5*pe[2]^2, pe[2], pe[3])

<u>Error fishing mortality</u>

fdevs=c(4,0.5,1)

dat$priors$logsdf <- c(log(fdevs[1])-0.5*fdevs[2]^2, fdevs[[2]], fdevs[3])

<u>Other generic settings</u>

Switch alpha and beta off when catch, observation or process error are informed

dat$priors$logalpha <- c(0,0,0)

dat$priors$logbeta <- c(0,0,0)

Improve the computational skills while the assessment results are not affected

dat$dteuler = ¼

<u>Scenario 1 base case index MEDITS complete + 1990 biomass estimate</u>

The input data (Figure 45) consisted of a landings time series from 1971 onwards and a biomass index to tune the model. The data for the biomass index was derived from the MEDITS bottom trawl survey from 1994 and an estimated value for 1990.

Indices were added considering the specific month when each survey per year was carried out. In the case of MEDITS, the survey was carried out in the middle of June.

Observation error

The mean observation error needs to be specified across the time series. Normally, both interannual variability and mean observation error can be directly informed by the CVs of the survey index. However, even if this not the case some additional uncertainty should be admitted by allowing to estimate observation error with a prior given the mean survey SE = 0.2 and a CV = 0.5.

Figure 46 shows a summary of the scenario 1 fit. At the beginning of the time series, the relative biomass was above one, and after 1990, it was below this reference point. For relative fishing mortality, the estimated value has been near one since the early 2000s. It is important to consider the uncertainty of the estimates.

<u>Scenario 11 MEDITS + CPUE LLS standardized</u>

The input data (Figure 47) consisted of a landings time series from 1971 onwards and a biomass index to tune the model. The biomass index data was derived from the MEDITS bottom trawl survey from 1994 and an estimated value for 1990. Also, CPUE standardized for LLS was added to this scenario.

CPUE standardized from 2004 to 2009 and 2023 for LLS data, SE was set to 2 and for 2010 to 2022 was set to 1. As for MEDITS, the Observation error for CPUE was set to 0.2.

Figure 48 shows a summary for the scenario 11 fit. The relative biomass was above one at the beginning of the time series, and after 1990, it was below this reference point. For relative fishing mortality, the estimated value has been near one since the early 2000s. It is important to consider the uncertainty of the estimates.

Stochastic Production model in Continuous Time (SPiCT)

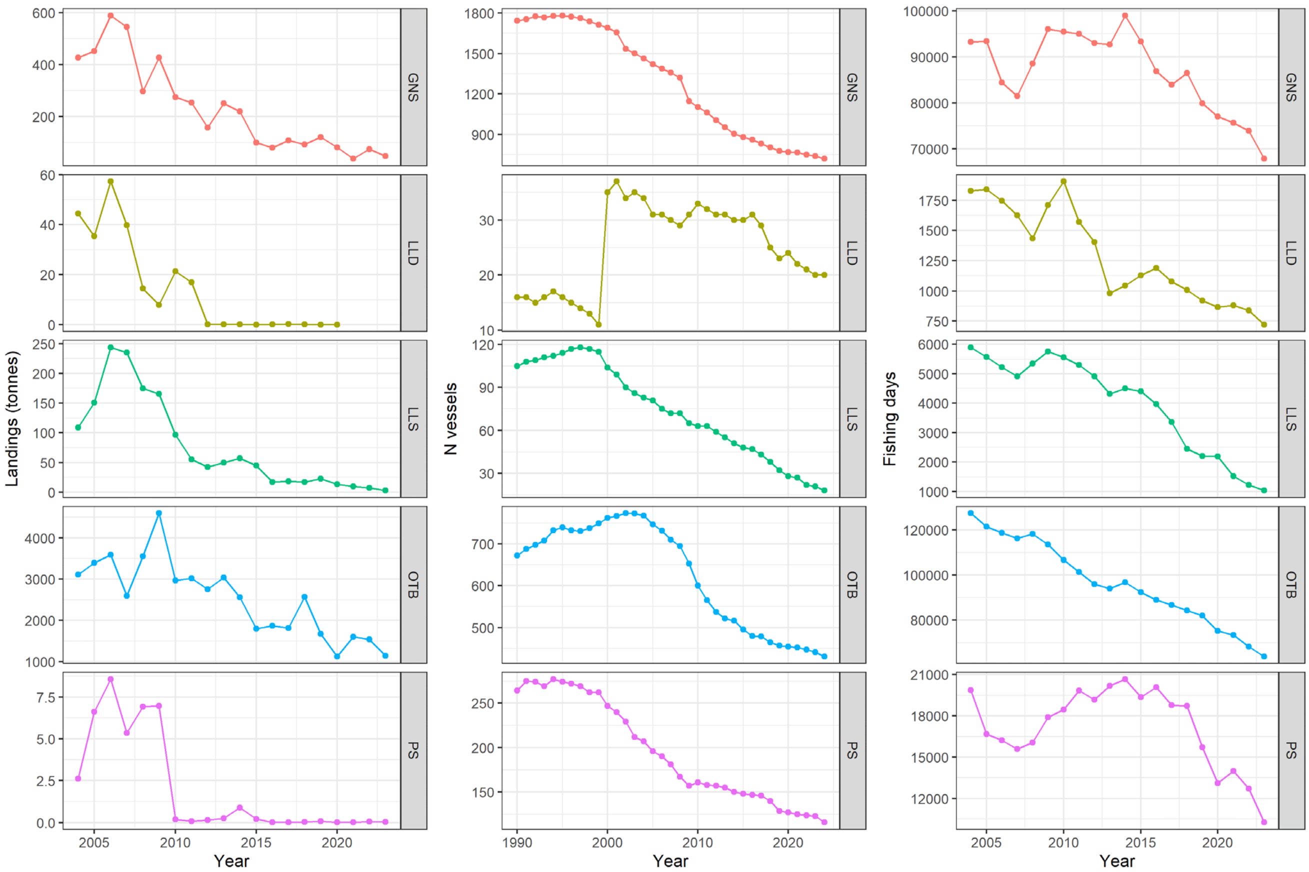


Figure 40. Landings (left) and numbers of fishing days (right) from 2004 to 2023 and number of vessels (center) from 1990 to 2023, for hake in GSA6 for all fishing gears. GNS: Set gillnet, LLD: Drifted long liner , LLS: Set longline, OTB: Bottom otter trawl, PS: Purse Seiner.

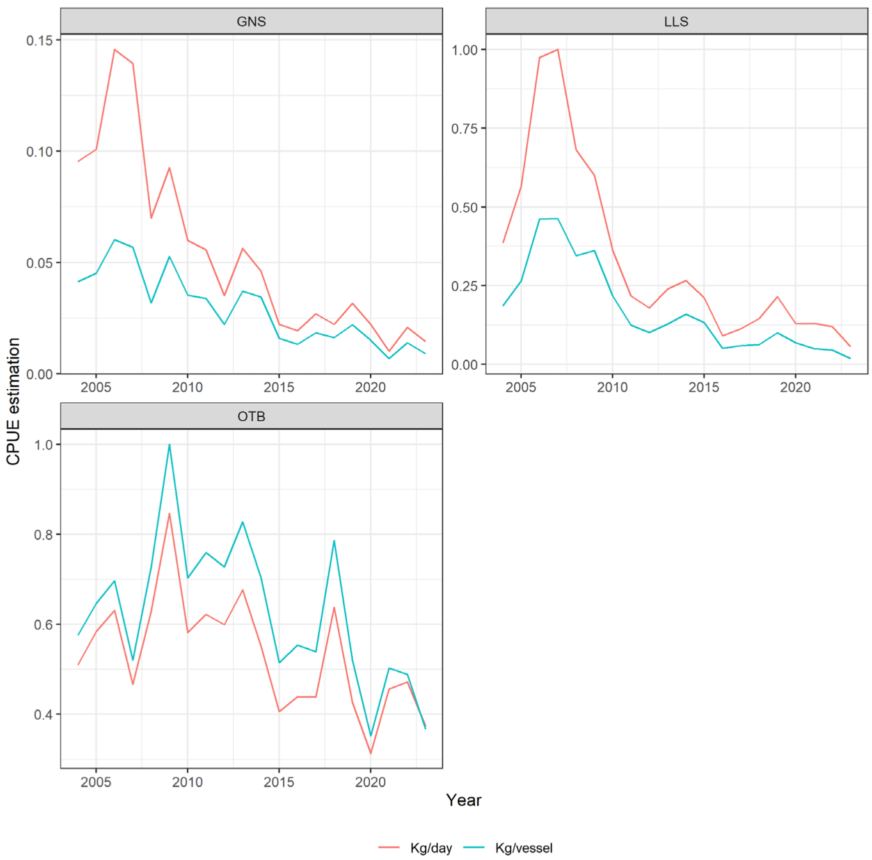


Figure 41. Comparison of CPUE estimation (data normalized) for kg/day and kg/vessel from 2005 to 2023 for the main fishing gears for hake in GSA6. GNS: Set gillnet, LLS: Set longline and OTB: Bottom otter trawl.

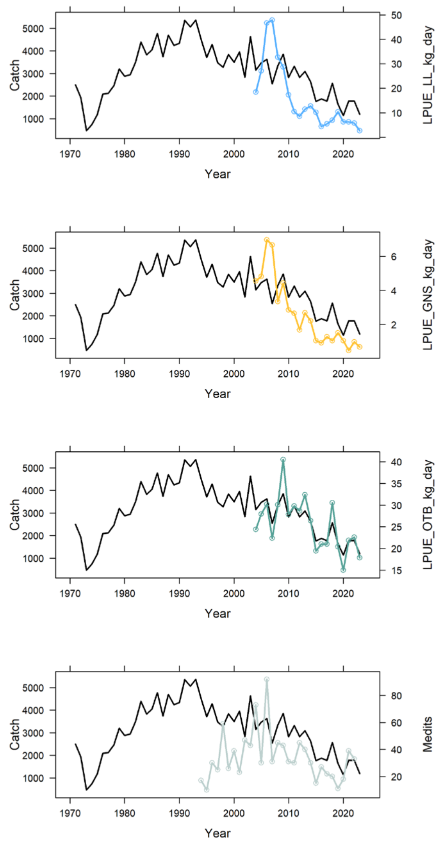


Figure 42. Double axis plot to compare trends between catch (form 1970 1971 to 2023) with nominal CPUE (kg/vessel) for the main fishing gears and Medits biomass index (from 1994 to 2022) for hake in GSA6. GNS: Set gillnet, LLS: Set longline and OTB: Bottom otter trawl.

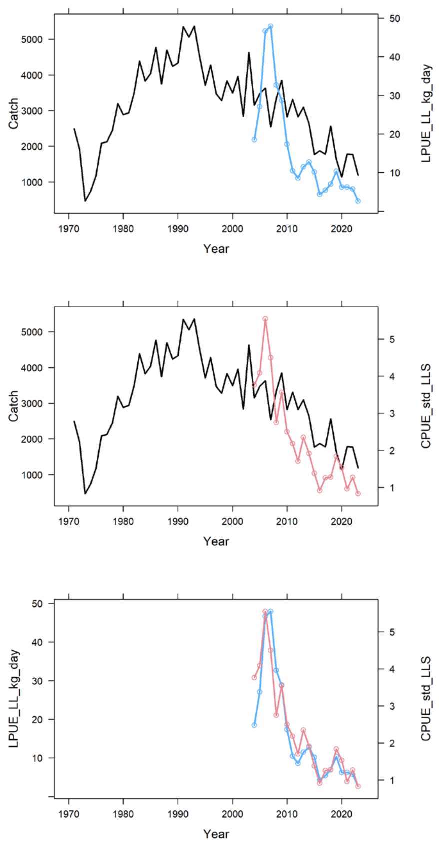


Figure 43. Double axis plot to compare trends between nominal CPUE for LLS and standardized CPUE for LLS. LLS: Set longline.

<u>Scenario 12 CPUE LLS standardized</u>

The input data (Figure 49) consisted of a landings time series from 1971 onwards and a biomass index to tune the model. The biomass index data were derived from CPUE standardized for LLS from 2004 to 2022.

CPUE standardized from 2004 to 2009 and 2023 for LLS data; SE was set to 2, and for 2010 to 2022, it was set to 1. The observation error for CPUE was set to 0.2.

Figure 50 shows a summary for the scenario 12 fit. At the beginning of the time series, the relative biomass was above one, and after 1990, it was below this reference point. For relative fishing mortality, the estimated value has been increasing since the early 1990s. It is important to consider the uncertainty of the estimates.

Finally, Figure 51 compares the three final scenarios selected. It is important to highlight the different perceptions of the stock status depending on the input data.

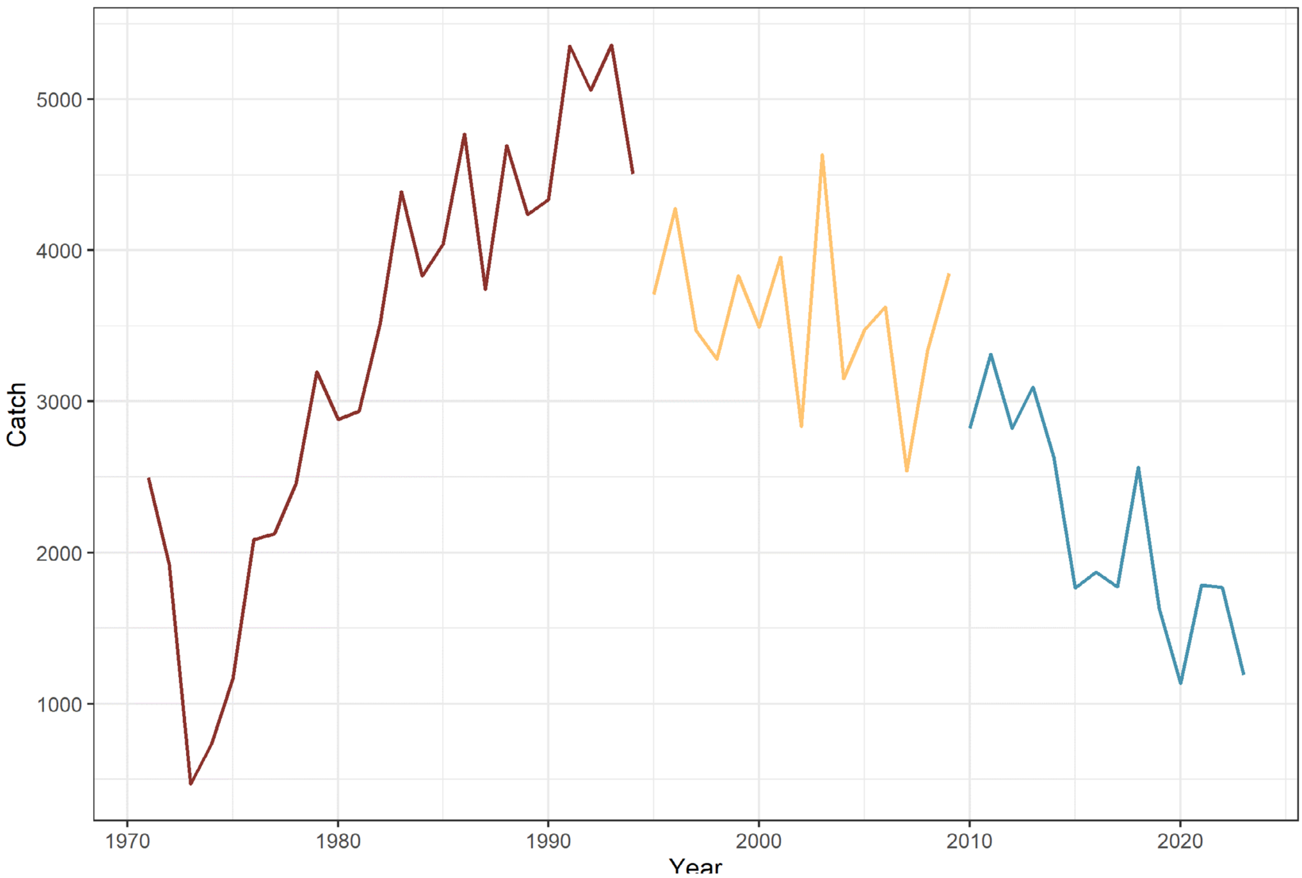


Figure 44. Historical catch from 1971 to 2023 for hake in GSA6. Each colour represents different selectivity periods: 1971-1994: Diamond codend mesh size 35; 1994-2009: Diamond codend mesh size 40; 2010-2023: Square codend mesh size 40 + MRSC>20cm.

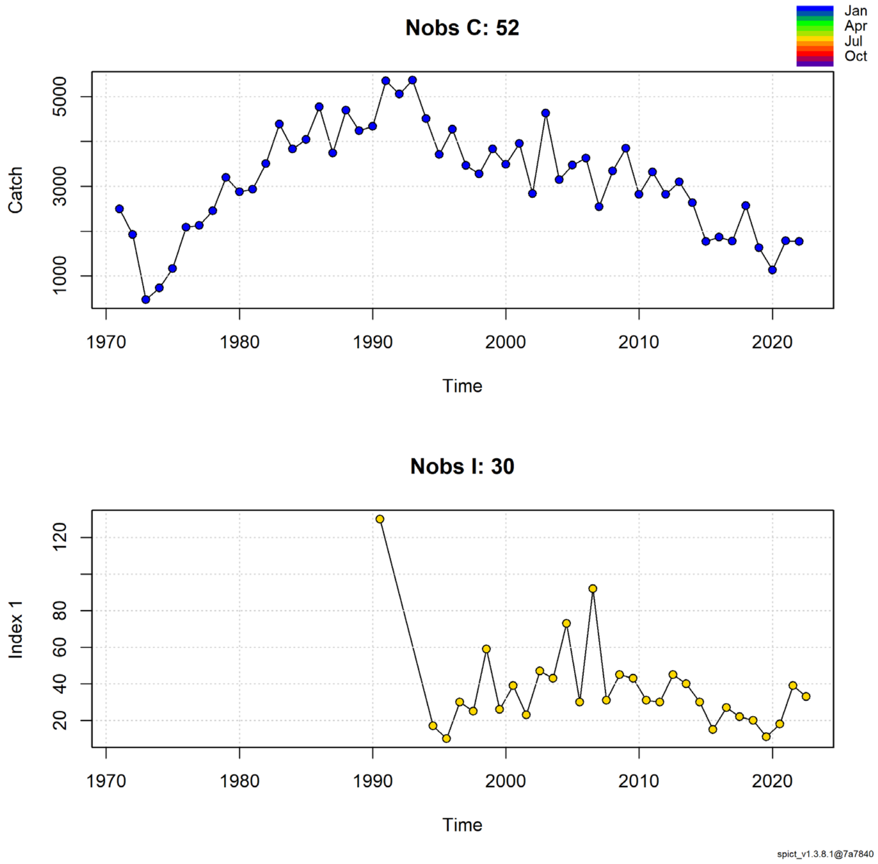


Figure 45. Input data for SPiCT model for hake in GSA6 for scenario 1. Top: catch in tones per year since 1971, bottom: index data of biomass derived from MEDITS since 1994 and 1990 biomass index value (kg/km2) assumed as comparable.

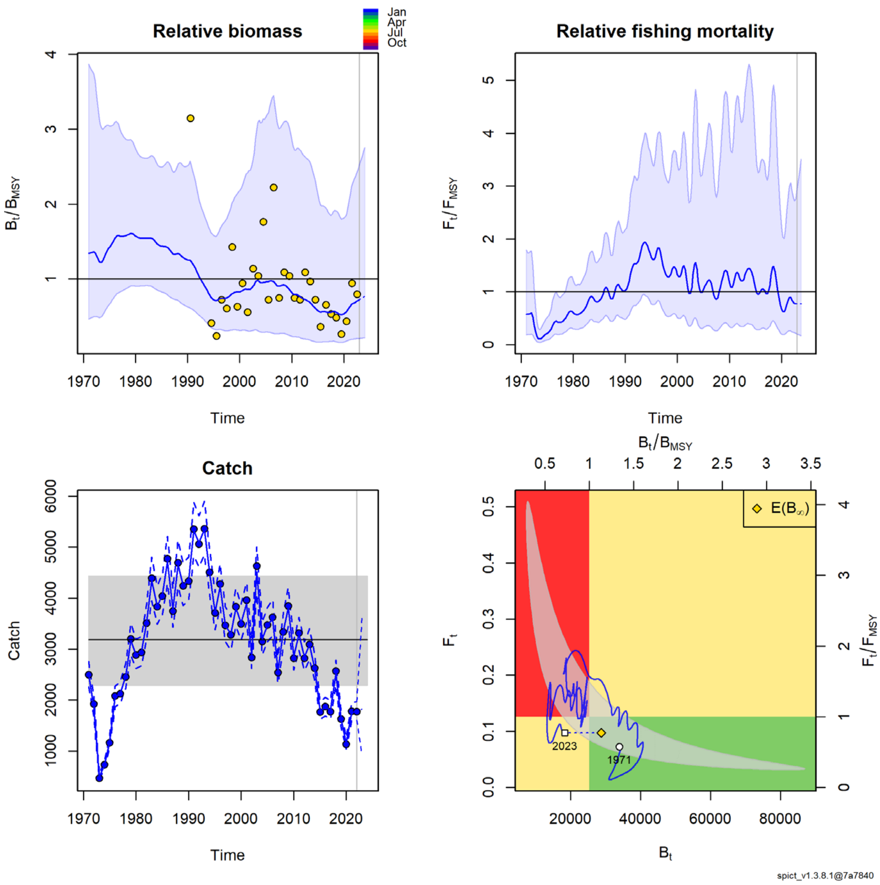


Figure 46. Stock assessment summary for SPiCT model for hake in GSA6 for scenario 1.

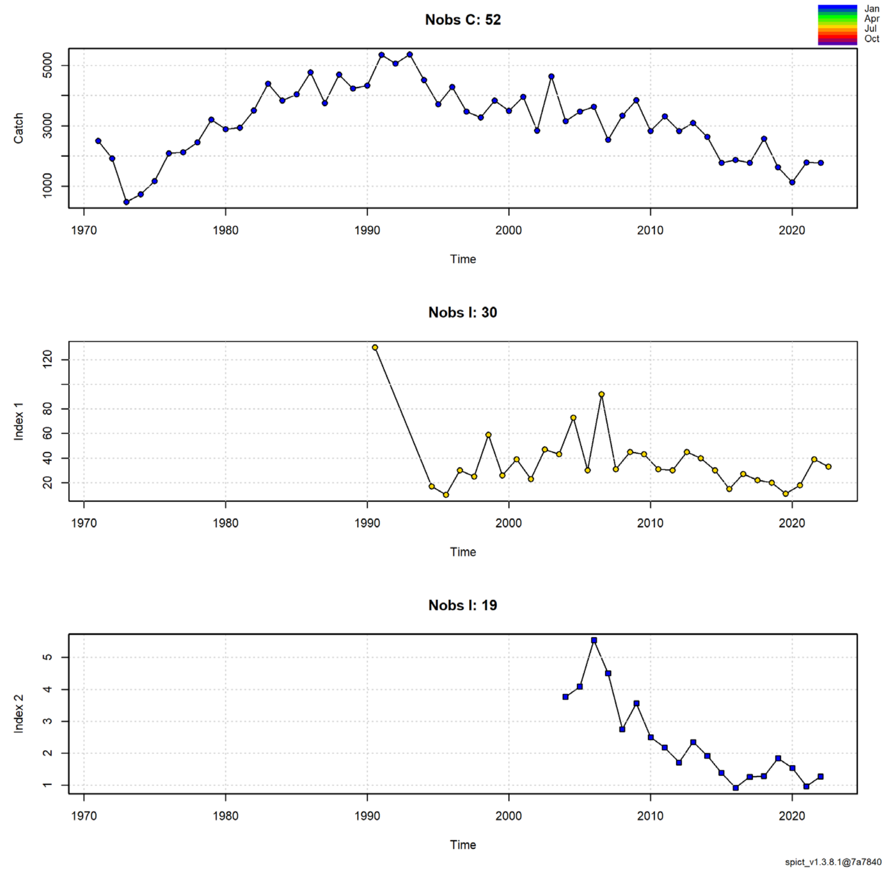


Figure 47. Input data for SPiCT model for hake in GSA6 for scenario 11. Top: catch in tones per year since 1997, center: index data of biomass derived from MEDITS since 1994 and 1990 biomass index value (kg/km2) assumed as comparable, and bottom: standardized CPUE for LLS since 2004. LLS: Long liners.

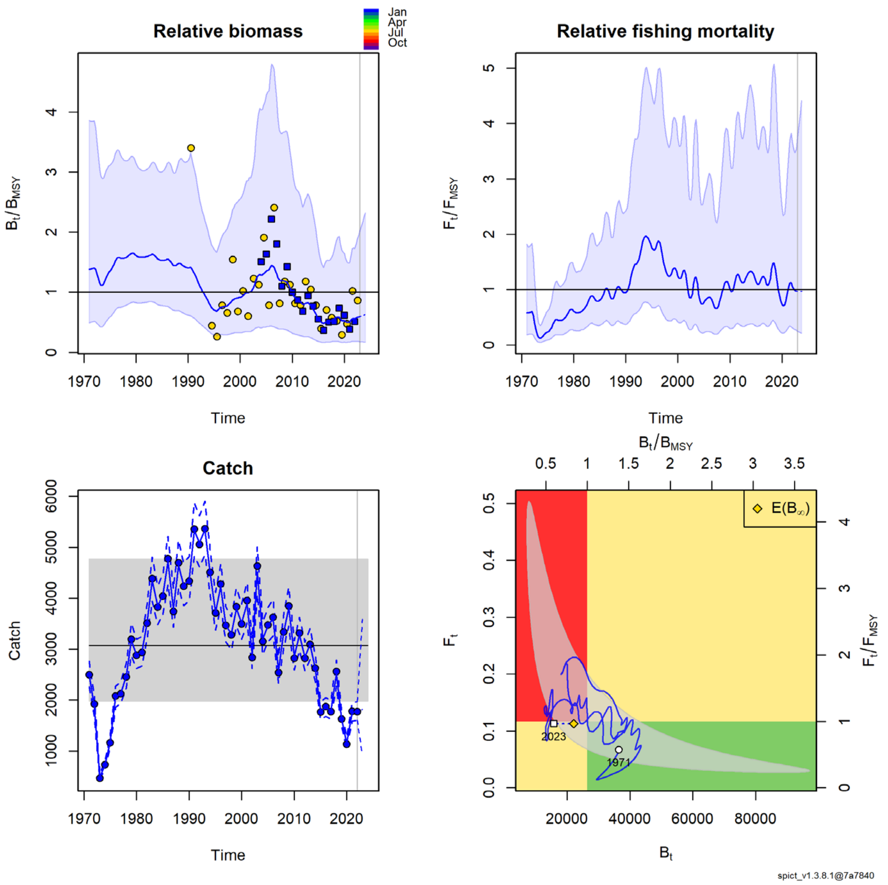


Figure 48. Stock assessment summary for SPiCT model for hake in GSA6 for scenario 11.

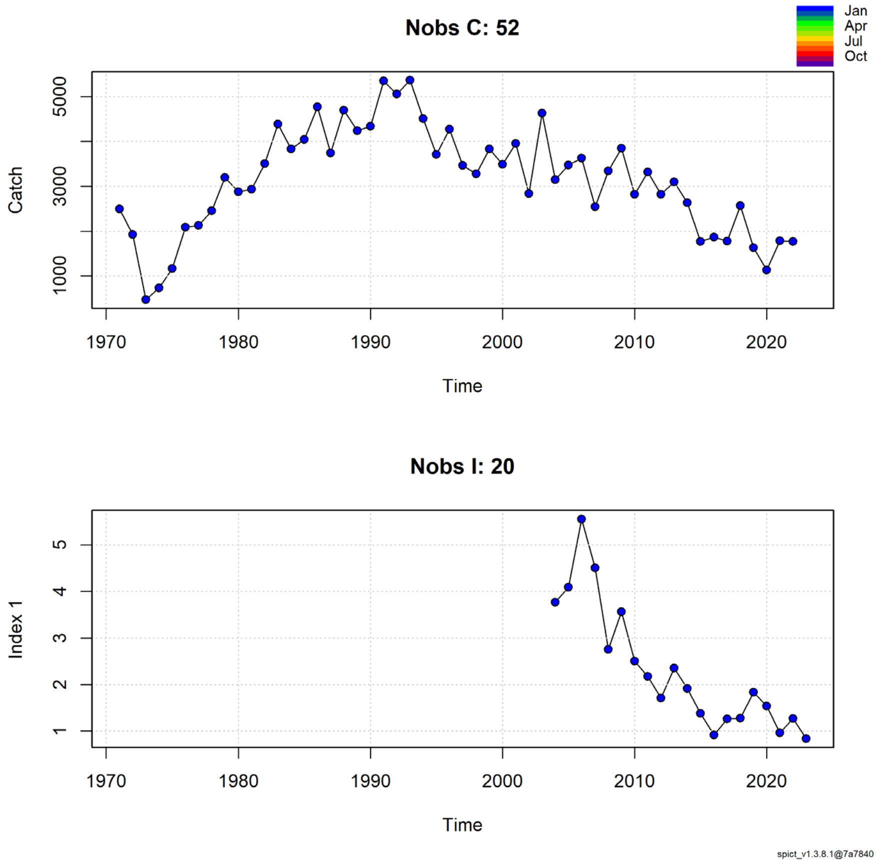


Figure 49. Input data for SPiCT model for hake in GSA6 for scenario 12. Top: catch in tones per year since 1970, bottom standardized CPUE for LLS since 2004. LLS: Long liners.

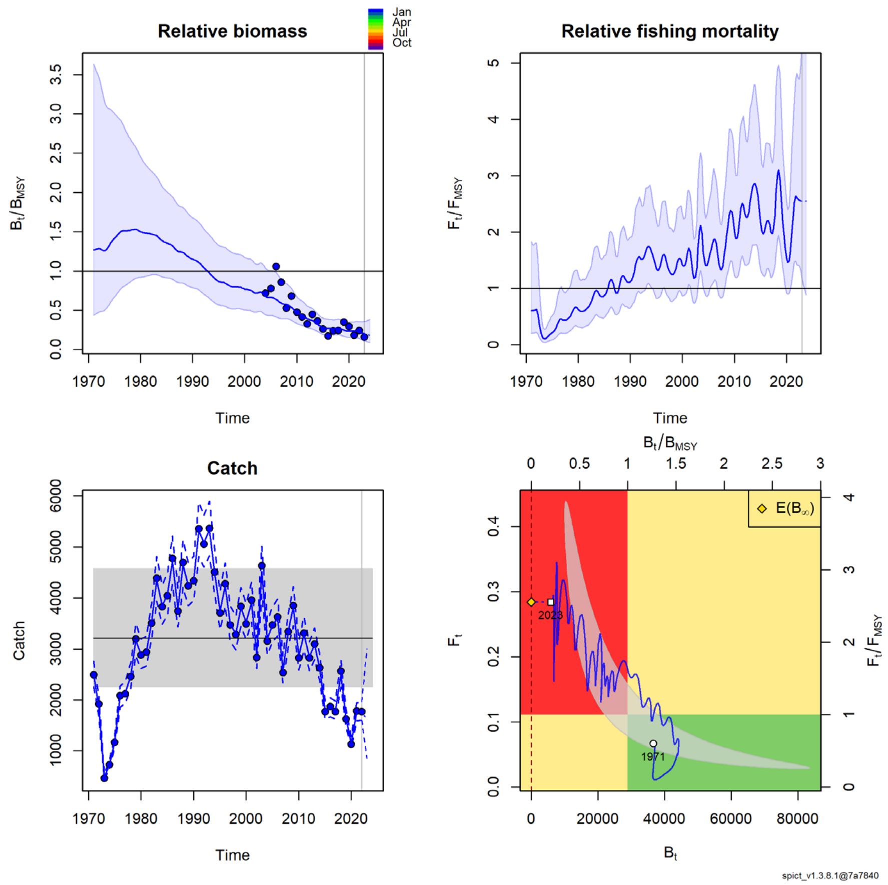


Figure 50. Stock assessment summary for SPiCT model for hake in GSA6 for scenario 12.

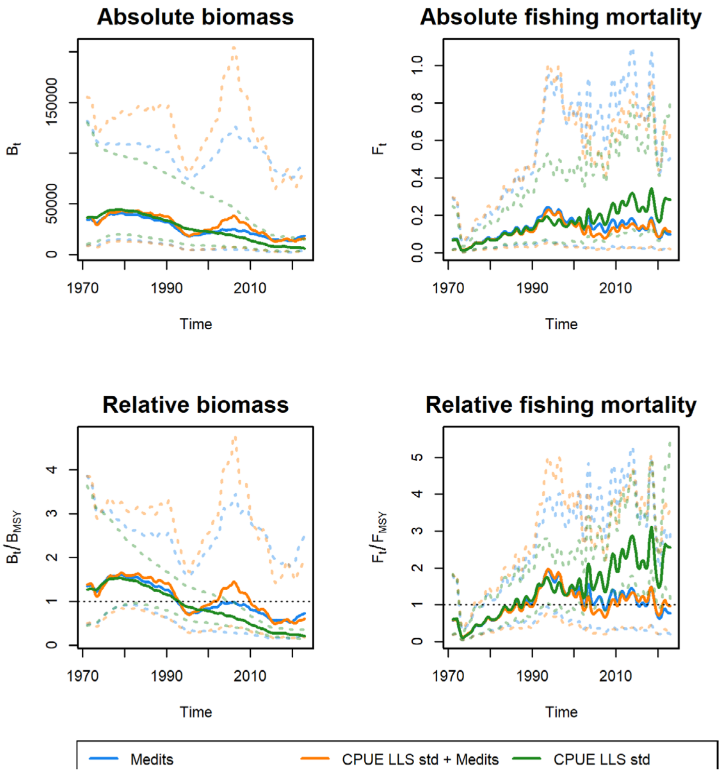


Figure 51. Final scenarios comparison for hake in GSA6.

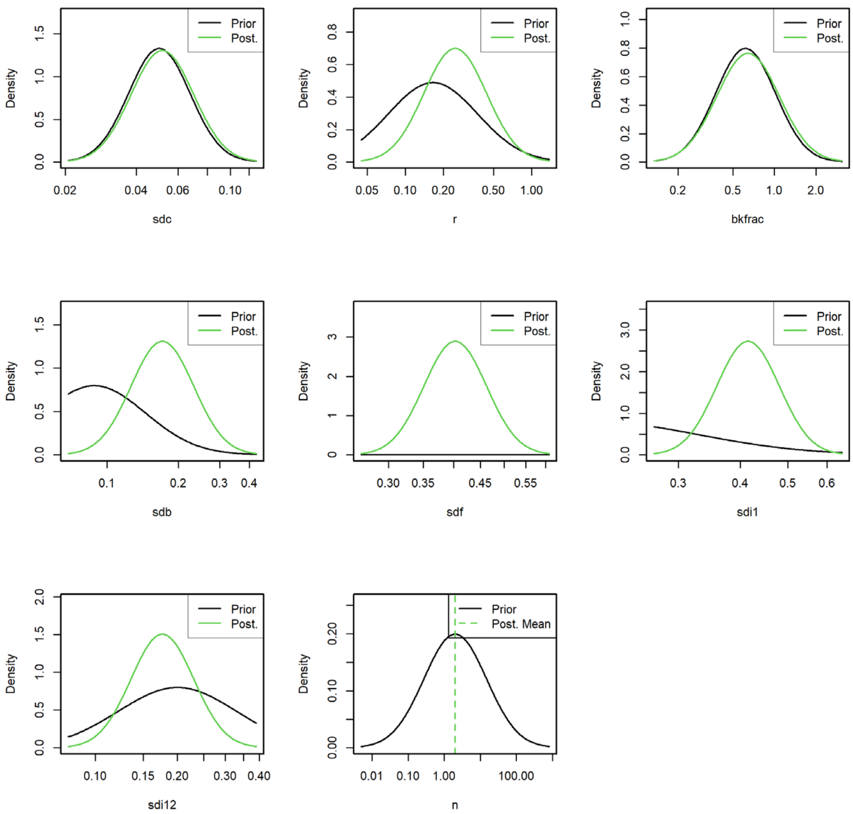


Figure 52. Estimated priors and posteriors for the updated assessment for hake in GSA6 for scenario 11.

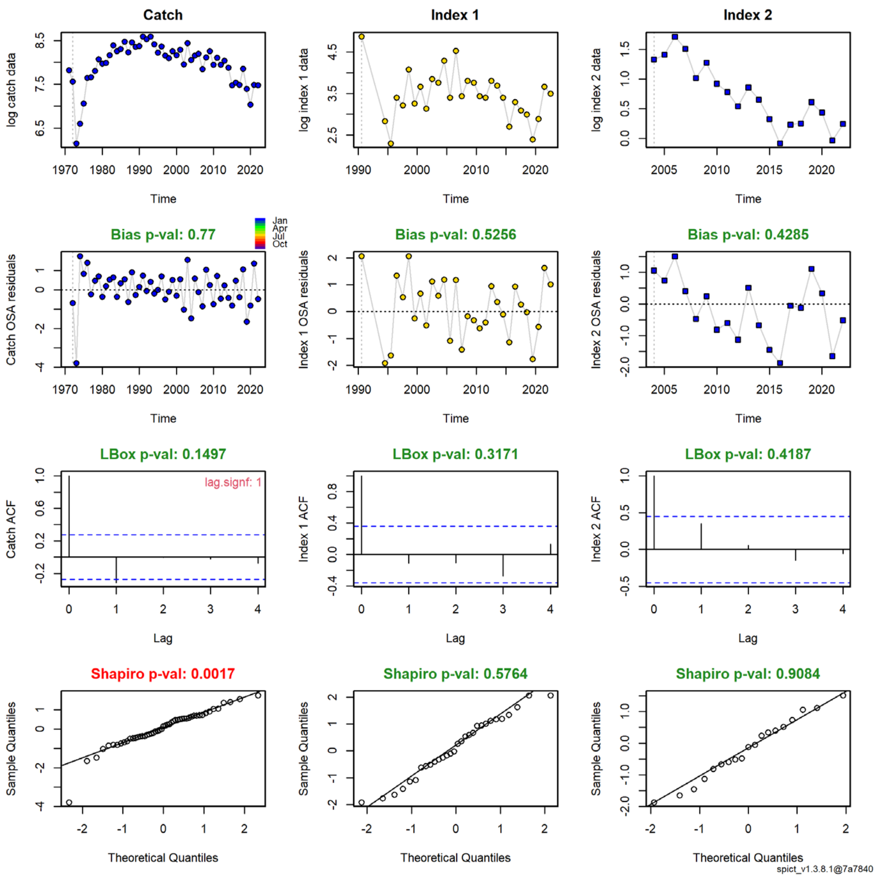


Figure 53. One-step-ahead residuals for the model for hake in GSA6 for scenario 11.

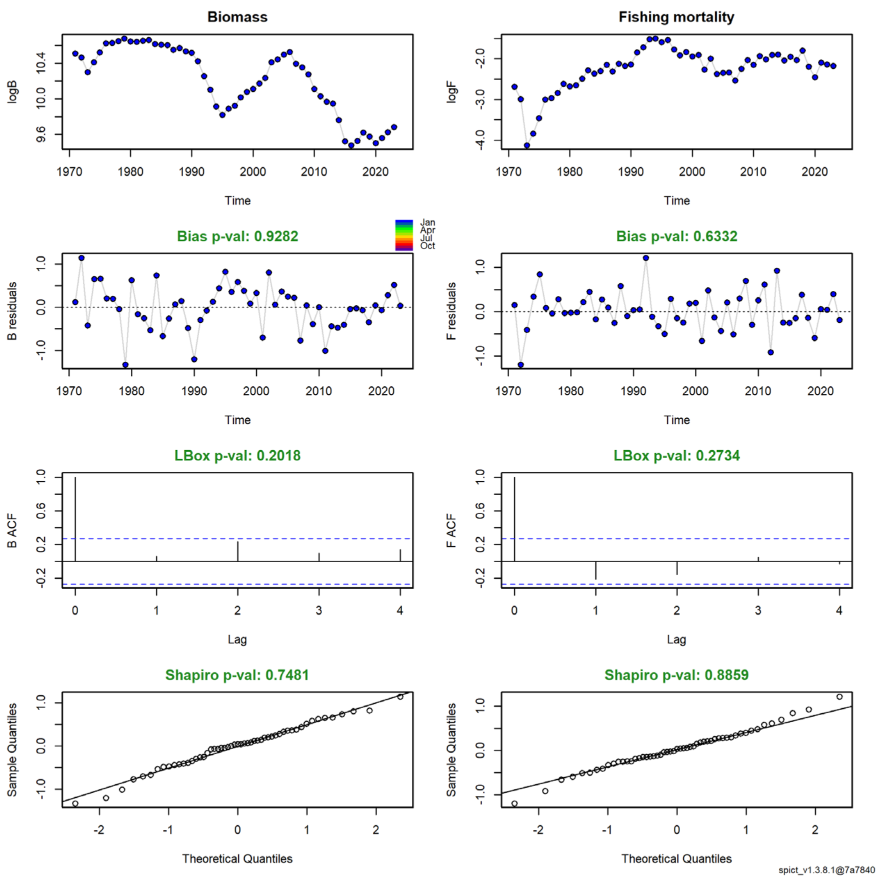


Figure 54. Process error deviations for the model for hake in GSA6 for scenario 11.

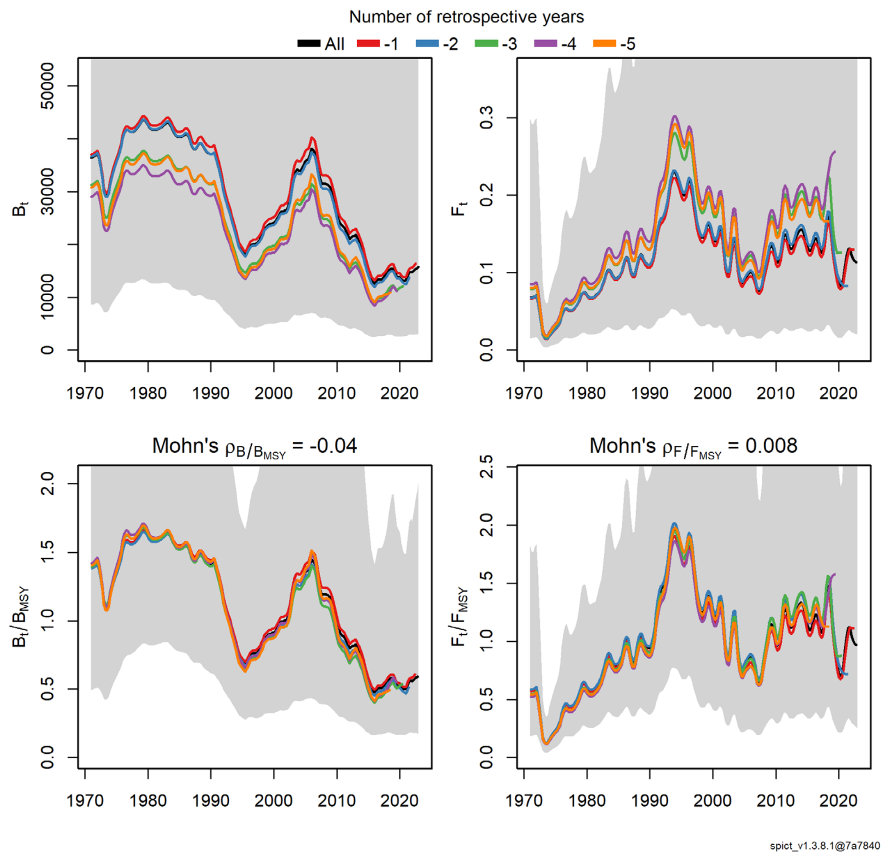


Figure 55. Retrospective analysis for hake in GSA6 for scenario 11.

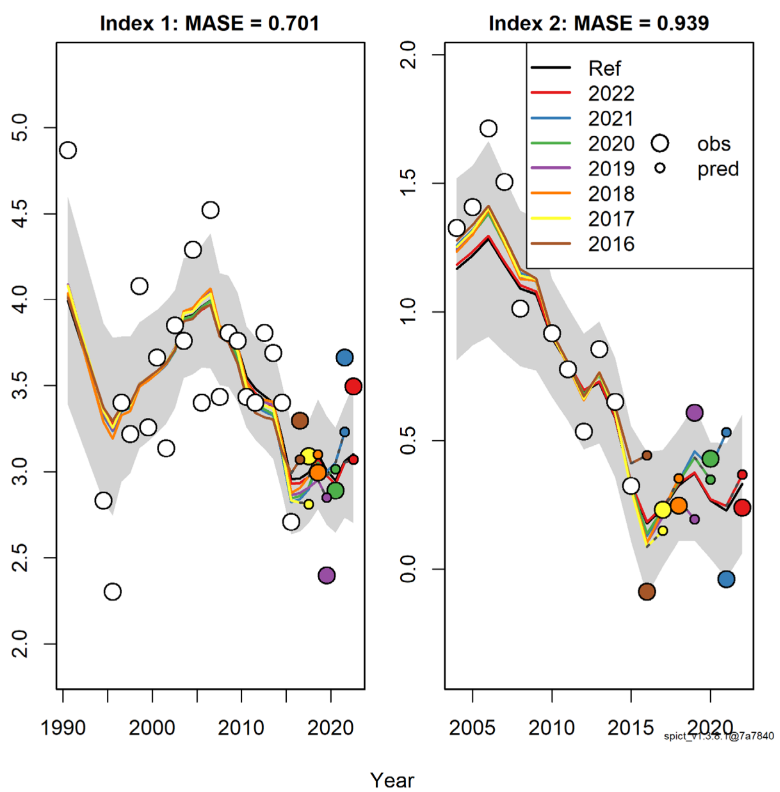


Figure 56. Hindcasting for the model for hake in GSA6 for scenario 11.

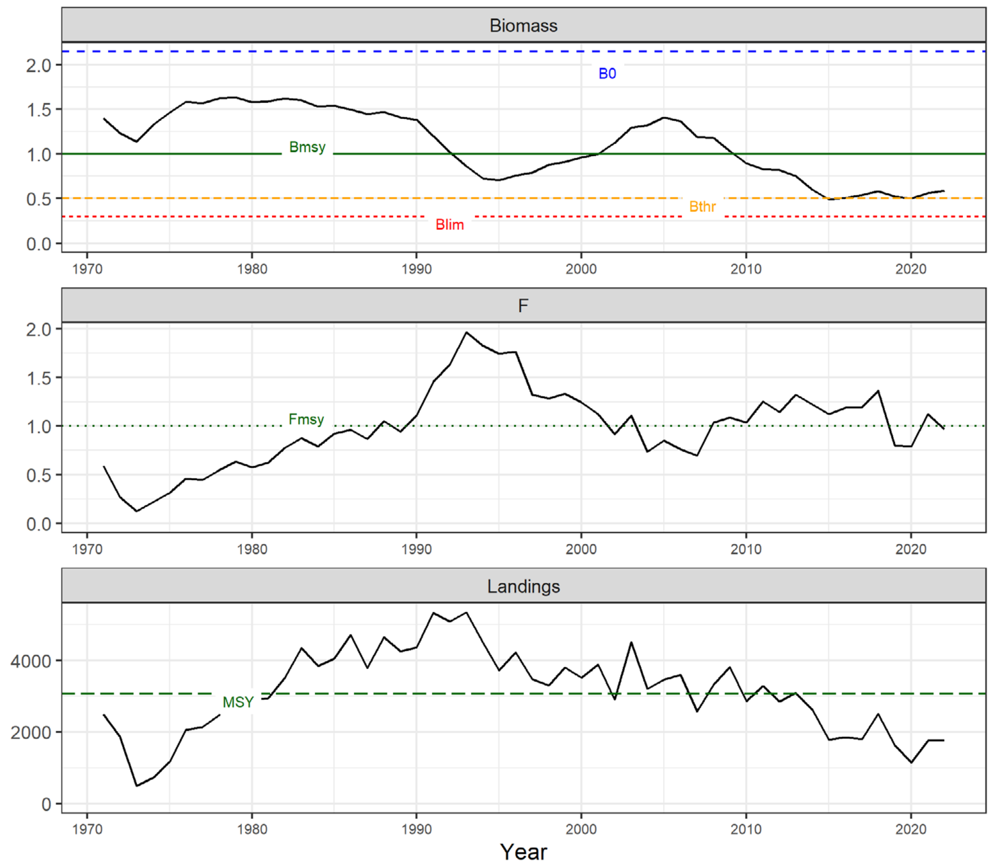


Figure 57. Advice for scenario 1 for hake in GSA6: Historical and current stock status regarding F_{msy}, B_{msy} and B_{lim}.

Table 10. Indicators in 2022 from SPiCT for hake in GSA6.

Species	Year	Catch (t)	FFmsy	BBmsy	BBpa	BBlim
HKE	**2022**	1777.78	0.97	0.59	1.18	1.96

Final scenarios diagnostics

Diagnostics for the final scenario selected (i.e., Scenario 11) are shown below (Figure 52, Figure 53, Figure 54, Figure 55 and Figure 56). In general terms, Scenario 11 was the one with the best diagnostics and also considers both the smaller and medium individuals (i.e., MEDITS) but also the biggest individuals (i.e., CPUE LLS Standardized). In detail, the chosen scenario met most of the model diagnostics and provided good retrospective analysis and hindcasting diagnostics.

For scenario 1 (Annex 15, Annex 16, Annex 17, Annex 18 and Annex 19) and scenario 12 (Annex 20, Annex 21, Annex 22, Annex 23 and Annex 24), all the diagnostics can be found in the annexes.

Also, a sensitivity analysis for scenario 11 was performed, testing r prior (Annex 25), bkfrac (Annex 26), process error (Annex 27), and observation error (Annex 28) to see how robust the model is within these priors.

Final scenarios advice

Figure 57 represents the stock assessment for the final scenario (i.e., scenario 11) (advice framework) using MEDITS and CPUE LLS data as biomass index. Table 10 shows indicators in 2022 for scenario 11 for hake in GSA6.

Deep-water rose shrimp (*Parapenaeus longirostris*) DPS

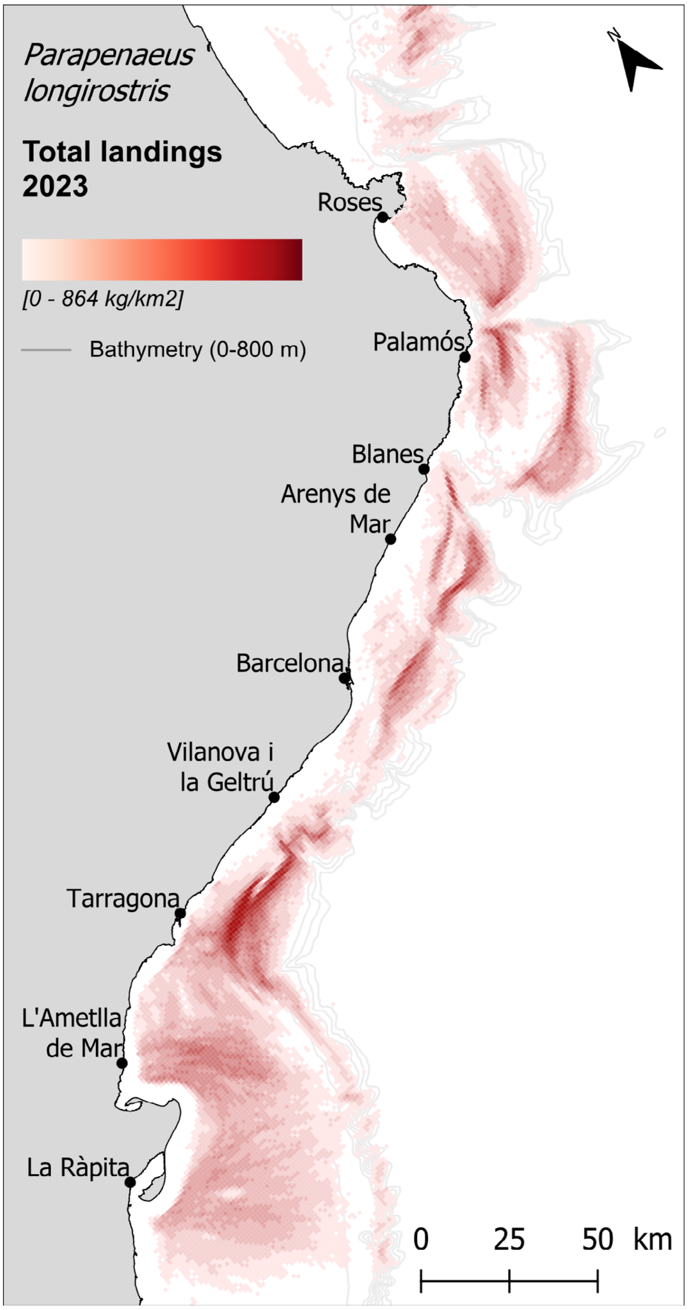


Figure 58. Spatial distribution of landings per unit of effort (LPUE) for deep-water rose shrimp in the Catalan fishing grounds (North GSA6) in the year analysed.

The spawning season for deep-water rose shrimp occurs between January and November, with a peak between April and September (ICATMAR, 23-07); recruitment occurs afterwards.

Input data

The spatial distribution of total landings for deep-water rose shrimp in the Catalan fishing ground is shown in Figure 58. Considering bathymetry, the species has a main distribution in slope areas. However, in terms of total landings per km^2, it is more abundant in the central and northern areas.

Historical deep-water rose shrimp landings in Catalonia from 2002 to 2023 are shown in Figure 59. The species shows a clear increase in landings since 2016, with the highest value in 2021.

Figure 60 shows deep-water rose shrimp landing distribution by métier from 2019 to 2023. The highest landings are obtained with bottom trawlers, specifically for deeper shelf and upper slope *métiers*.

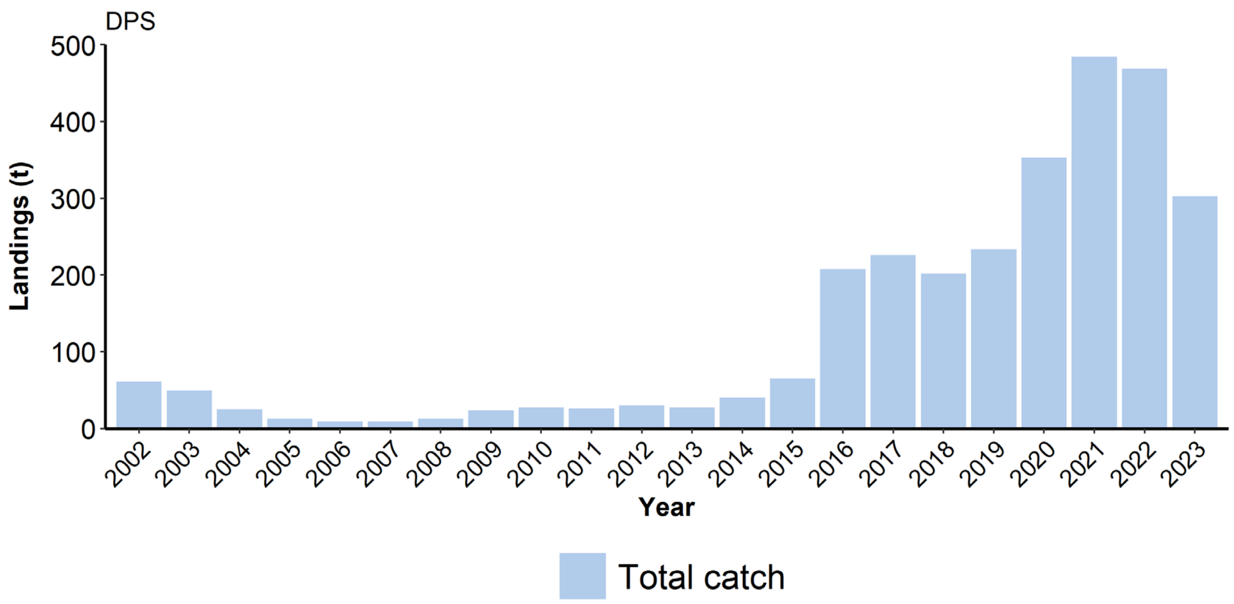


Figure 59. Historical landings (t) for deep-water rose shrimp in Catalonia.

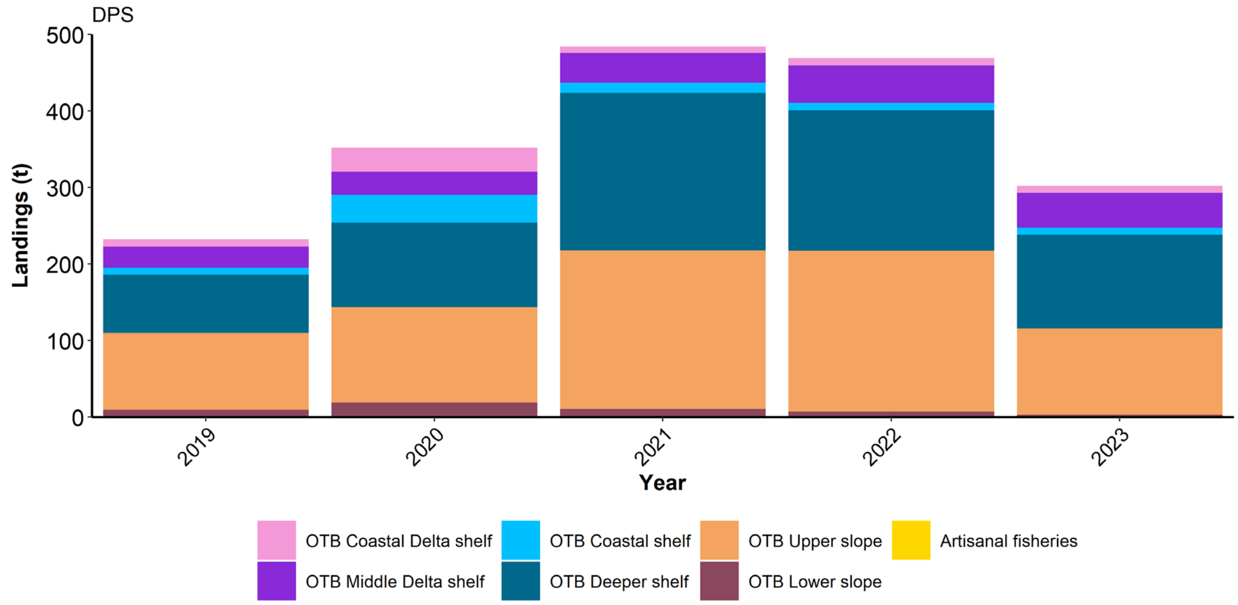


Figure 60. Landings (t) for deep-water rose shrimp by *métier* and fishing gear. OTB: bottom trawling.

Annual LFD

After raising the length frequencies obtained with the monitoring program (Table 11), and considering discards, the annual length frequency of deep-water rose shrimp in Catalonia is plotted in Figure 35. A decrease in small-length classes is observed in 2022. The medium-length classes are more abundant in 2021 and 2022 but are reduced in 2023.

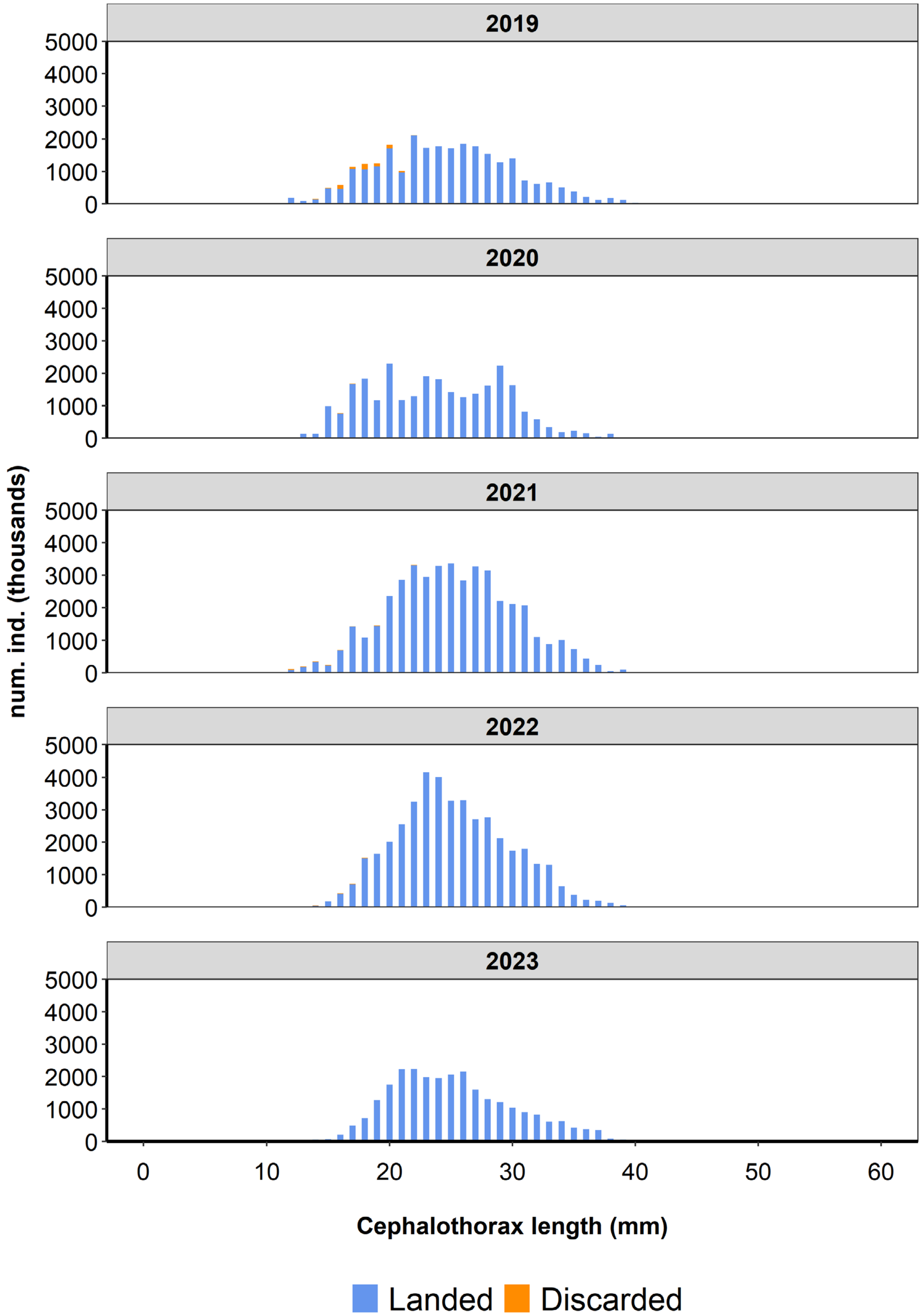


Figure 61. Annual length frequency distributions of deep-water rose shrimp from bottom trawling and small-scale fisheries. The data from bottom trawling is raised from ICATMAR data and details landed and discarded deep-water rose shrimp. The data from small-scale fisheries is obtained from DCF (Data Collection Frame-

Table 11. Number of deep-water rose shrimp individuals sampled by zone and season from ICATMAR monitoring data used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N hauls
			Number individuals sampled				
Bottom trawl	2019	North	206	459	212	328	30
Bottom trawl	2019	Center	204	263	157	553	21
Bottom trawl	2019	South	402	170	285	272	23
Bottom trawl	2020	North	206	236	405	532	24
Bottom trawl	2020	Center	292	308	364	425	23
Bottom trawl	2020	South	368	77	156	340	15
Bottom trawl	2021	North	518	676	818	591	34
Bottom trawl	2021	Center	402	404	387	214	19
Bottom trawl	2021	South	297	41	204	224	16
Bottom trawl	2022	North	397	419	931	983	32
Bottom trawl	2022	Center	311	239	1197	659	19
Bottom trawl	2022	South	186	242	380	753	13
Bottom trawl	2023	North	1245	880	1012	565	25
Bottom trawl	2023	Center	585	369	591	207	18
Bottom trawl	2023	South	895	517	449	311	14

Length-Based Spawning Potential Ratio (LBSPR)

Model setting and results

Scenarios

Three different scenarios were applied for the sensitivity analysis for deep-water rose shrimp (Table 12). Scenarios 1 used growth parameters and natural mortality from STECF whereas scenarios 2 and 3 used GFCM stock assessment data. Scenario 1 used maturity data from GFCM stock assessment but 3 used that from ICATMAR.

Table 12. Biological parameters used in the different LBSPR scenarios for deep-water rose shrimp (DPS). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Species	Scenario	L_{inf} (mm)	M/k	L_{mat50} (mm)	L_{mat95} (mm)
DPS	1	45	1.070	25.6	43.6
DPS	2	44	1.134	25.6	43.6
DPS	3	44	1.134	17.05	29

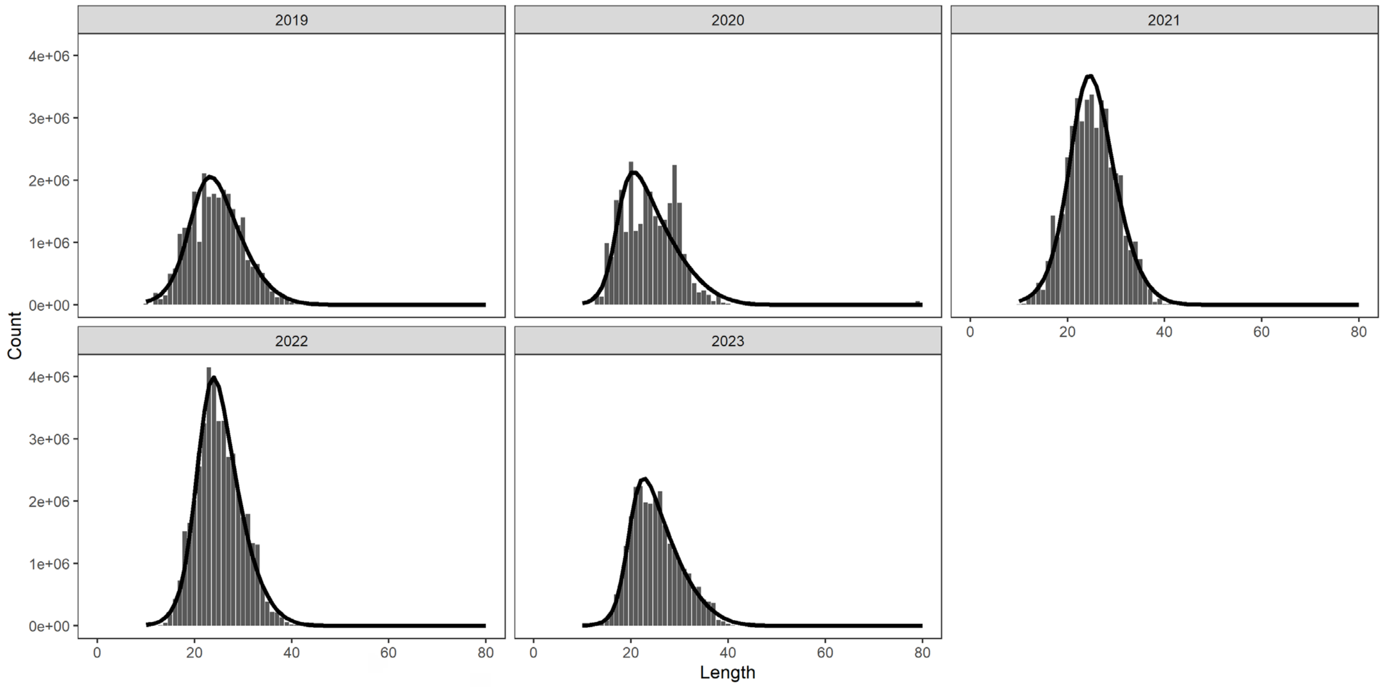


Figure 62. Fit of the data using the LBSPR model for deep-water rose shrimp for each studied year. Grey columns indicate length frequencies. Black lines indicate the fit of the model.

Fitted data

The length frequency distribution fit per year is shown in Figure 62. The model generally follows the mode for all years, except for 2020, when the model does not fit the data properly due to the presence of different pics with no normal distribution of the observed data.

Selectivity

The outputs of the model for the selectivity of the fishery are shown for each scenario in Table 13. The outputs are also plotted together with L_{mat50} and SL_{50} in Figure 63. For the different scenarios, the model outputs reveal that the fishery is fishing below L_{mat50} in scenarios 1 and 2 but it is fishing similar or above L_{mat50} in scenario 3.

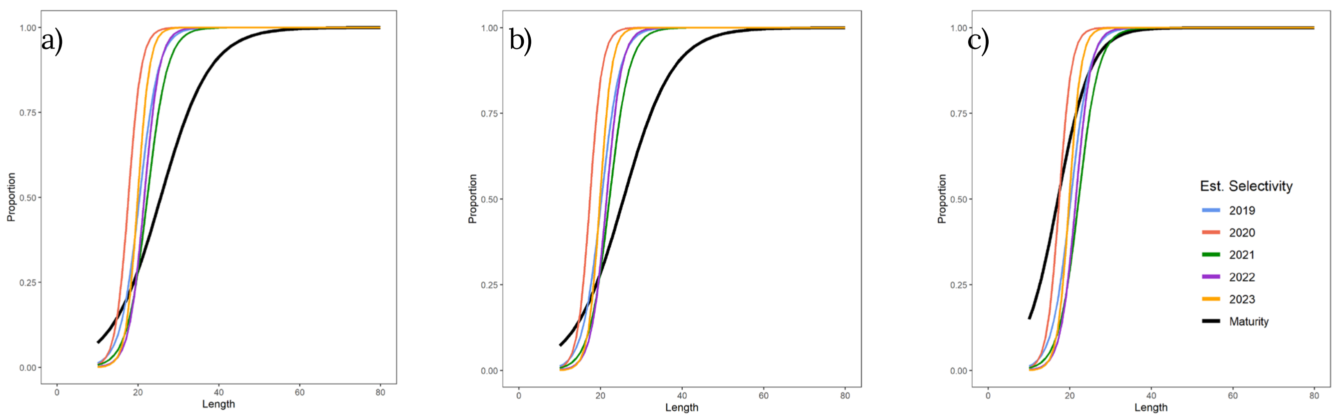


Figure 63. Length curves for deep-water rose shrimp. Black line shows the length curve at maturity. Colour lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (a), scenario 2 (b) and scenario 3 (c).

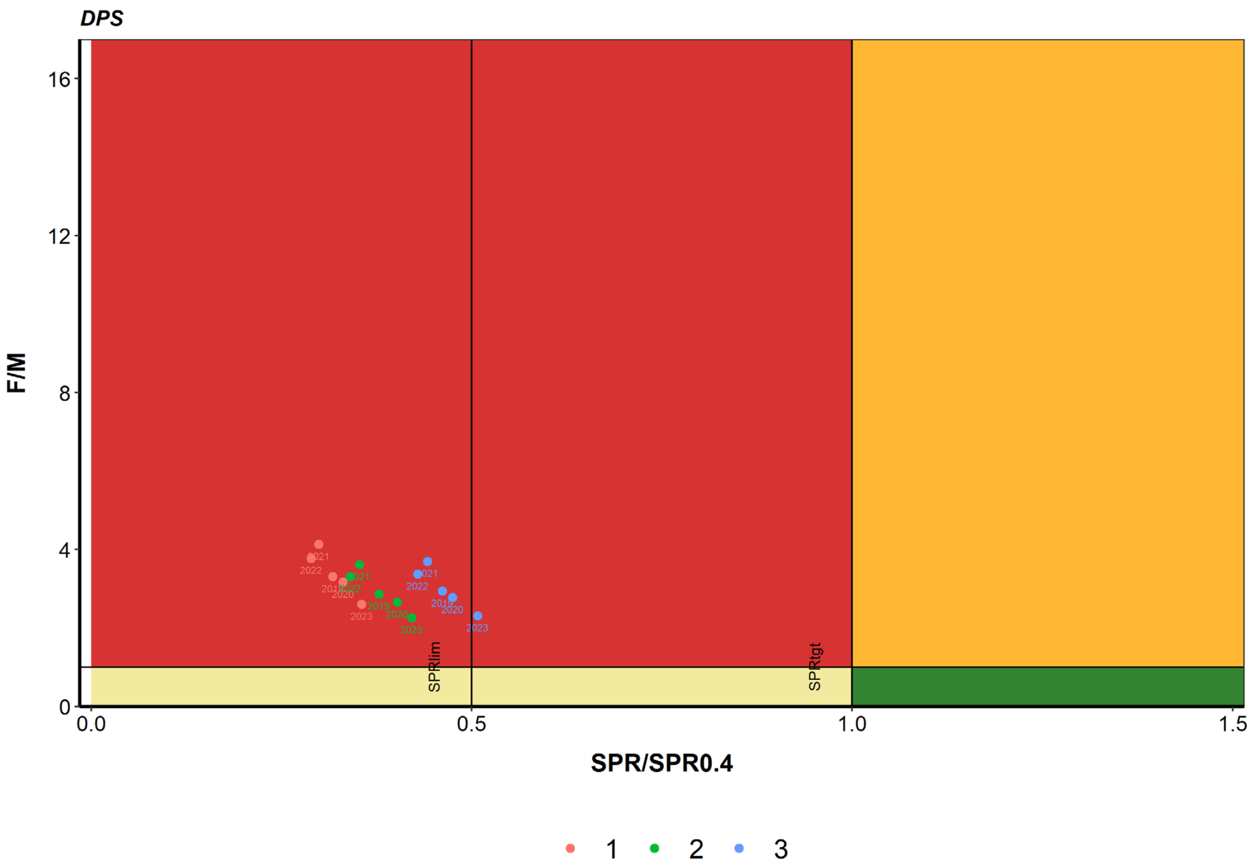


Figure 64. Kobe plot for deep-water rose shrimp by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

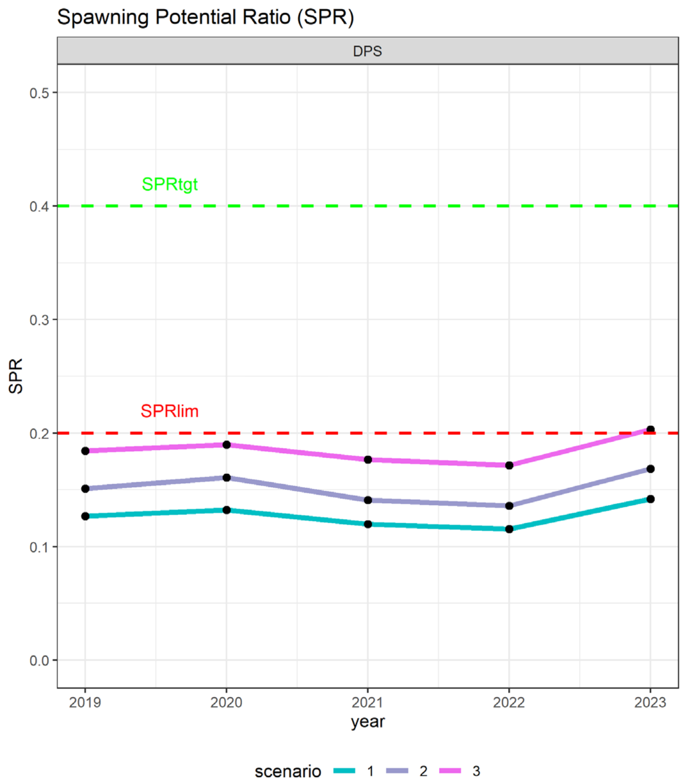


Figure 65. Spawning potential ratio (SPR) per year analysed for deep-water rose shrimp evaluated with LBSPR model. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. Coloured lines show the results for each scenario.

Reference points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is between SPR_{lim} (=0.1) and SPR_{pa} (=0.2) in all the scenarios (Figure 65). The Kobe plot for deep-water rose shrimp (Figure 64) shows the stock status throughout the different years, with a no clear trend. In all cases, the stock status is located in the red zone, meaning that it is overfished and under overfishing.

Table 13. LBSPR model results for deep-water rose shrimp with the different scenarios tested for each year analysed. SL_{50}: Length where 50% of individuals are caught, SPR: spawning potential ratio and FM: fishing mortality. SD is the standard deviation calculated for each indicator.

Species	Scenario	Year	SL_{50}	SD	SPR	SD	FM	SD
DPS	**1**	**2019**	21.46	1.19	0.13	0.10	3.31	1.50
DPS	**1**	**2020**	19.63	2.40	0.13	0.11	3.17	1.95
DPS	**1**	**2021**	23.32	0.99	0.12	0.09	4.13	1.77
DPS	**1**	**2022**	22.19	0.65	0.12	0.08	3.77	1.51
DPS	**1**	**2023**	20.35	0.51	0.14	0.10	2.61	1.08
DPS	**2**	**2019**	21.39	1.18	0.15	0.13	2.87	1.29
DPS	**2**	**2020**	19.36	2.31	0.16	0.14	2.66	1.66
DPS	**2**	**2021**	23.28	0.97	0.14	0.11	3.61	1.52
DPS	**2**	**2022**	22.16	0.63	0.14	0.10	3.31	1.30
DPS	**2**	**2023**	20.32	0.49	0.17	0.13	2.26	0.93
DPS	**3**	**2019**	21.44	1.20	0.18	0.12	2.94	1.33
DPS	**3**	**2020**	19.52	2.39	0.19	0.14	2.78	1.75
DPS	**3**	**2021**	23.32	0.99	0.18	0.11	3.70	1.57
DPS	**3**	**2022**	22.19	0.65	0.17	0.10	3.37	1.34
DPS	**3**	**2023**	20.34	0.51	0.20	0.12	2.31	0.96

Final scenario

As LFD and L_{mat} originated from ICATMAR data, scenario three was selected to provide final advice for the LBSPR model.

Stochastic Production model in Continuous Time (SPiCT)

For deep-water rose shrimp data was taken from EU fleet register provided by the European Commission (Reg. EU 2017/218), GSA6 daily commercial fishing landings provided by the Spanish Ministry of Agriculture, Fisheries and Food, DCF and GFCM Stock Assessment Form (SAF) for DPS in GSA6 RY2022 (Figure 66)

Landings from 2002 to 2022 (Tons)

OTB CPUE from 2002 to 2022 (kg/vessel/day)

Index: MEDITS survey data from 1994 to 2022 (Biomass, kg/km2)

To compare input data, a double axis plot was presented in Figure 67. Both indexes had an increasing trend since 2013. Catches and CPUE follow similar trends, but this is not the case for the MEDITS index. Considering the data available, three scenarios were defined as follows:

Scenario 1: MEDITS + CPUE OTB

Scenario 2: MEDITS

Scenario 3: CPUE OTB

All the final scenarios end in 2022 because no MEDITS data for 2023 was available. Further work will be needed regarding the longest time series and standardized CPUE.

Settings for all final scenarios selected:

Catches from 2002 to 2022.

```
dat$stdevfacC = rep(1,length(dat$obsC))

ce = 0.05

dat$priors$logsdc <- c(log(ce), 0.3, 1)

dat$priors$logr <- c(log(1.4),0.05,1)

bk.pr=c(0.5,0.5,1)

dat$priors$logbkfrac <- c(log(bk.pr[1])-bk.pr[2]^2/2,bk.pr[2],bk.pr[3])

dat$ini$logn <- log(2)

dat$phases$logn <- -1

pe = c(0.1,0.5,1)

dat$priors$logsdb <- c(log(pe[1])-0.5*pe[2]^2, pe[2], pe[3])

fdevs=c(4,0.5,1)

dat$priors$logsdf <- c(log(fdevs[1])-0.5*fdevs[2]^2,

                fdevs[[2]], fdevs[3])

dat$priors$logalpha <- c(0,0,0)

dat$priors$logbeta <- c(0,0,0)

dat$dteuler = ¼
```

Scenario 1 MEDITS + CPUE OTB

The input data (Figure 68) consisted of a landings time series from 2002 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 2002 and since 2009 for CPUE for OTB.

Indices were added considering the specific month each survey was carried out per year. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value 0.3 was set for BK frac. PE= 0.2

The observation error for the MEDITS survey was set SE=0.4 and CPUE: SE = 0.2, and CV = 0.3.

Figure 69 shows a summary of the scenario 1 fit. The relative biomass has been above 1 since 2016, and the estimated fishing mortality has been above 1 since 2019. It is important to consider the estimates uncertainty.

Scenario 2 MEDITS

The input data (Figure 70) consisted of a landings time series from 2002 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 2002.

Indices were added considering the specific month each survey was carried out per year. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value 0.5 was set for BK frac. PE=0.2

The observation error for MEDITS is SE=0.4 with CV = 0.3 for both.

Figure 71 shows a summary of the scenario 2 fit. For the whole time series, the relative biomass was below 1. The estimated fishing mortality has been below 1 since 2020. It is important to consider the estimates' uncertainty.

Scenario 3 CPUE OTB

The input data (Figure 72) consisted of a landings time series from 1996 onwards and a biomass index to tune the model. The biomass index data were derived from CPUE for OTB from 2004.

For this scenario, a final value of 0.3 was set for BK frac.

The observation error for CPUE, SE = 0.3, with CV = 0.3.

Figure 73 shows a summary of the scenario 3 fit. For the whole time series, the relative biomass was below 1. The estimated fishing mortality has been below 1 since 2020. It is important to consider the estimates' uncertainty.

Finally, Figure 74 compares the three final scenarios. It is important to highlight the different perceptions of the stock status depending on the input data.

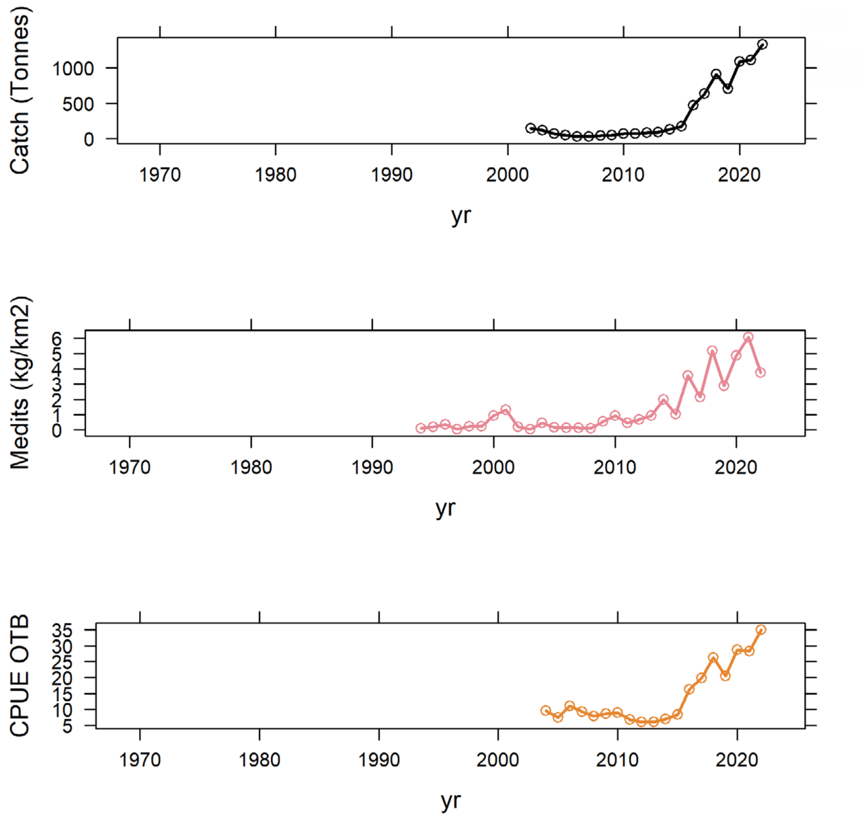


Figure 66. Data available for the assessment for deep-water rose shrimp in GSA6 to run SPiCT model. Top: catch data from 2002 to 2022. Centre: Medits survey data since 1994 to 2022. Bottom: CPUE data since 2009 to 2022.

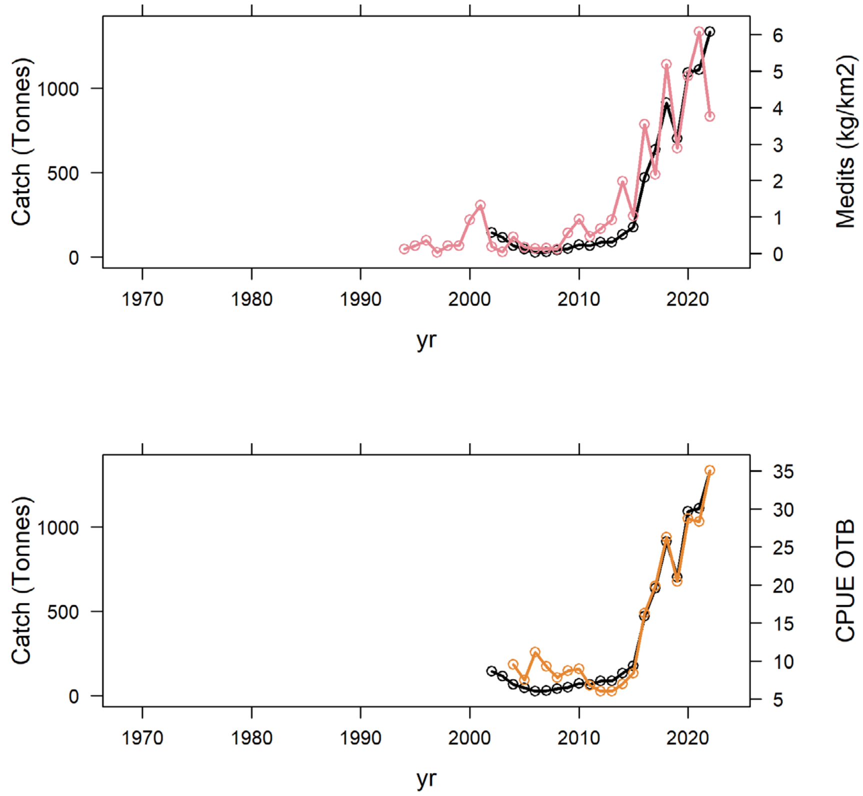


Figure 67. Double axis plot to compare trends between catch and Medits index (top) and catch and CPUE for OTB (bottom) for deep-water rose shrimp.

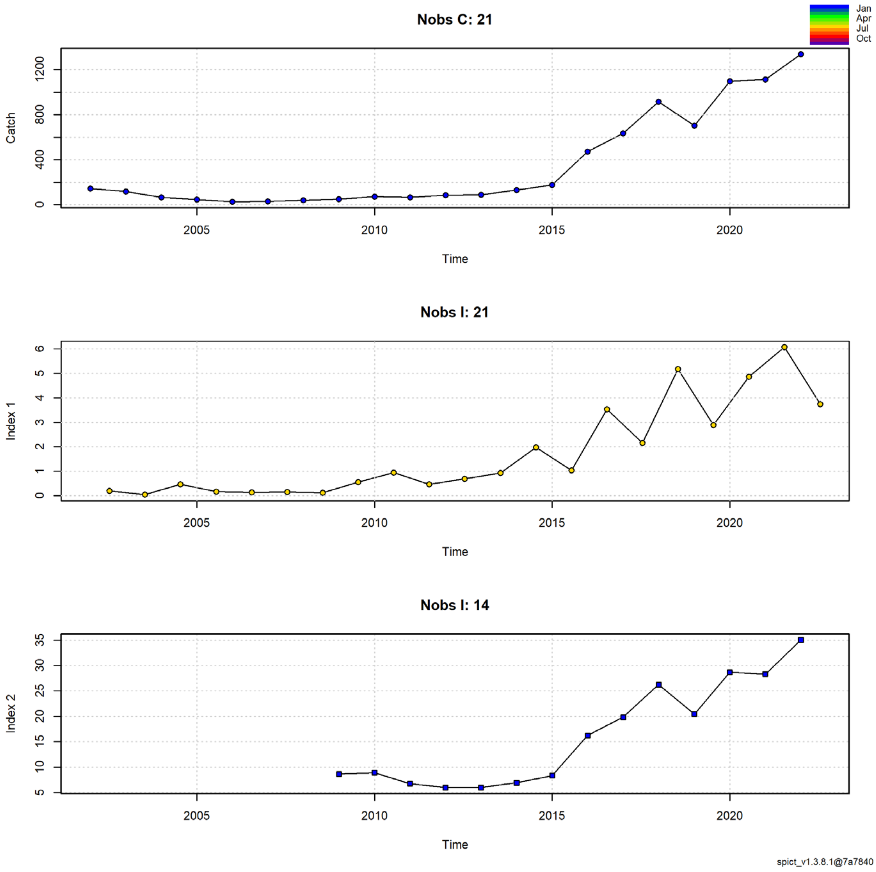


Figure 68. Input data for SPiCT model for deep-water rose shrimp in GSA6 for scenario 1. Top: catch in tones per year since 2002, centre: index data of biomass derived from MEDITS since 2002, and bottom: CPUE data since 2009 to 2022.

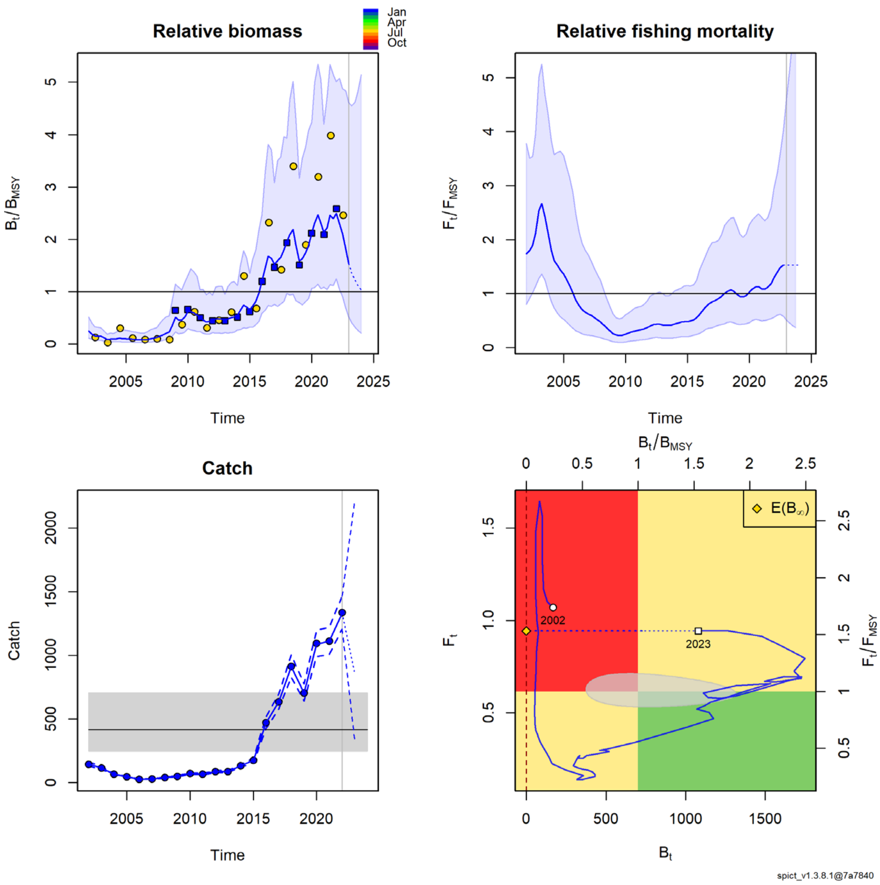


Figure 69. Stock assessment summary for SPiCT model for deep-water rose shrimp in GSA6 for scenario 1.

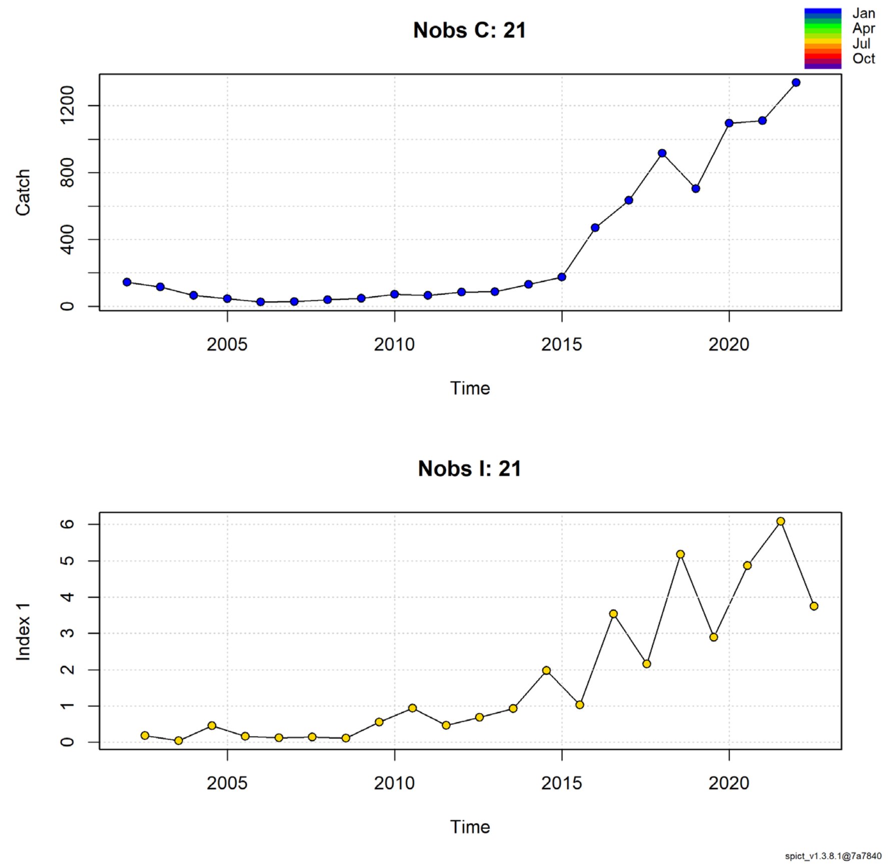


Figure 70. Input data for SPiCT model for deep-water rose shrimp in GSA6 for scenario 2. Top: catch in tones per year since 2002 and bottom: index data of biomass derived from MEDITS since 2002.

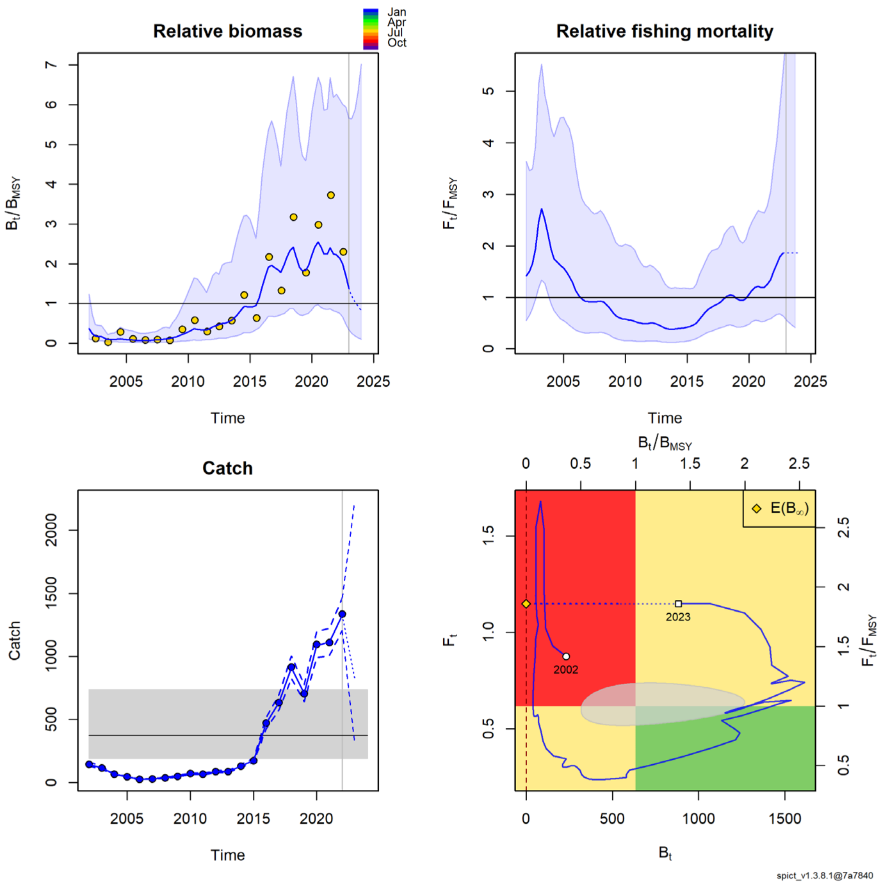


Figure 71. Stock assessment summary for SPiCT model for deep-water rose shrimp in GSA6 for scenario 2.

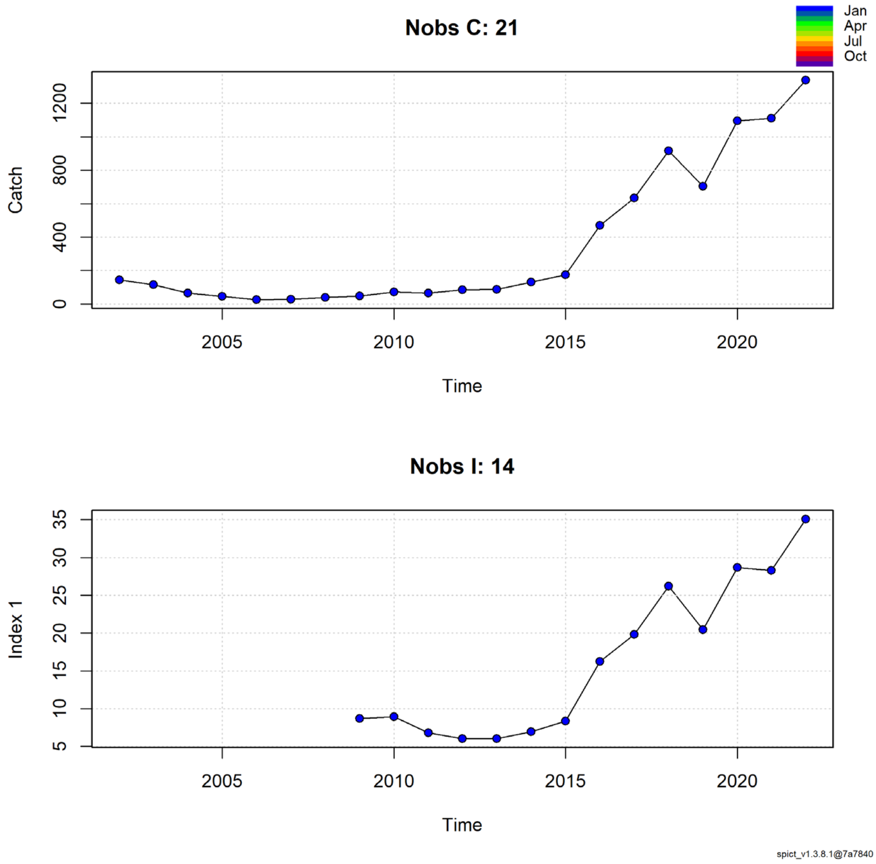


Figure 72. Input data for SPiCT model for deep-water rose shrimp in GSA6 for scenario 3. Top: catch in tones per year since 2002, bottom: CPUE for OTB data since 2009 to 2022.

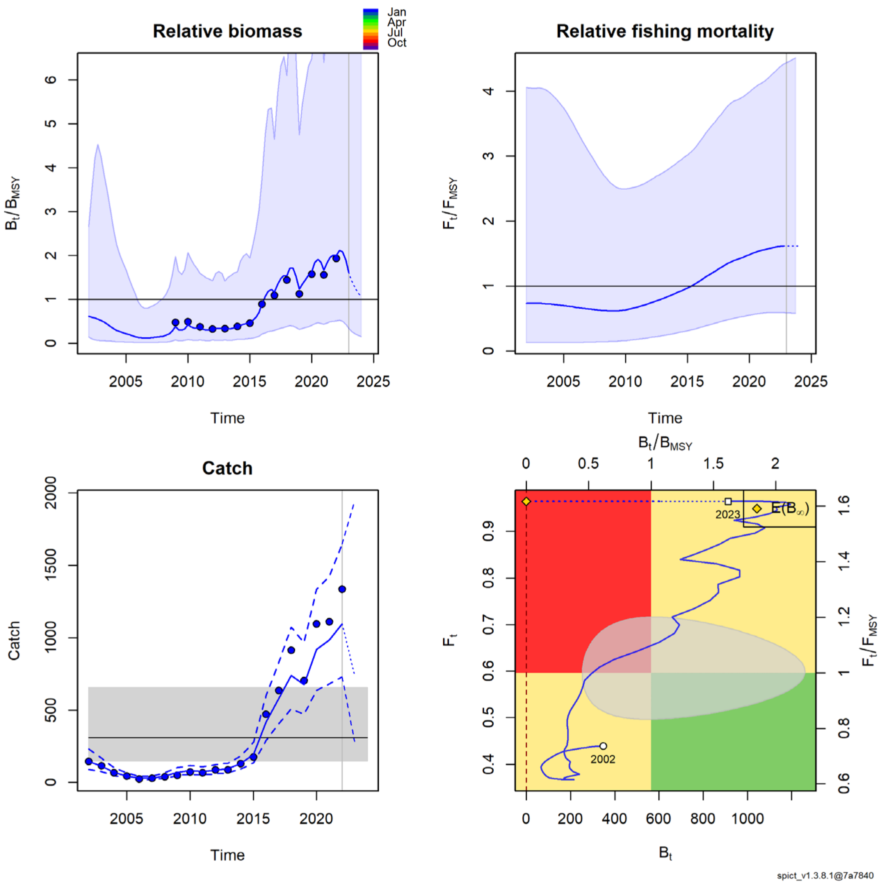


Figure 73. Stock assessment summary for SPiCT model for deep-water rose shrimp in GSA6 for scenario 3.

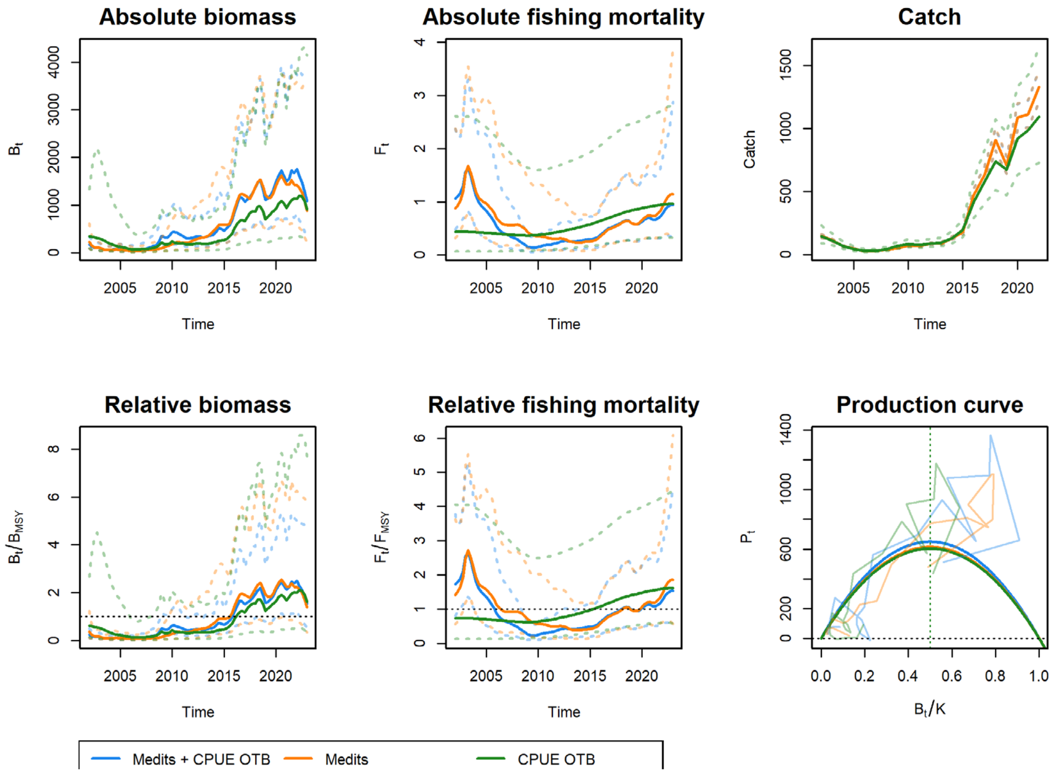


Figure 74. Scenarios comparison for deep-water rose shrimp in GSA6.

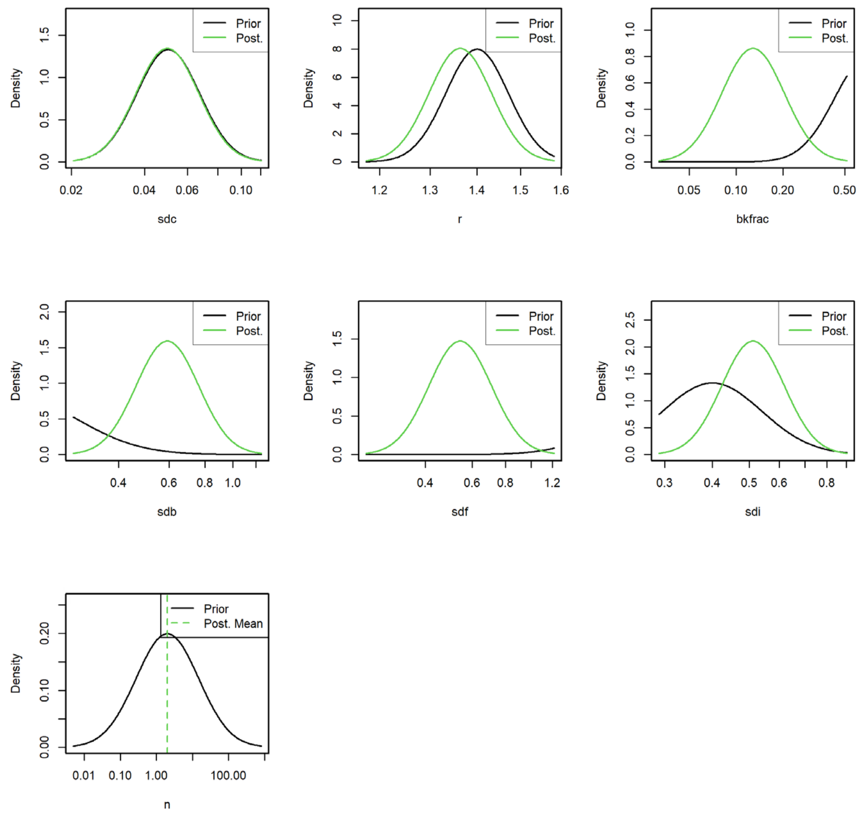


Figure 75. Estimated priors and posteriors for the updated assessment for deep-water rose shrimp in GSA6 for scenario 2.

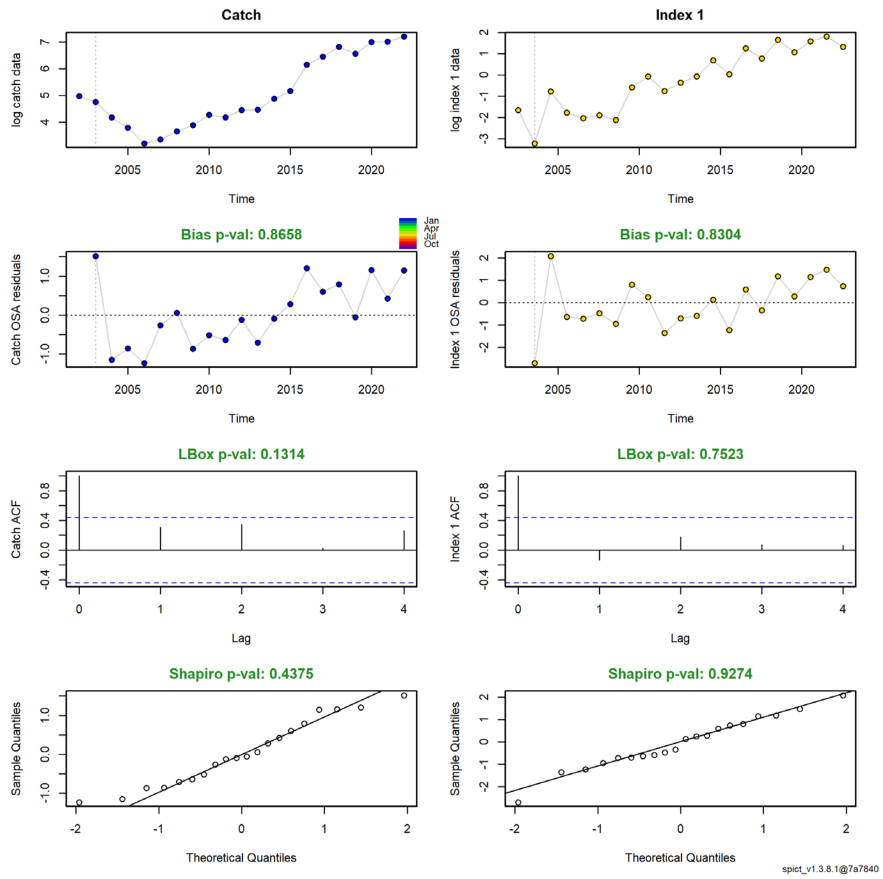


Figure 76. One-step-ahead residuals for the model for deep-water rose shrimp in GSA6 for scenario 2.

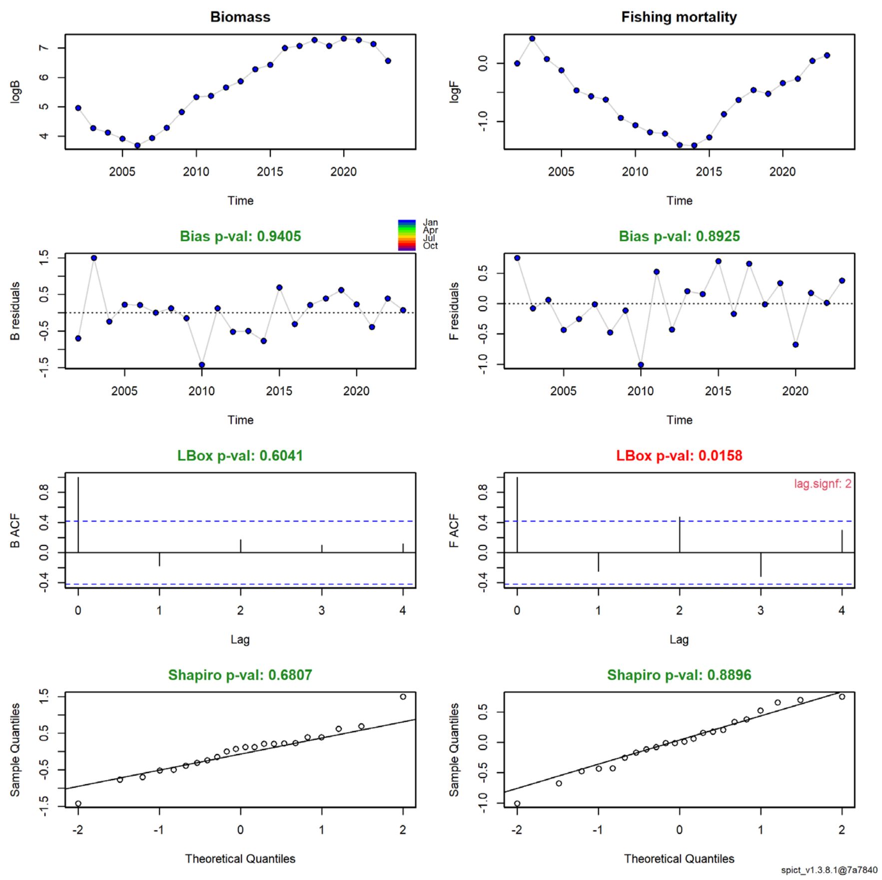


Figure 77. Process error deviations for the model for deep-water rose shrimp in GSA6 for scenario 2.

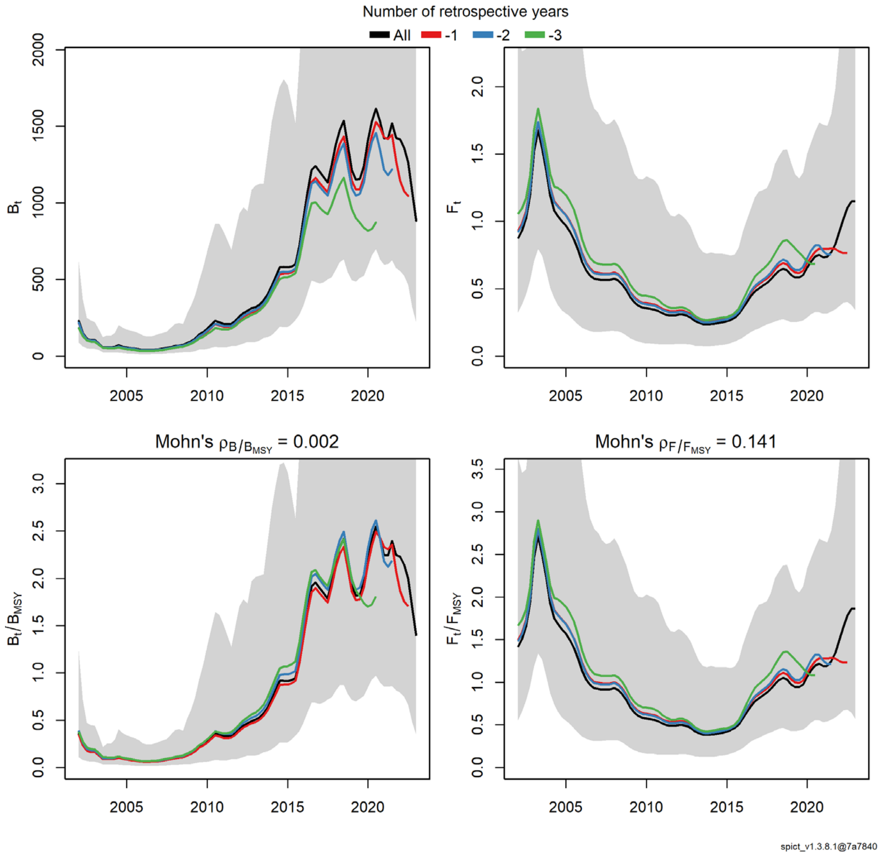


Figure 78. Retrospective analysis for deep-water rose shrimp in GSA6 for scenario 2.

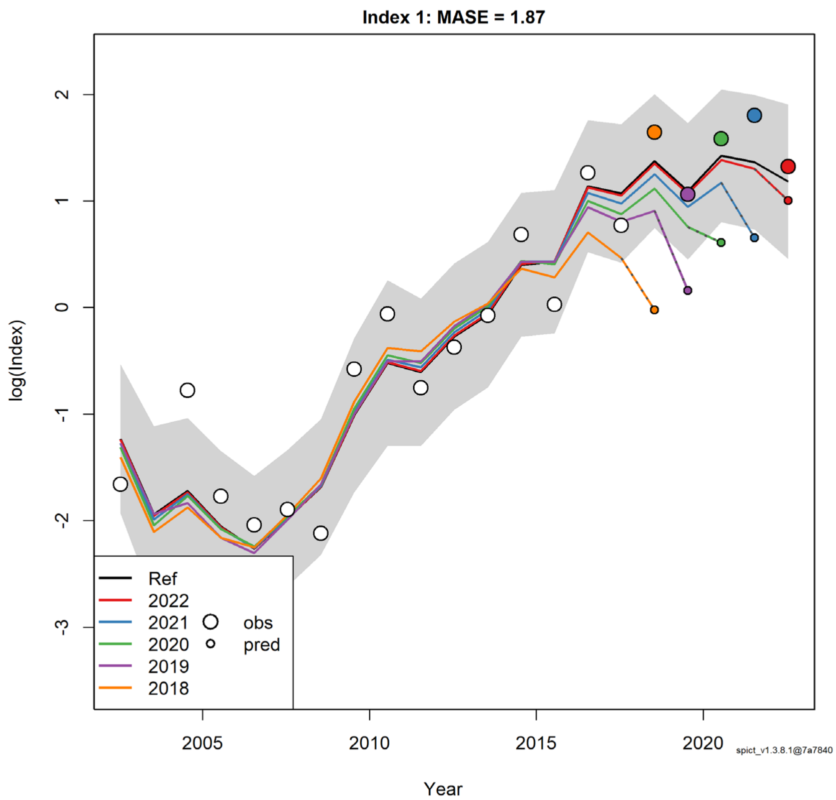


Figure 79. Hindcasting for the model for deep-water rose shrimp in GSA6 for scenario 2.

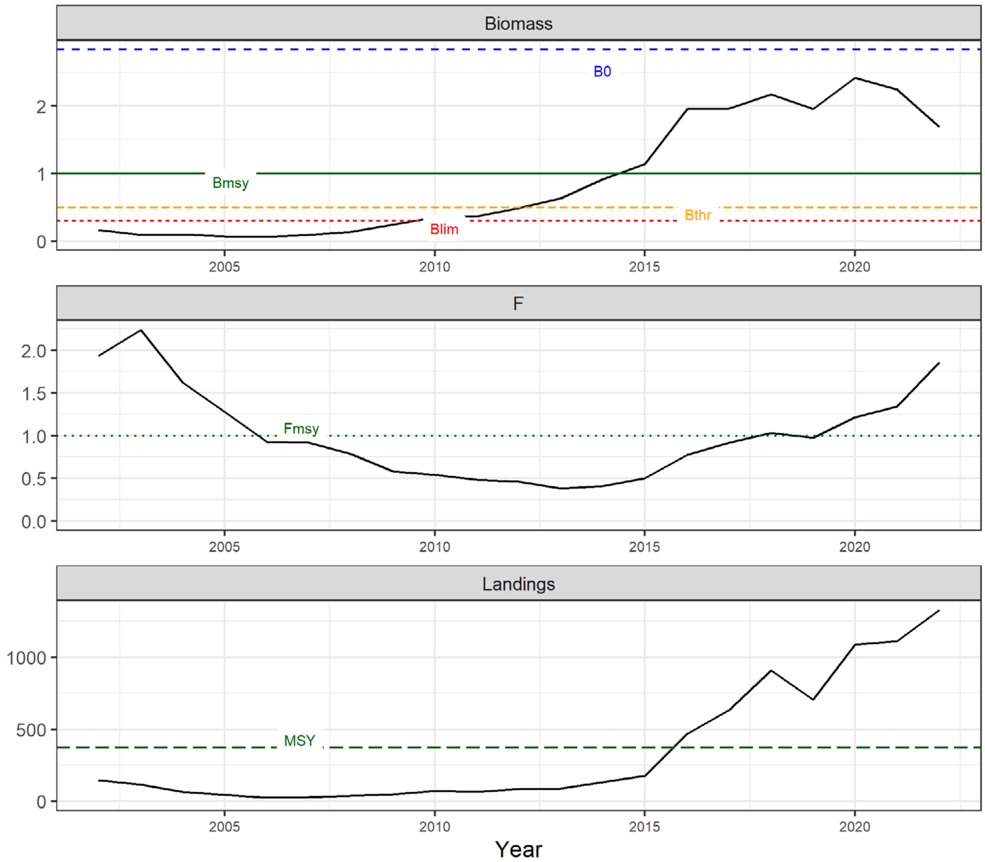


Figure 80. Advice for scenario 2 for deep-water rose shrimp in GSA6: Historical and current stock status regarding F_{msy}, B_{msy} and B_{lim}.

Table 14. Indicators in 2022 from SPiCT for deep-water rose shrimp in GSA6.

Species	Year	Catch (t)	FFmsy	BBmsy	BBpa	BBlim
DPS	**2022**	1328.81	1.86	1.69	3.38	5.63

Scenario 2 was selected as the final one since the CPUE OTB index did not give contrast to the model.

Final scenarios diagnostics

Diagnostics for the final scenario selected (i.e., Scenario 2) were shown below (Figure 75, Figure 76, Figure 77, Figure 78 and Figure 79). The chosen scenario met most of the model diagnostics and provided good retrospective analysis and hindcasting diagnostics.

The annexes contain all the diagnostics for scenario 1 (Annex 29, Annex 30, Annex 31, Annex 32, Annex 33) and scenario 3 (Annex 34, Annex 35, Annex 36, Annex 37, Annex 38).

Also, a sensitivity analysis for scenario 2 was performed, testing r prior (Annex 39), bkfrac (Annex 40), process error (Annex 41), and observation error (Annex 42Annex 14) to see how robust the model is within these priors.

Final scenarios advice

Figure 80 represents the stock assessment for the final scenario (i.e., scenario 2) (advice framework) using MEDITS as a biomass index. Table 14 shows indicators in 2022 for scenario 2 for deep-water rose shrimp in GSA6.

Norway lobster (*Nephrops norvegicus*) NEP

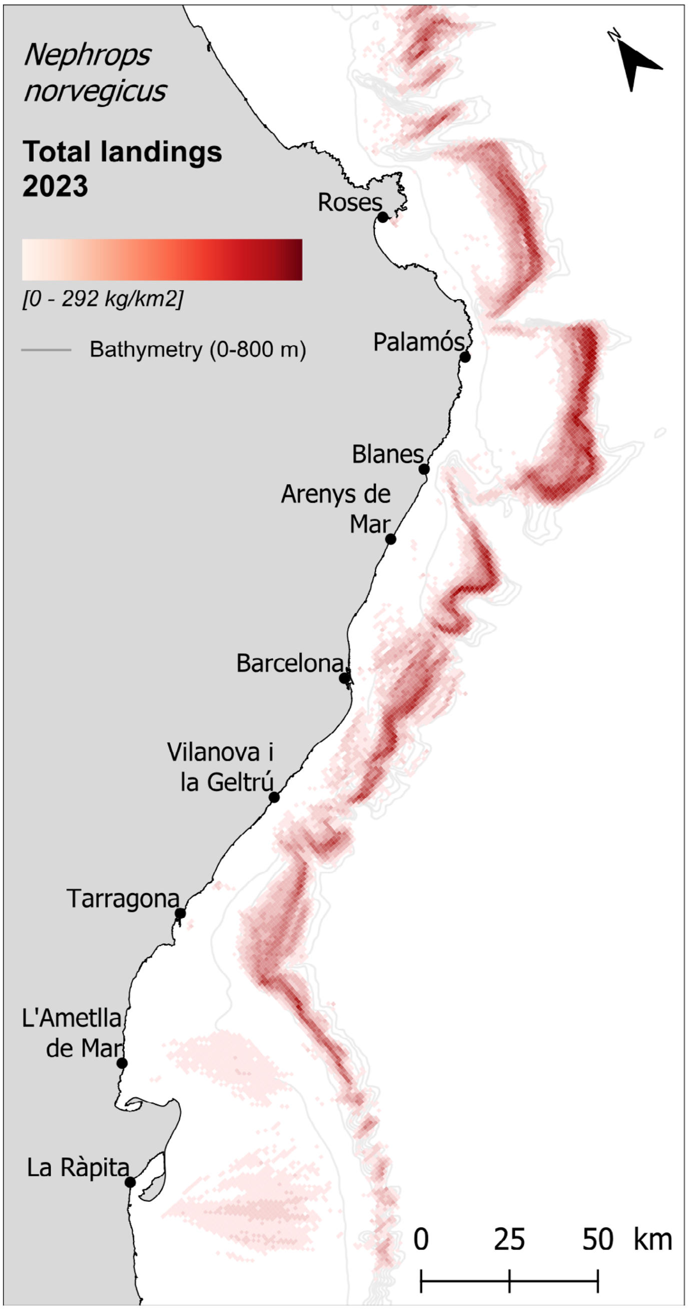


Figure 81. Spatial distribution of landings per unit of effort (LPUE) for Norway lobster in the Catalan fishing grounds (North GSA6) in the year analysed.

The Norway lobster is known to have a dimorphic growth pattern, with males growing slower and reaching larger sizes than females. Reproduction occurs between April and September, and recruitment is observed afterwards, in autumn fall and winter (ICATMAR, 23-07).

Input data

The spatial distribution of total landings for Norway lobster in the Catalan fishing ground is shown in Figure 81. The species is mainly distributed in upper slope areas (300-600 m) along the Catalan coast, with less occurrence in the Delta area (i.e. L'Ametlla de Mar and La Ràpita). Discards of Norway lobster are negligible.

Historical Norway lobster landings in Catalonia from 2002 to 2023 are shown in Figure 82. The species shows a decreasing trend in landings, especially since 2015, with the lowest value recorded in 2021.

Figure 83 shows the Norway lobster landing distribution by *métier* from 2019 to 2023. The highest landings are obtained with bottom trawlers, specifically for upper slope métiers.

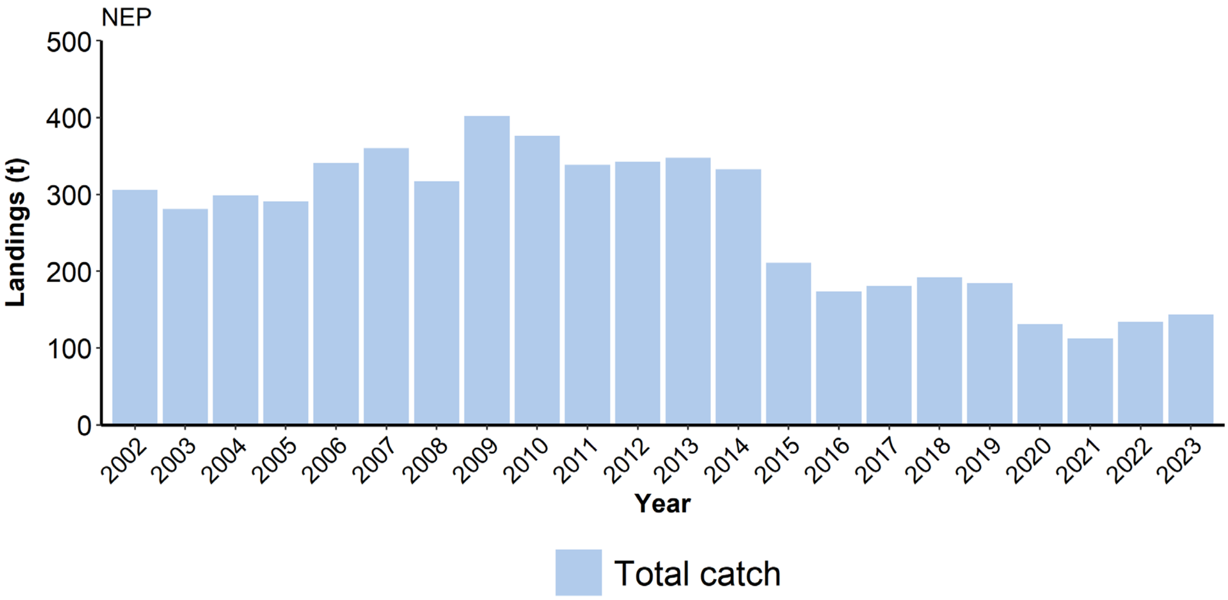


Figure 82. Historical landings (t) for Norway lobster in Catalonia.

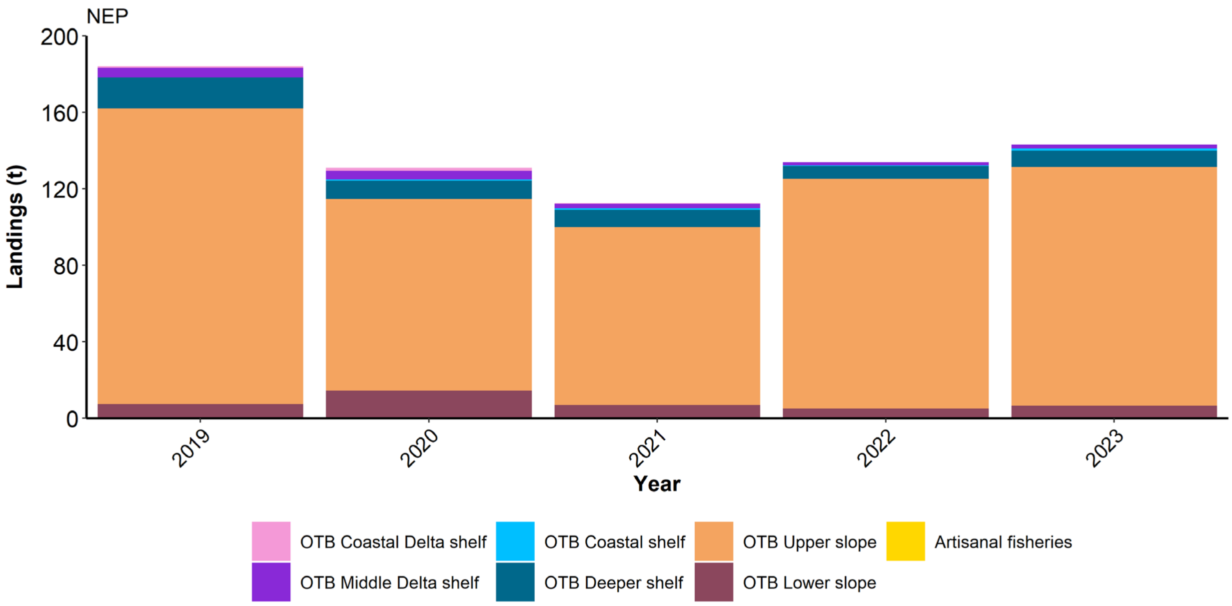


Figure 83. Landings (t) for Norway lobster by *métier* and fishing gear. OTB: bottom trawling.

Annual LFD

After raising the length frequencies obtained with the monitoring program (Table 15), and considering discards, the annual length frequency of Norway lobster in Catalonia is plotted in Figure 84. A decrease in number is observed.

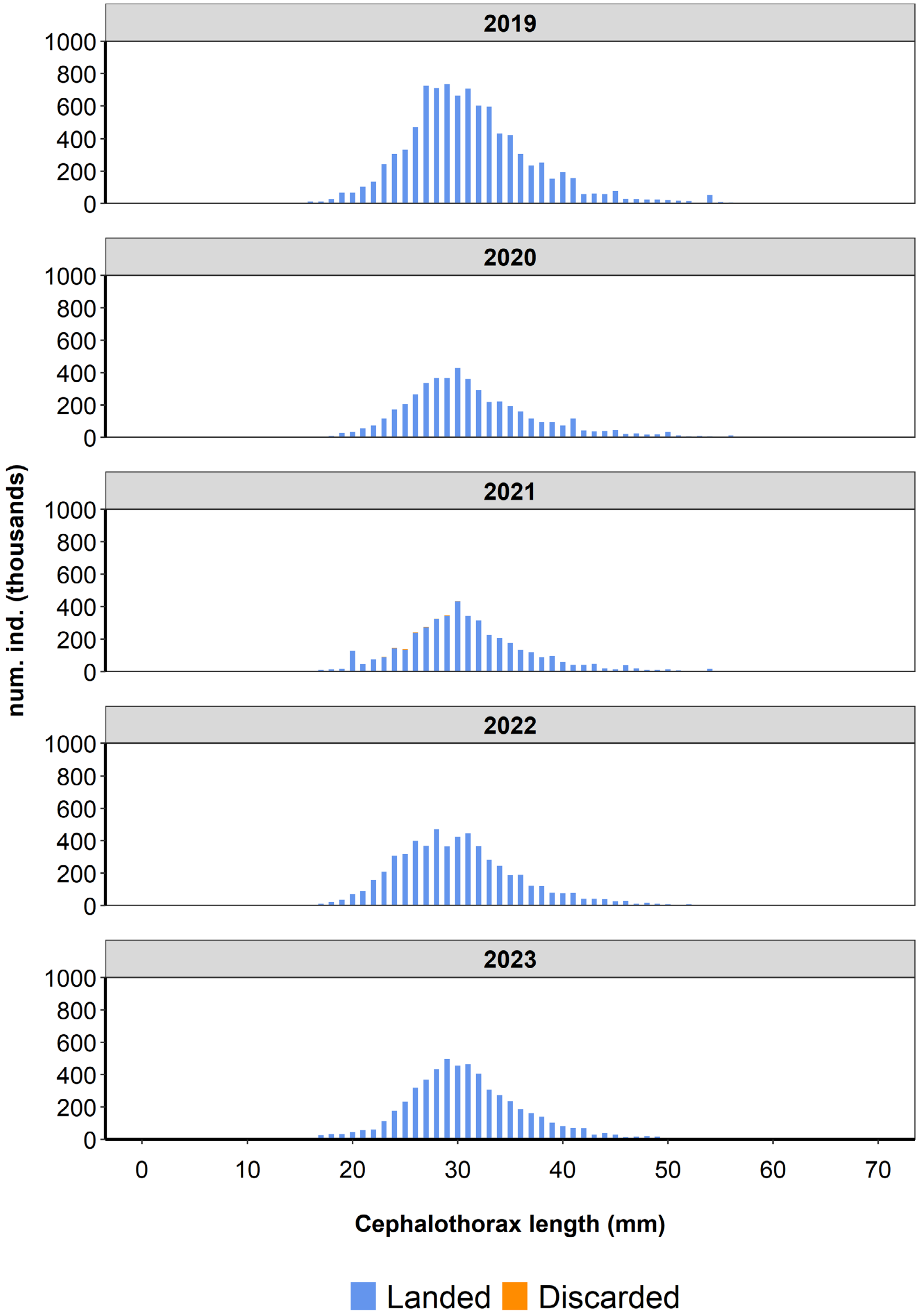


Figure 84. Annual length frequency distributions of Norway lobster from bottom trawling and small-scale fisheries. The data from bottom trawling is raised from ICATMAR data and details landed and discarded Norway lobster. The data from small-scale fisheries is obtained from DCF (Data Collection Framework) dataset.

Table 15. Number of Norway lobster individuals sampled by zone and season from ICATMAR monitoring data used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N hauls
			Number individuals sampled				
Bottom trawl	2019	North	16	1968	906	545	23
Bottom trawl	2019	Center	497	639	621	642	20
Bottom trawl	2019	South	183	23	187	6	12
Bottom trawl	2020	North	633	483	747	618	25
Bottom trawl	2020	Center	433	376	556	450	20
Bottom trawl	2020	South	75	1	12	2	9
Bottom trawl	2021	North	348	666	892	676	30
Bottom trawl	2021	Center	732	484	807	417	16
Bottom trawl	2021	South	15	1	6	2	8
Bottom trawl	2022	North	273	642	724	713	27
Bottom trawl	2022	Center	446	313	573	844	22
Bottom trawl	2022	South	1	1	2	0	4
Bottom trawl	2023	North	738	1017	1023	1044	27
Bottom trawl	2023	Center	414	803	662	450	24
Bottom trawl	2023	South	2	1	0	0	3

Length-Based Spawning Potential Ratio (LBSPR)

Model setting and results

Scenarios

Three different scenarios were applied for the sensitivity analysis for Norway lobster (Table 16). All scenarios used the same growth and natural mortality parameters. For scenario 1, maturity information was obtained from STECF and GFCM stock assessment, for scenario 2, maturity data was obtained from the literature (Vigo et al. 2023) and for scenario 3, it was obtained from ICATMAR data (ICATMAR, 24-05).

Table 16. Biological parameters used in the different LBSPR scenarios for Norway lobster (NEP). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Species	Scenario	L_{inf} (mm)	M/k	L_{mat50} (mm)	L_{mat95} (mm)
NEP	1	86.1	3.968	32.5	36
NEP	2	86.1	3.968	25.6	28.4
NEP	3	86.1	3.968	17.8	19.7

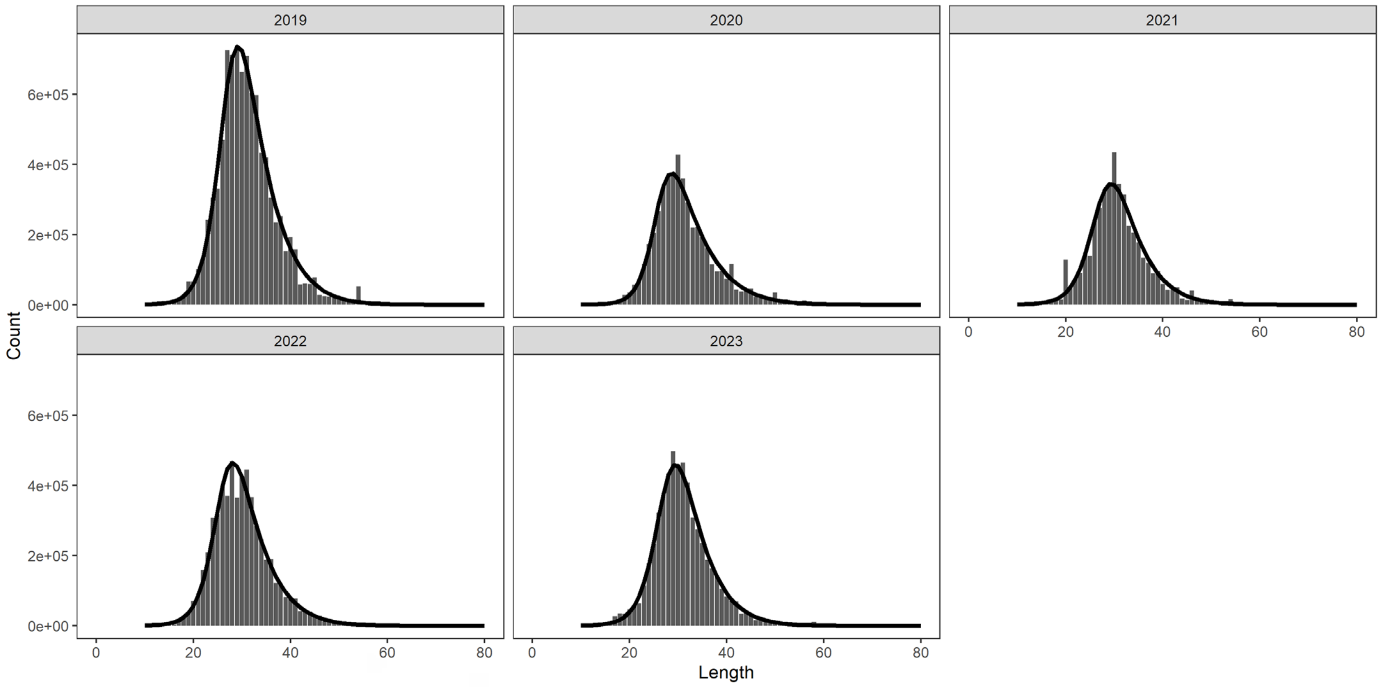


Figure 85. Fit of the data using the LBSPR model for Norway lobster for each studied year. Grey columns indicate length frequencies. Black lines indicate the fit of the model.

Fitted data

The length frequency distribution fit per year is shown in Figure 85. The model generally follows the mode for all years, but for example in 2022 for some middle lengths the model overestimates the length frequency

Selectivity

The outputs of the model for the selectivity of the fishery are shown by scenario in Table 17. The outputs are also plotted together with L_{mat50} and SL_{50} in Figure 86. For scenario 1, the model reveals that the fishery is fishing below L_{mat50} whereas for scenarios 2, it is fishing around L_{mat50} and for scenario 3 the fishery is fishing above L_{mat50}.

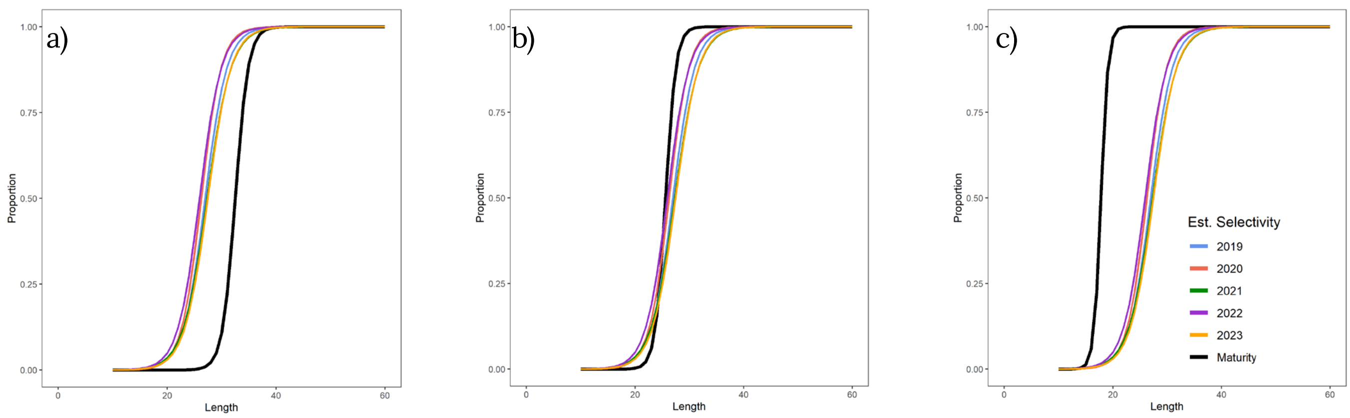


Figure 86. Length curves for Norway lobster. Black line shows the length curve at maturity. Colour lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (a), scenario 2 (b) and scenario 3 (c).

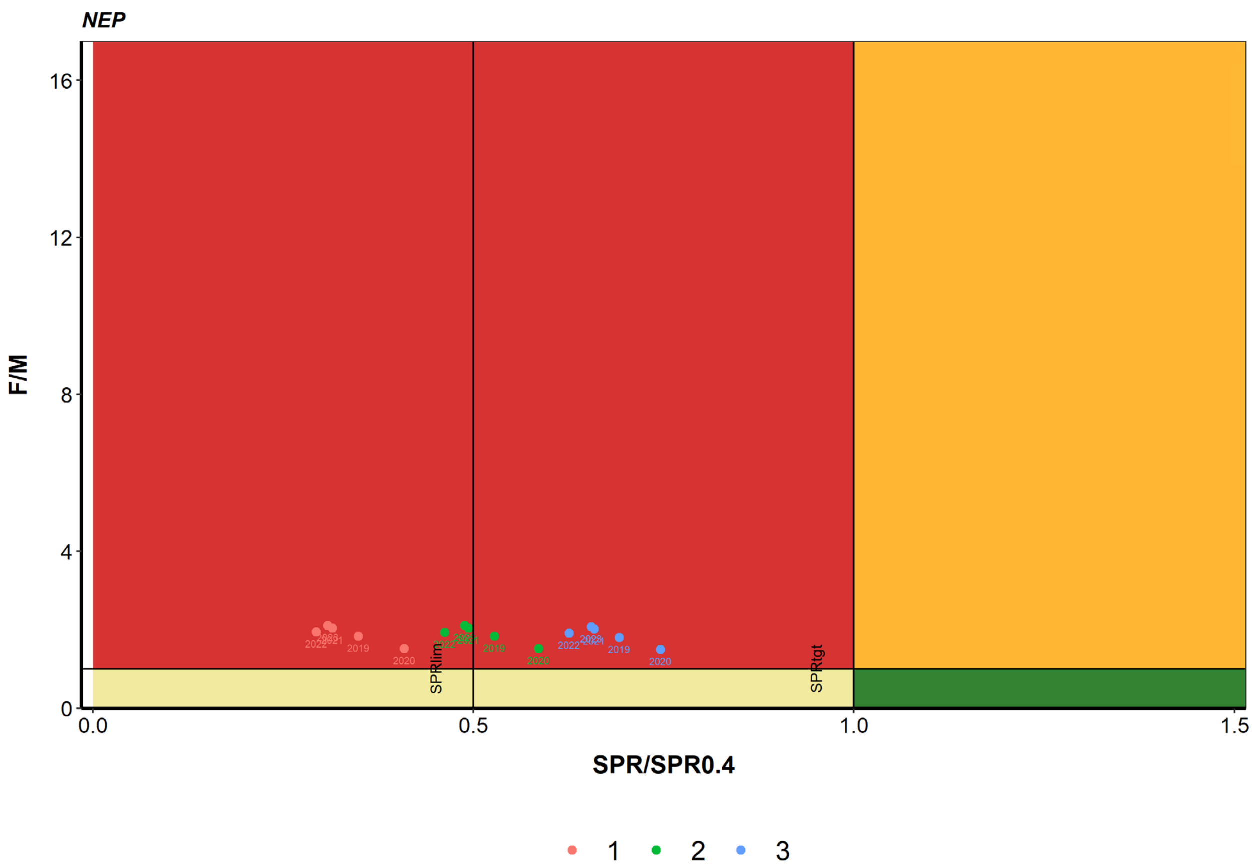


Figure 87. Kobe plot for Norway lobster by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio,SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

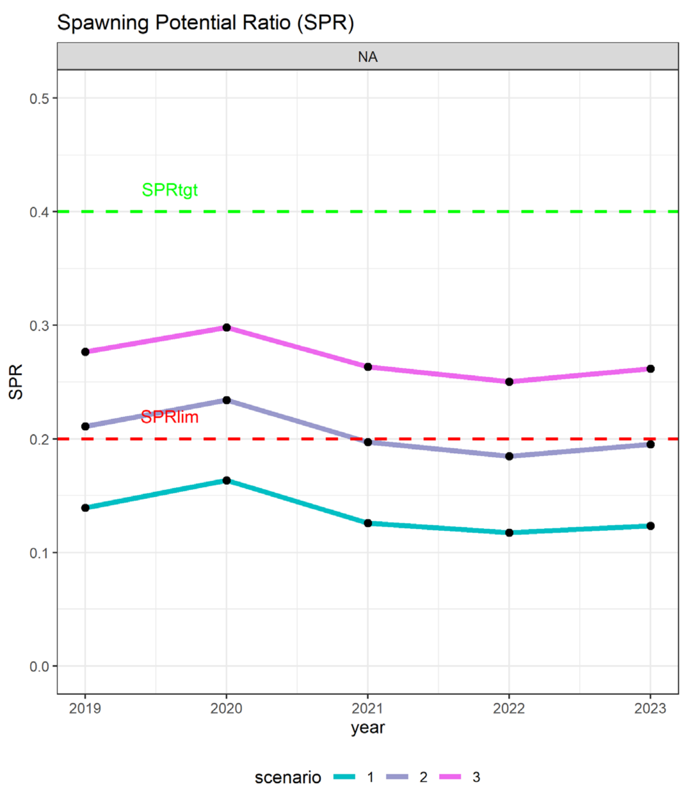


Figure 88. Spawning potential ratio (SPR) per year analysed for Norway lobster evaluated with LBSPR model. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. Coloured lines show the results for each scenario.

Reference points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is betweem SPR_{lim} (=0.1) and SPR_{pa} (=0.2) in scenario 1. However, in scenarios 2, the stock is similar or above SPR_{pa} (=0.2). (Table 17 and Figure 88). The Kobe plot for Norway lobster (Figure 87) shows the stock status throughout the different years, with no clear trend. Nevertheless, the stock is located in the red zone in all cases, meaning that the stock is overfished and under overfishing.

Table 17. LBSPR model results for Norway lobster with the different scenarios tested for each year analysed. SL_{50}: Length where 50% of individuals are caught, SPR: spawning potential ratio and FM: fishing mortality. SD is the standard deviation calculated for each indicator.

Species	Scenario	Year	SL_{50}	SD	SPR	SD	FM	SD
NEP	**1**	**2019**	27.23	0.19	0.14	0.10	1.84	0.58
NEP	**1**	**2020**	26.48	0.17	0.16	0.11	1.52	0.51
NEP	**1**	**2021**	27.60	0.19	0.13	0.09	2.05	0.62
NEP	**1**	**2022**	26.22	0.21	0.12	0.08	1.94	0.60
NEP	**1**	**2023**	27.71	0.18	0.12	0.09	2.11	0.63
NEP	**2**	**2019**	27.23	0.19	0.21	0.11	1.83	0.57
NEP	**2**	**2020**	26.48	0.17	0.23	0.11	1.52	0.50
NEP	**2**	**2021**	27.60	0.19	0.20	0.10	2.05	0.61
NEP	**2**	**2022**	26.22	0.21	0.18	0.10	1.94	0.58
NEP	**2**	**2023**	27.71	0.18	0.20	0.10	2.10	0.62
NEP	**3**	**2019**	27.24	0.19	0.28	0.11	1.81	0.56
NEP	**3**	**2020**	26.48	0.18	0.30	0.12	1.50	0.49
NEP	**3**	**2021**	27.60	0.20	0.26	0.10	2.02	0.60
NEP	**3**	**2022**	26.22	0.22	0.25	0.10	1.92	0.57
NEP	**3**	**2023**	27.71	0.19	0.26	0.10	2.08	0.61

Final scenario

As LFD and L_{mat} originated from ICATMAR data, scenario three was selected to provide final advice for the LBSPR model.

Stochastic Production model in Continuous Time (SPiCT)

For Norway lobster data was taken from EU fleet register provided by the European Commission (Reg. EU 2017/218), GSA6 daily commercial fishing landings provided by the Spanish Ministry of Agriculture, Fisheries and Food, DCF and GFCM Stock Assessment Form (SAF) for NEP in GSA6 RY2022, and historical landings from Paloma, 1991. (Figure 89)

Landings from 1970 to 2022 (Tons)

OTB CPUE from 2009 to 2022 (kg/vessel/day)

Index: MEDITS survey data from 1994 to 2022 (Biomass, kg/km2)

To compare input data, a double axis plot was presented in Figure 90. MEDITS index remains constant with some fluctuations for the whole time series. Catches and CPUE follow similar trends, with a clear decrease since 2012. Considering the data available, three scenarios were defined as follows:

Scenario 1: MEDITS + CPUE OTB

Scenario 2: MEDITS

Scenario 3: CPUE OTB

All the final scenarios end in 2022 because no MEDITS data for 2023 was available. Further work will be needed regarding the longest time series and standardized CPUE.

Settings for all final scenarios selected:

Catches from 1970 to 2022.

dat$stdevfacC = rep(1,length(dat$obsC))

ce = 0.05

dat$priors$logsdc <- c(log(ce), 0.3, 1)

dat$priors$logr <- c(log(0.5),0.05,1)

bk.pr=c(0.5,0.5,1)

dat$priors$logbkfrac <- c(log(bk.pr[1])-bk.pr[2]^2/2,bk.pr[2],bk.pr[3])

datinilogn <- log(2)

dat$phases$logn <- -1

pe = c(0.1,0.5,1)

dat$priors$logsdb <- c(log(pe[1])-0.5*pe[2]^2, pe[2], pe[3])

fdevs=c(4,0.5,1)

dat$priors$logsdf <- c(log(fdevs[1])-0.5*fdevs[2]^2, fdevs[[2]], fdevs[3])

dat$priors$logalpha <- c(0,0,0)

dat$priors$logbeta <- c(0,0,0)

dat$dteuler = ¼

Scenario 1 MEDITS + CPUE OTB

The input data (Figure 91) consisted of a landings time series from 1970 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 1994 and since 2009 for CPUE for OTB.

Indices were added considering the specific month each survey was carried out per year. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value 0.3 was set for BK frac. And dat1$priors$logbeta <- c(2,0.1,1).

The observation error for the MEDITS survey was set SE=0.2 and CPUE: SE = 0.2, and CV = 0.3.

Figure 92 shows a summary of the scenario 1 fit. The relative biomass has been below 1 since 2016, and the model does not properly estimate the fishing mortality. It is important to consider the estimates' uncertainty.

Scenario 2 MEDITS

The input data (Figure 93Figure 21) consisted of a landings time series from 1970 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 1994.

Indices were added considering the specific month each survey was carried out per year. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value 0.5 was set for BK frac. And dat1$priors$logbeta <- c(2,0.1,1).

The observation error for MEDITS is SE=0.2 with CV = 0.3 for both.

Figure 94 shows a summary of the scenario 2 fit. The relative biomass has been below 1 since 2016, and the model does not properly estimate the fishing mortality. It is important to consider the estimates' uncertainty.

Scenario 3 CPUE OTB

The input data (Figure 95) consisted of a landings time series from 1970 onwards and a biomass index to tune the model. The biomass index data were derived from CPUE for OTB from 2009.

For this scenario, a final value of 0.3 was set for BK frac.

The observation error for CPUE, SE = 0.2, with CV = 0.3.

Figure 96 shows a summary of the scenario 3 fit. The relative biomass has been below 1 since 2016, and the model does not properly estimate the fishing mortality. It is important to consider the estimates' uncertainty.

Finally, Figure 97 compares the three final scenarios. It is important to highlight the different perceptions of the stock status depending on the input data.

Scenario 2 was selected as the final one since the CPUE OTB index did not give contrast to the model.

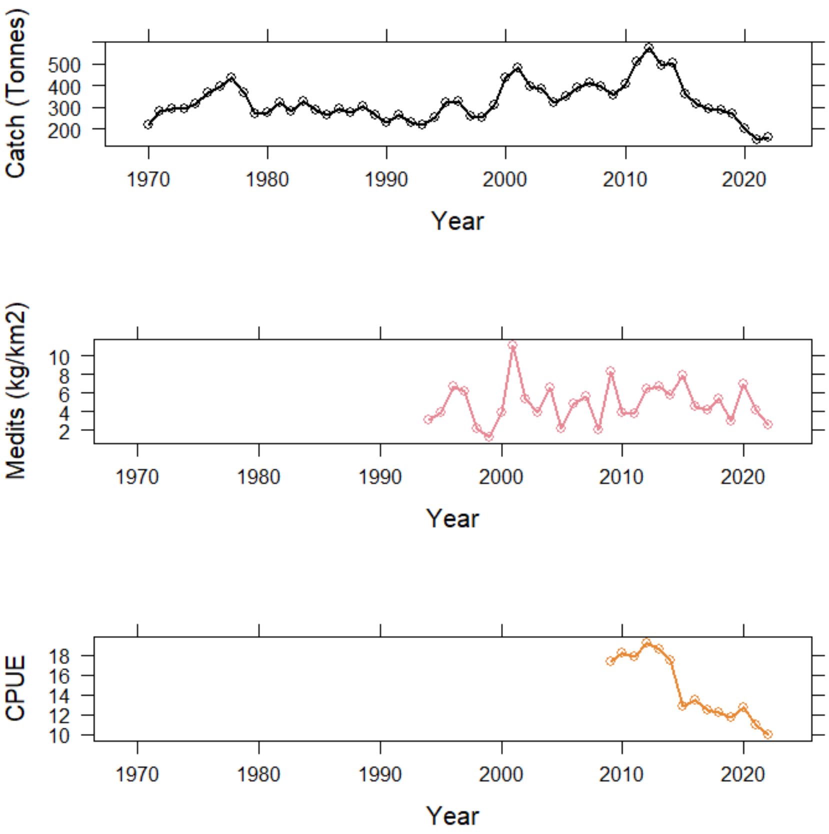


Figure 89. Data available for the assessment for Norway lobster in GSA6 to run SPiCT model. Top: catch data from 1970 to 2022. Centre: Medits survey data since 1994 to 2022. Bottom: CPUE data since 2009 to 2022.

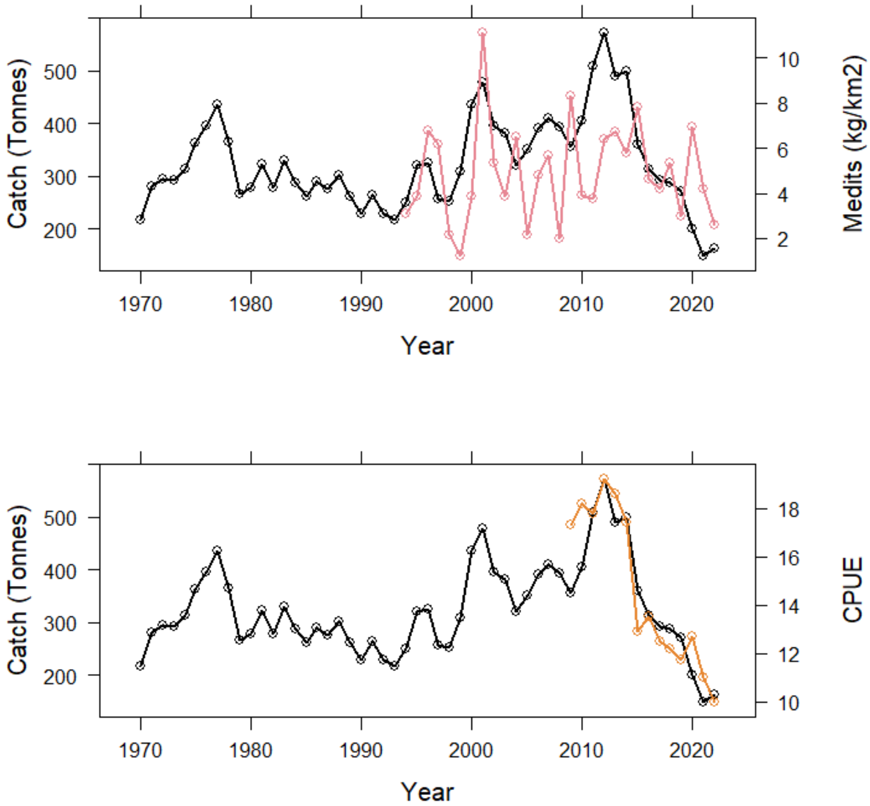


Figure 90. Double axis plot to compare trends between catch and Medits index (top) and catch and CPUE (bottom) for Norway lobster.

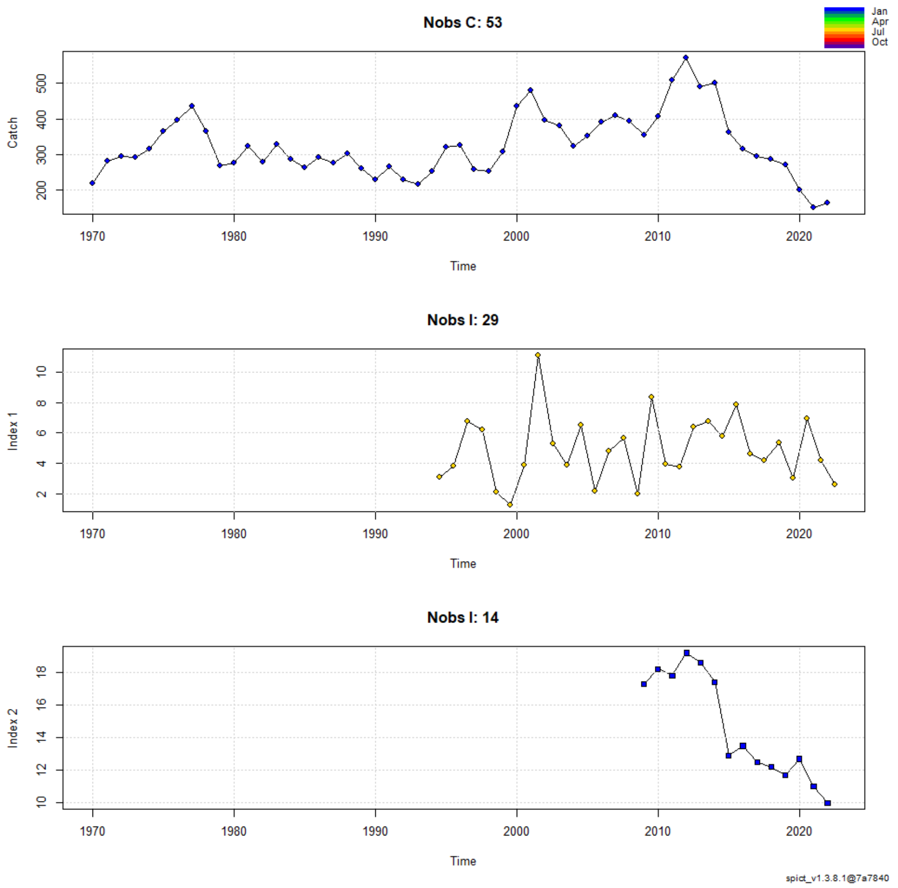


Figure 91. Input data for SPiCT model for Norway lobster in GSA6 for scenario 1. Top: catch in tones per year since 1970, centre: index data of biomass derived from MEDITS since 1994, and bottom: CPUE data since 2009 to 2022.

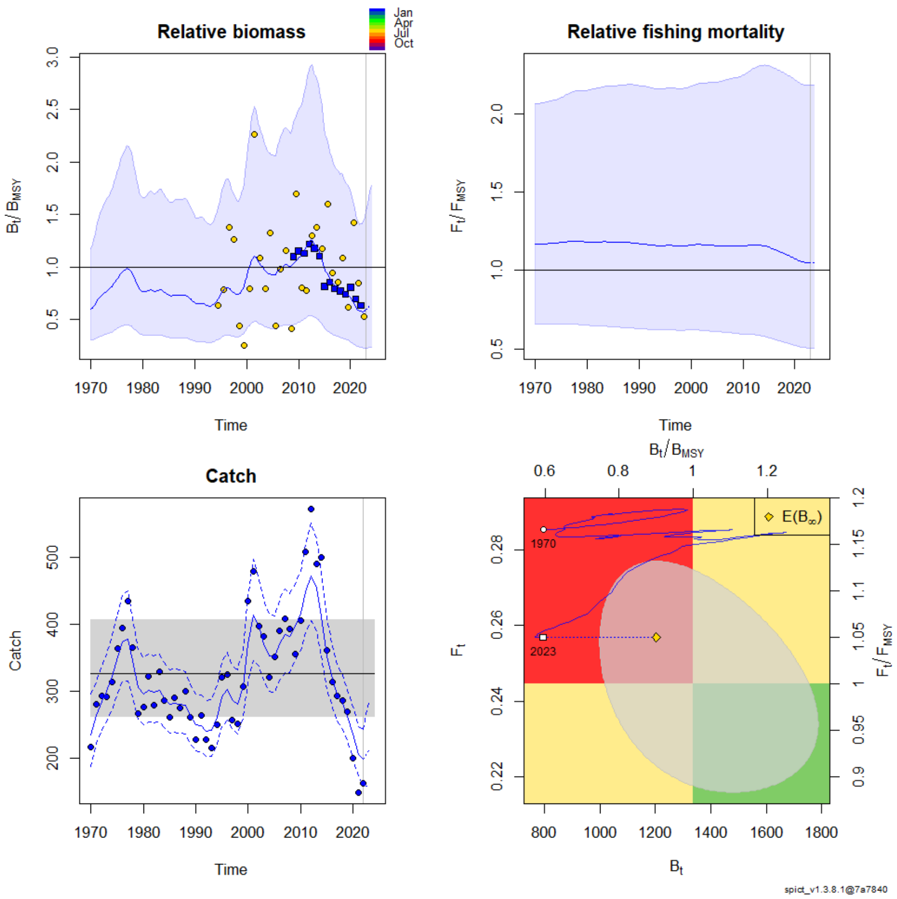


Figure 92. Stock assessment summary for SPiCT model for Norway lobster in GSA6 for scenario 1.

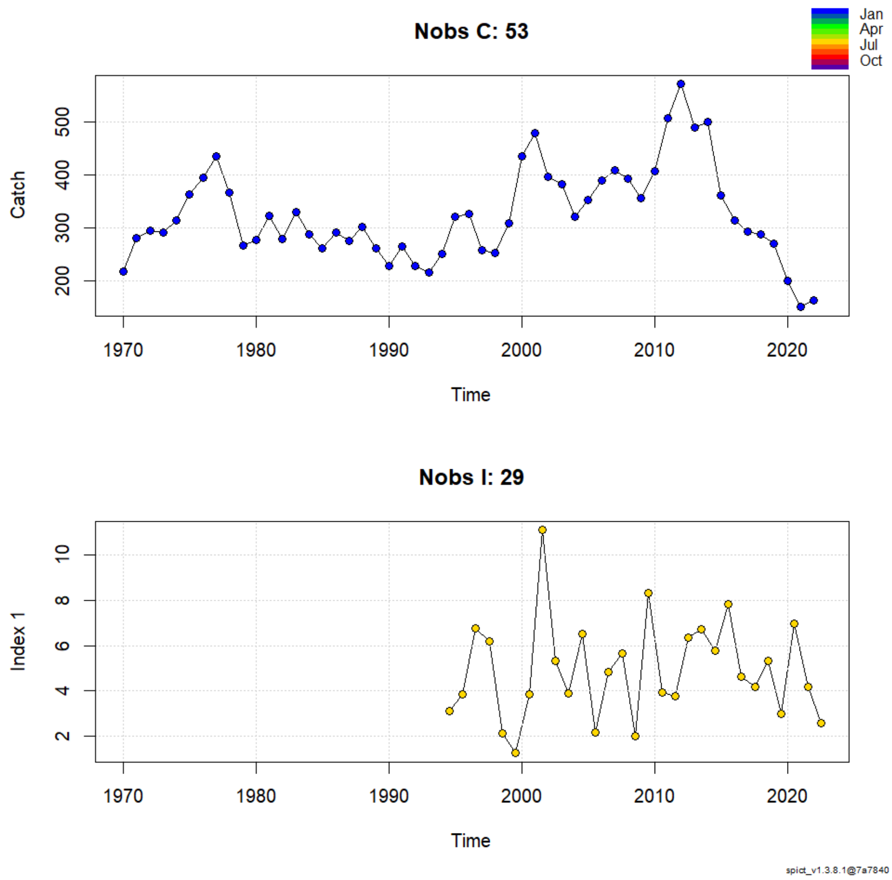


Figure 93. Input data for SPiCT model for Norway lobster in GSA6 for scenario 2. Top: catch in tones per year since 1970 and bottom: index data of biomass derived from MEDITS since 1994.

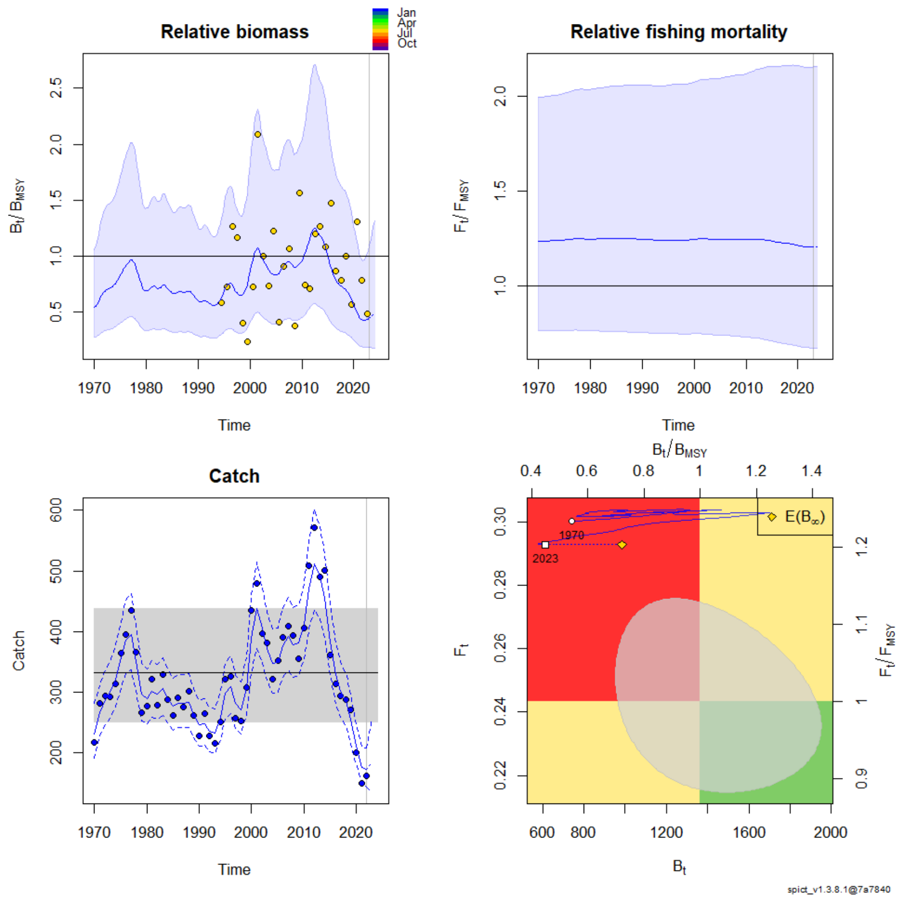


Figure 94. Stock assessment summary for SPiCT model for Norway lobster in GSA6 for scenario 2.

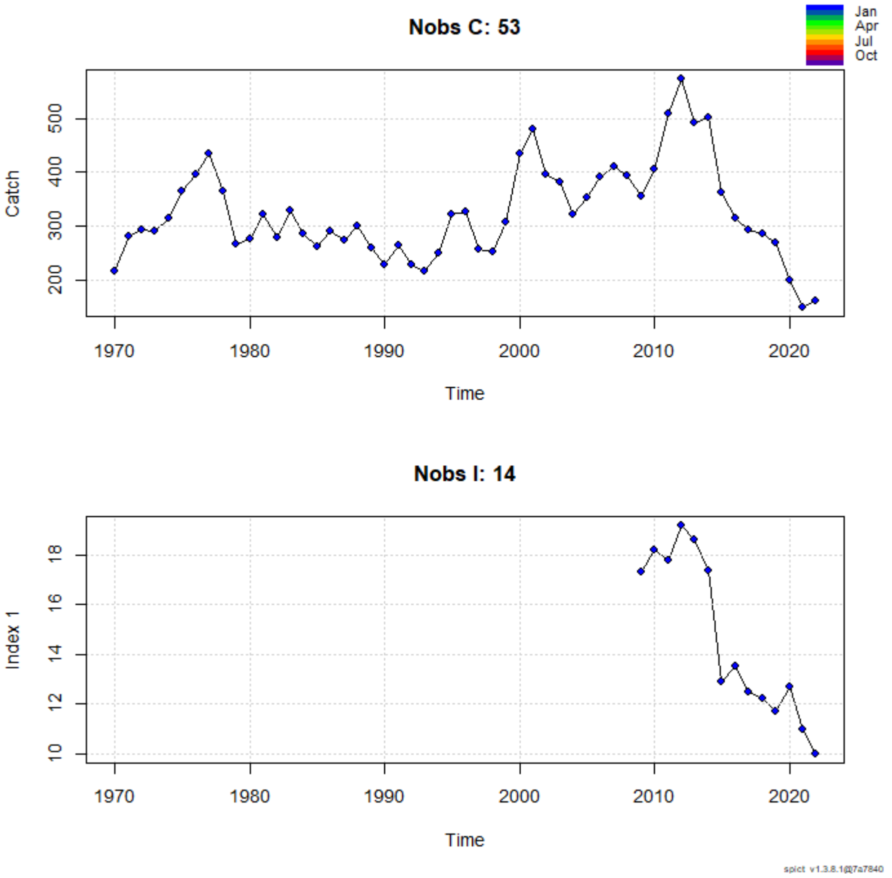


Figure 95. Input data for SPiCT model for Norway lobster in GSA6 for scenario 3. Top: catch in tones per year since 1970, bottom: CPUE data since 2009 to 2022.

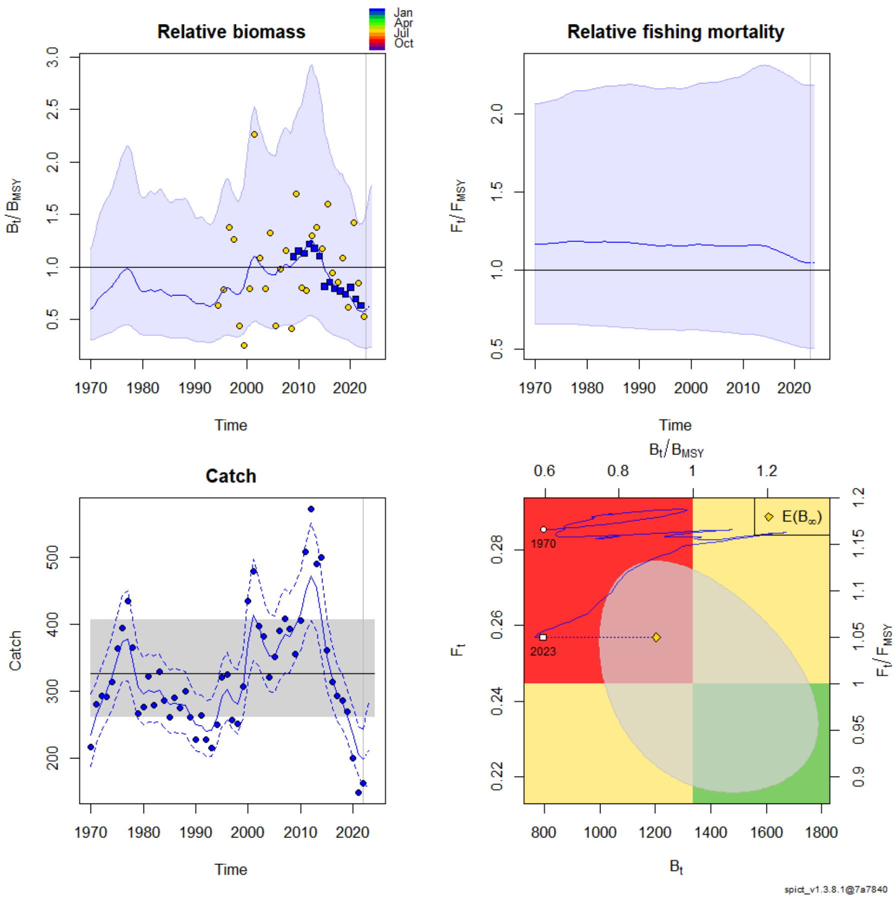


Figure 96. Stock assessment summary for SPiCT model for Norway lobster in GSA6 for scenario 3.

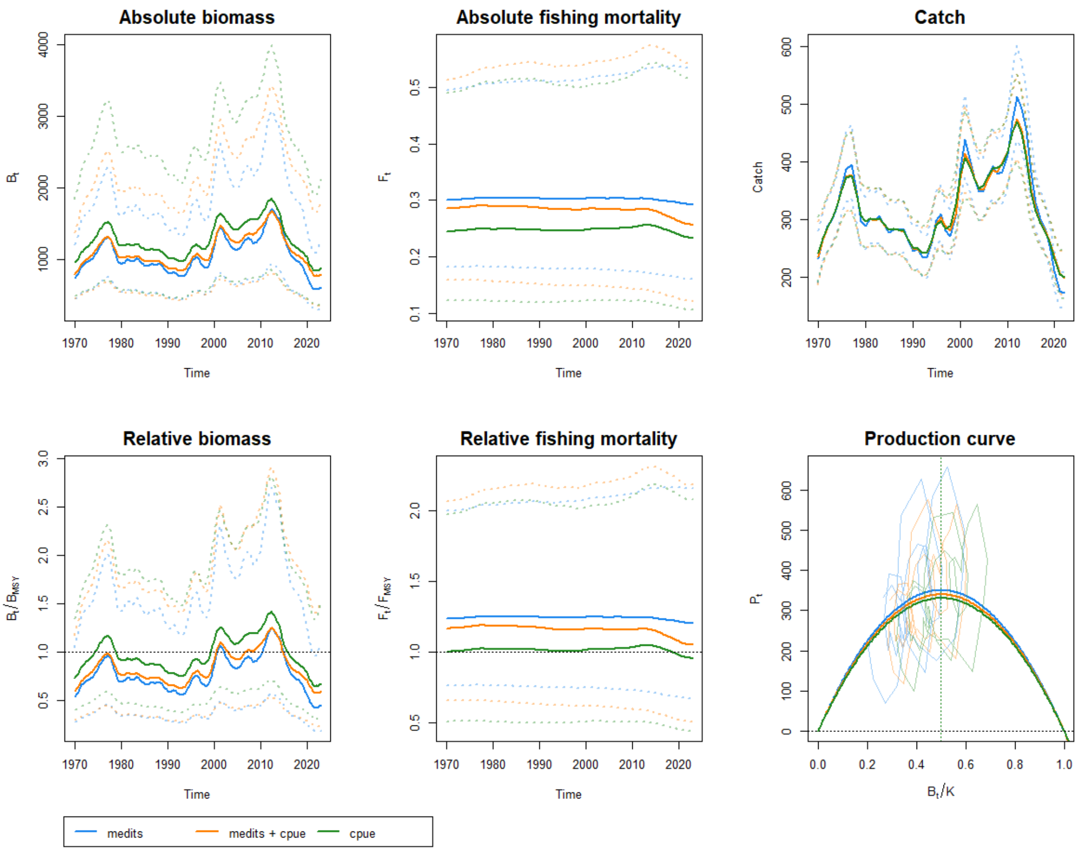


Figure 97. Scenarios comparison for Norway lobster in GSA6.

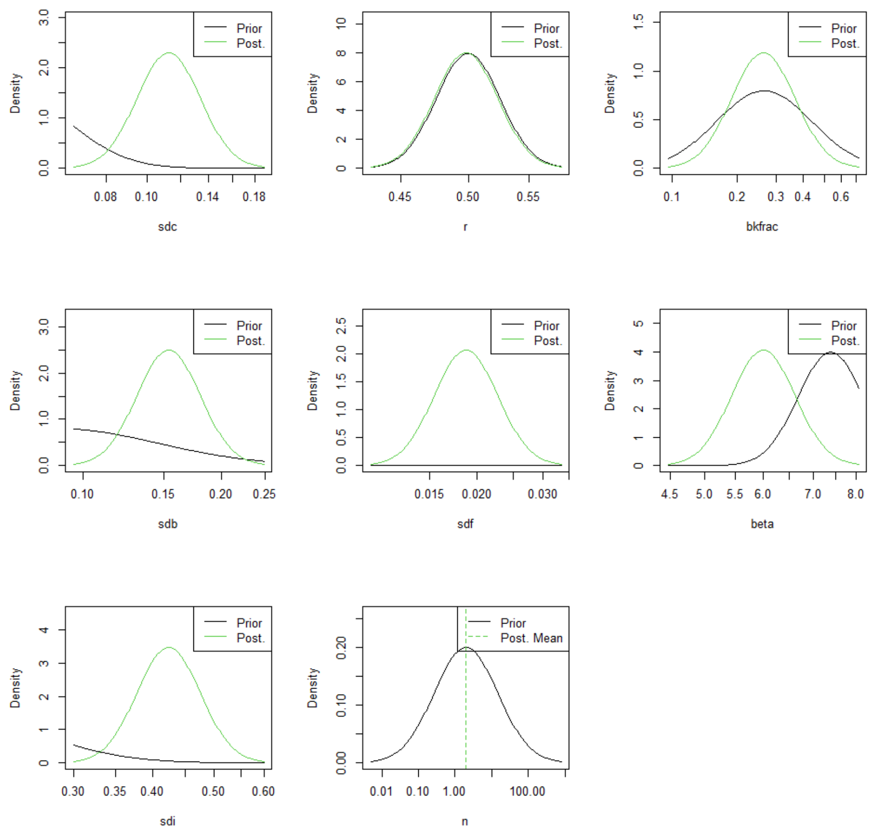


Figure 98. Estimated priors and posteriors for the updated assessment for Norway lobster in GSA6 for scenario 2.

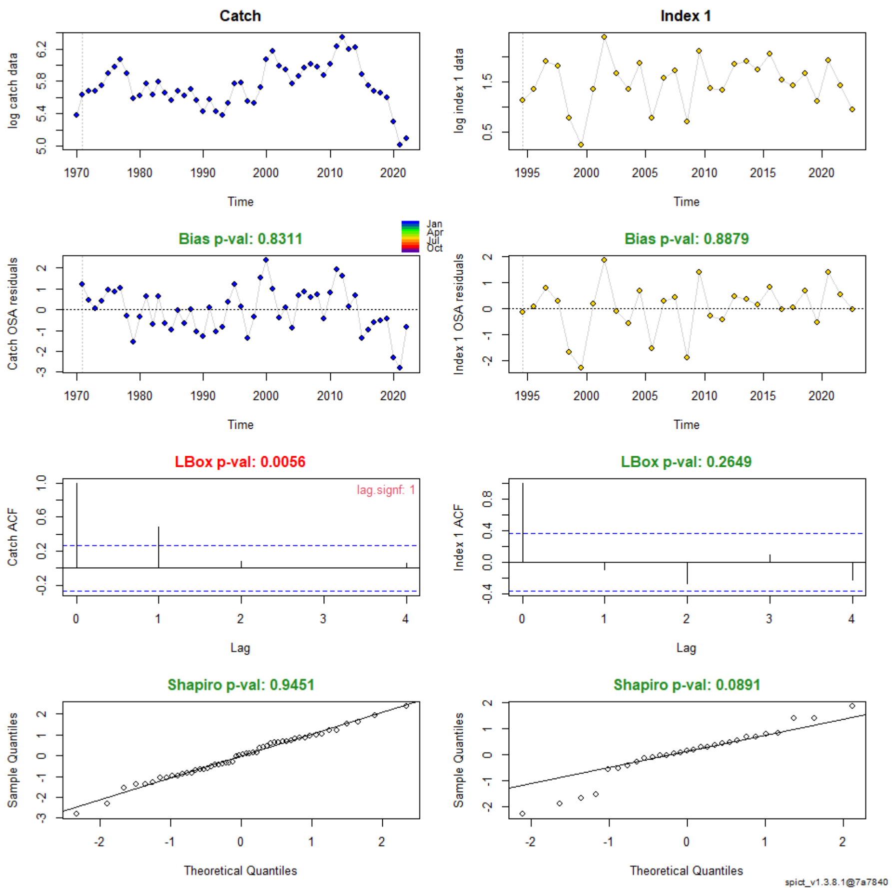


Figure 99. One-step-ahead residuals for the model for Norway lobster in GSA6 for scenario 2.

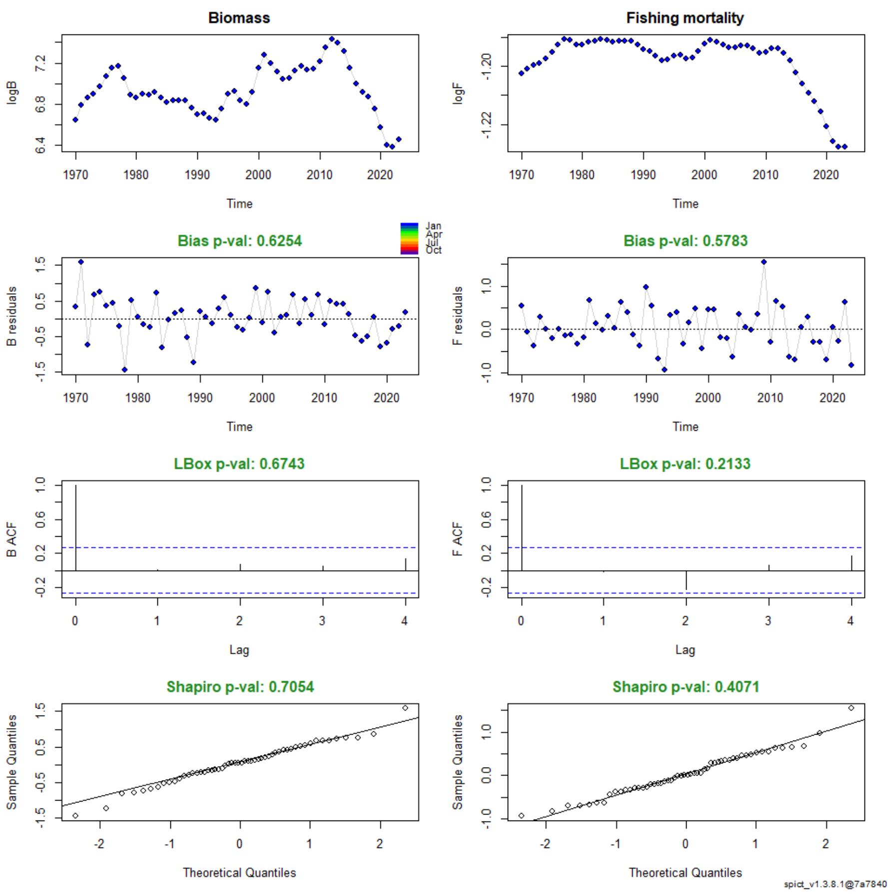


Figure 100. Process error deviations for the model for Norway lobster in GSA6 for scenario 2.

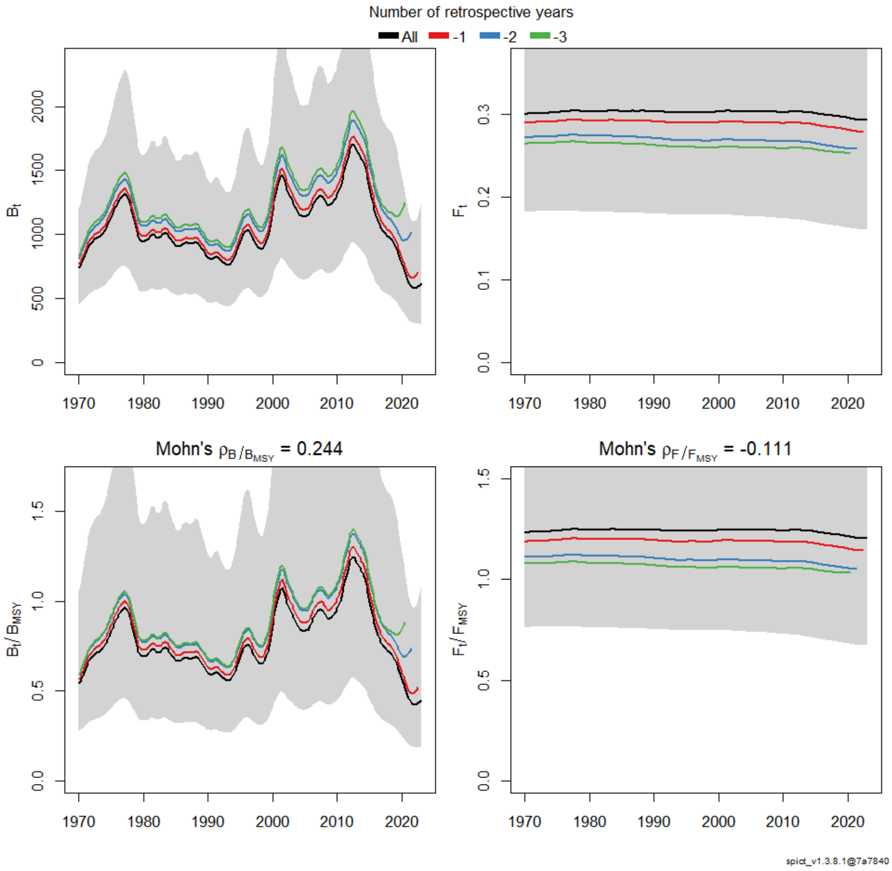


Figure 101. Retrospective analysis for Norway lobster in GSA6 for scenario 2.

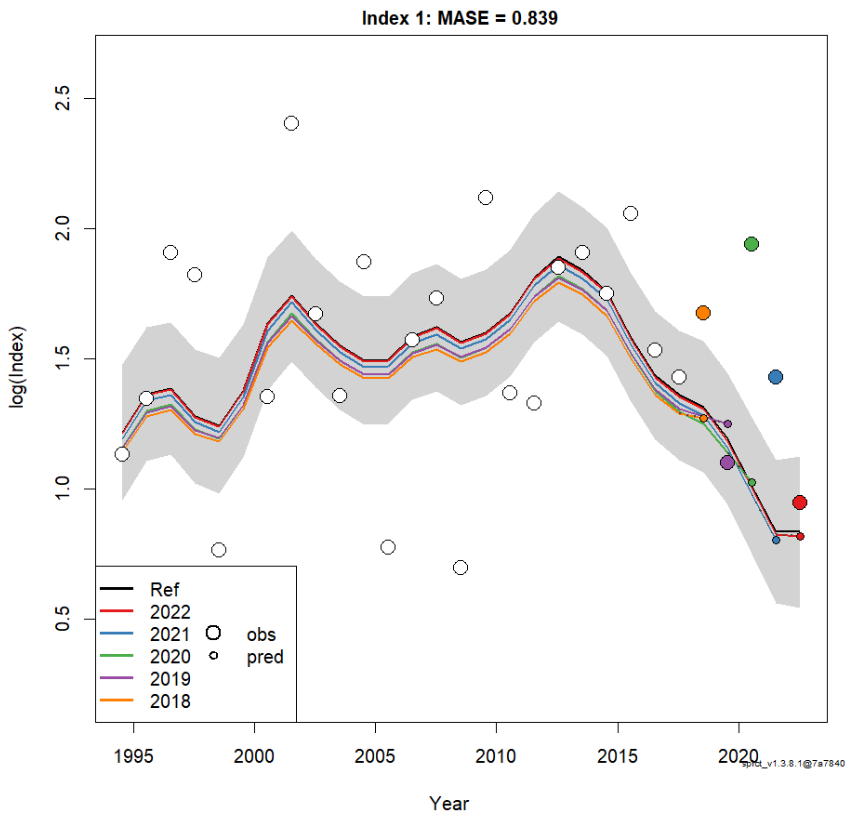


Figure 102. Hindcasting for the model for Norway lobster in GSA6 for scenario 2.

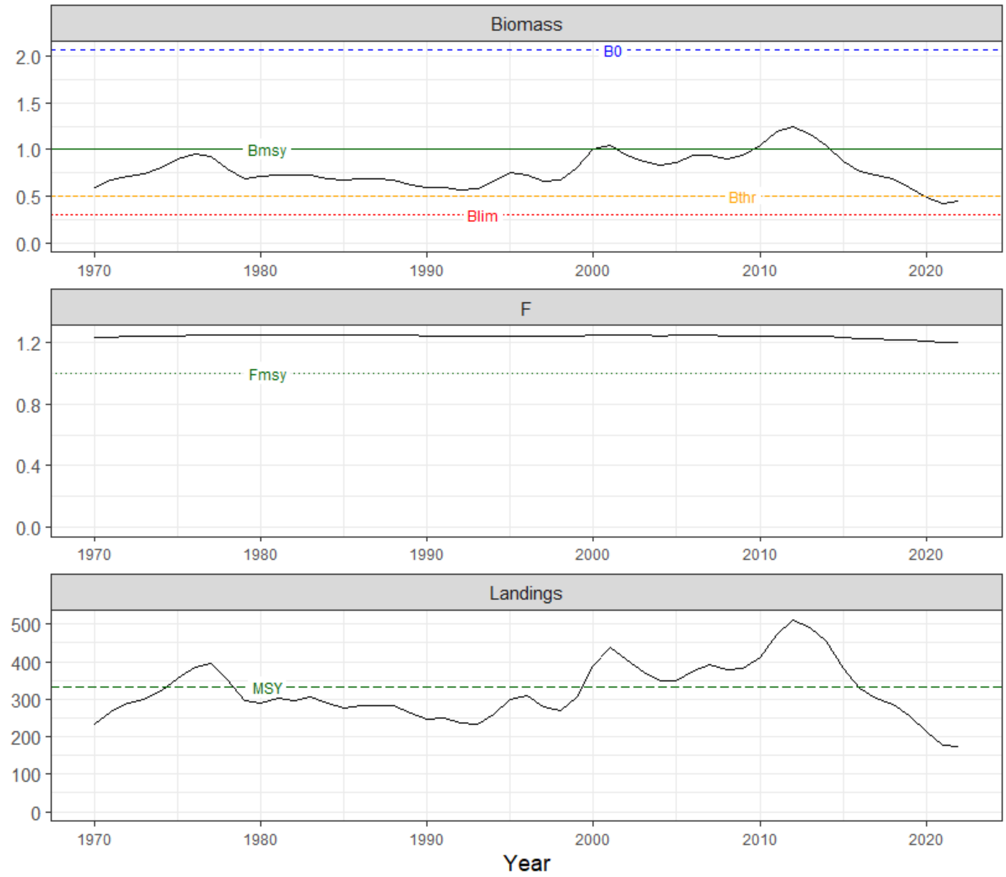


Figure 103. Advice for scenario 2 for Norway lobster in GSA6: Historical and current stock status regarding F_{msy}, B_{msy} and B_{lim}.

Table 18. Indicators in 2022 from SPiCT for Norway lobster in GSA6.

Species	Year	Catch (t)	FFmsy	BBmsy	BBpa	BBlim
NEP	**2022**	172.61	1.2	0.44	0.88	1.47

Final scenarios diagnostics

Diagnostics for the final scenario selected (i.e., Scenario 2) were shown below (Figure 98, Figure 99, Figure 100, Figure 101, Figure 102). The chosen scenario met most of the model diagnostics and provided good retrospective analysis and hindcasting diagnostics.

The annexes contain all the diagnostics for scenario 1 (Annex 43, Annex 44, Annex 45, Annex 46, Annex 47)and scenario 3 (Annex 48, Annex 49, Annex 50, Annex 51, Annex 52).

Also, a sensitivity analysis for scenario 2 was performed, testing r prior (Annex 53), bkfrac (Annex 54Annex 40), process error (Annex 55), and observation error (Annex 56Annex 42Annex 14) to see how robust the model is within these priors.

Final scenarios advice

Figure 103 represents the stock assessment for the final scenario (i.e., scenario 2) (advice framework) using MEDITS as a biomass index. Table 18 shows indicators in 2022 for scenario 2 for Norway lobster in GSA6.

Blue and red shrimp (*Aristeus antennatus*) ARA

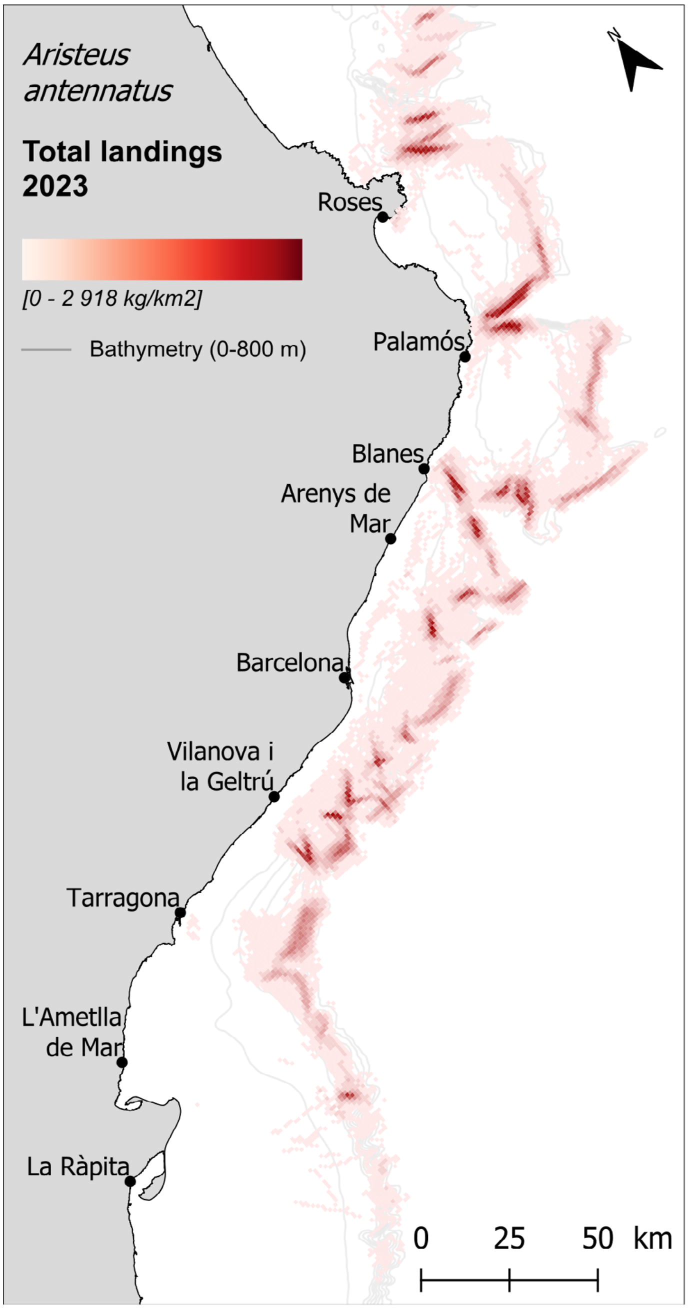


Figure 104. Spatial distribution of landings per unit of effort (LPUE) for blue and red shrimp in the Catalan fishing grounds (North GSA6) in the year analysed.

The blue and red shrimp presents sexual dimorphism, with females reaching larger sizes than males. To analyse the data, though, only a combined set of growth parameters was used; thus, the length data available was a dataset with both male and female parameters. The reproduction of the blue and red shrimp occurs between April and September (ICATMAR, 24-05), and recruitment is observed afterwards, in autumn and winter. The blue and red shrimp is a deep-water species caught exclusively by bottom trawling. The species has a wide bathymetric distribution, between 80 and 3300 m depth (Sardà *et al.*, 2004), although commercial fishing grounds are located between 450 and 900 m depth.

Input data

The spatial distribution of total landings for blue and red shrimp in the Catalan fishing ground is shown in Figure 104. The species is mainly distributed in the lower slope along the Catalan coast, with less occurrence in the Delta area (i.e. L'Ametlla de Mar and La Ràpita).

Historical blue and red shrimp landings in Catalonia from 2002 to 2023 are shown in Figure 105. The lowest value was observed in 2005. After a peak of landings in 2008, they decreased afterwards and for the last five years, landings have remained more or less the same.

Figure 106 shows the blue and red shrimp landing distribution by *métier* from 2019 to 2023, with the highest landings obtained with bottom trawlers, especially for lower slope *métier*.

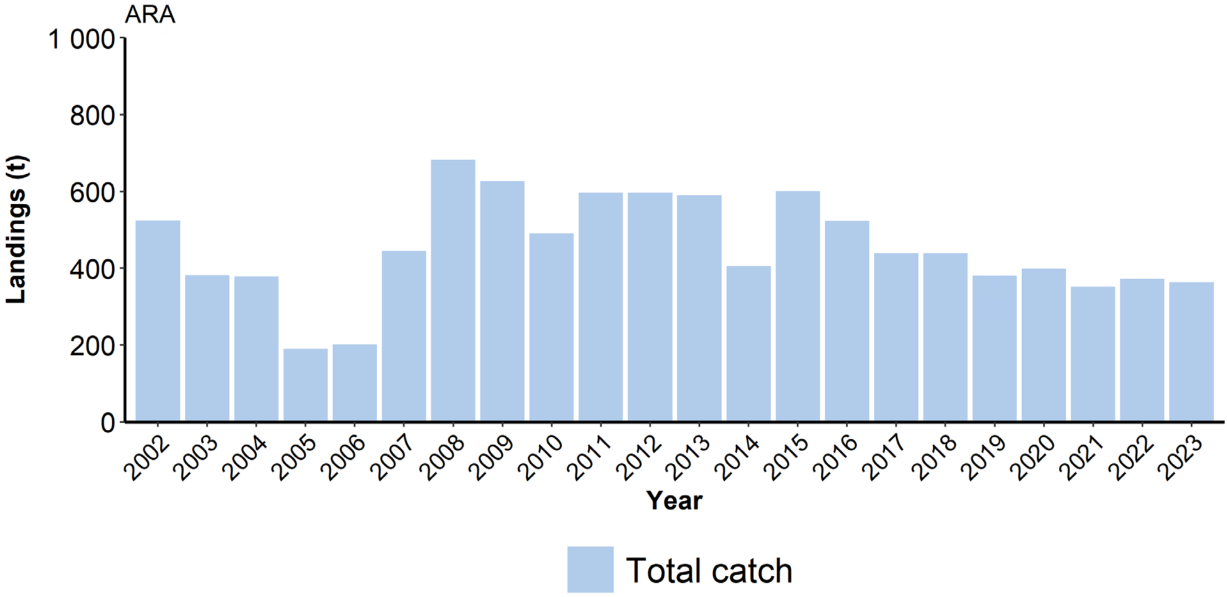


Figure 105. Historical landings (t) for blue and red shrimp in Catalonia.

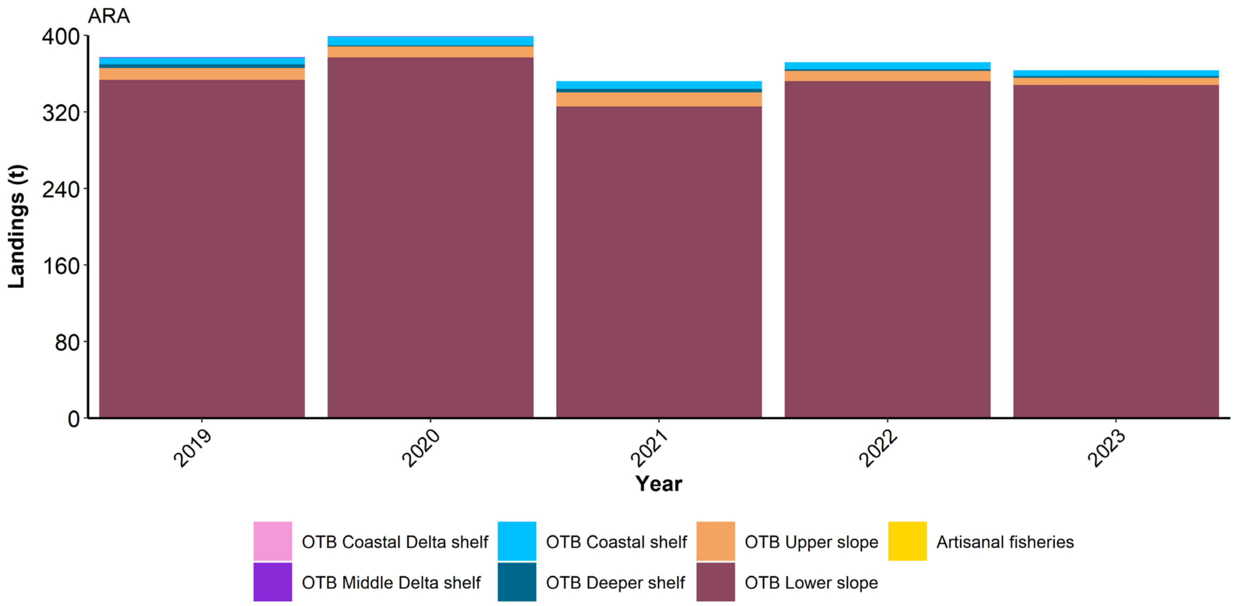


Figure 106. Landings (t) for blue and red shrimp by *métier* and fishing gear. OTB: bottom trawling.

Annual LFD

After raising the length frequencies obtained with the monitoring program (Table 19), and considering discards, the annual length frequency of blue and red shrimp in Catalonia is plotted in Figure 107. A decrease in bigger individuals is observed whereas there is an increase of the smaller ones.

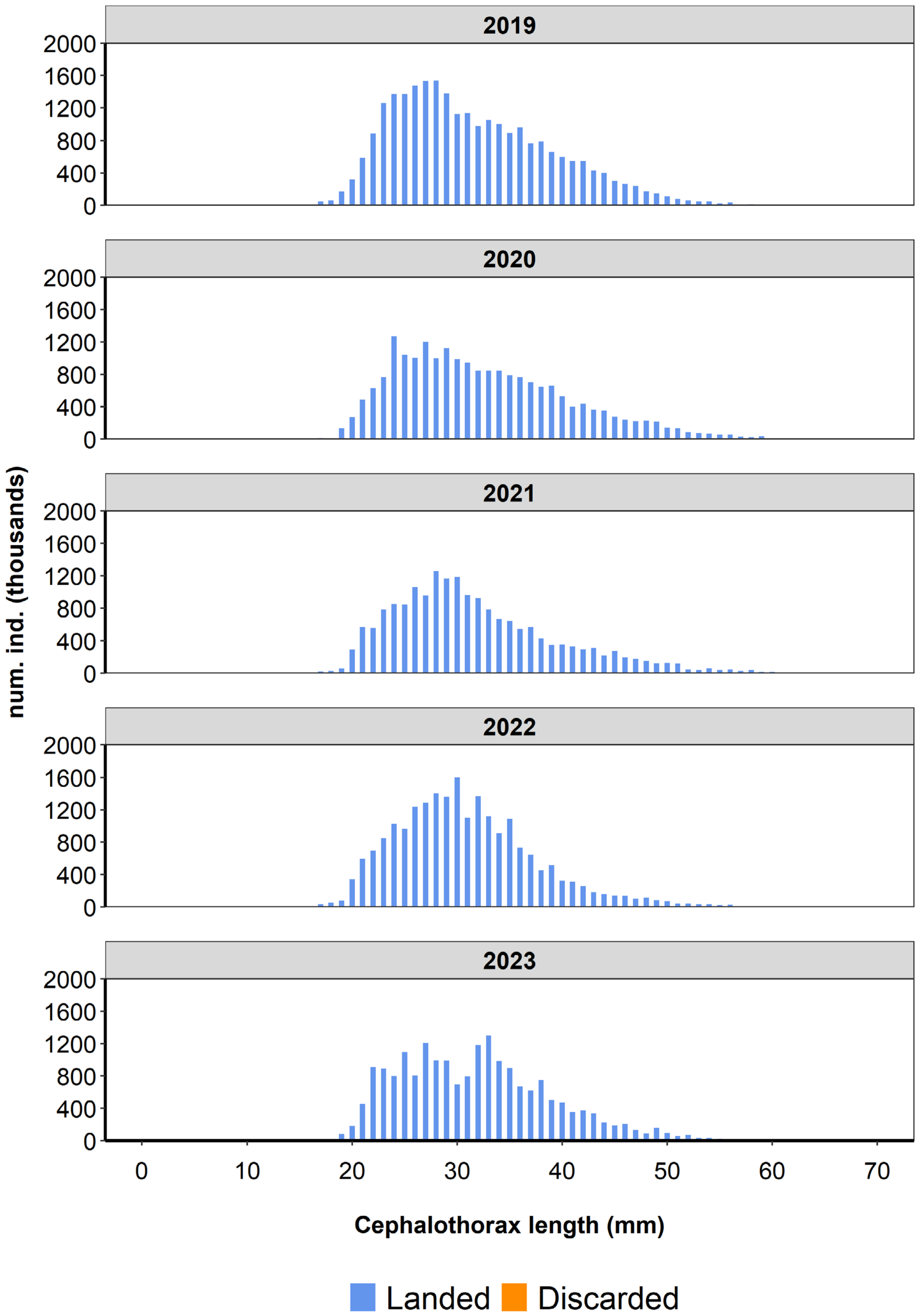


Figure 107. Annual length frequency distributions of blue and red shrimp from bottom trawling and small-scale fisheries. The data from bottom trawling is raised from ICATMAR data and details landed and discarded blue and red shrimp. The data from small-scale fisheries is obtained from DCF (Data Collection Framework) dataset.

Table 19. Number of blue and red shrimp individuals sampled by zone and season from ICATMAR monitoring data used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N hauls
			Number individuals sampled				
Bottom trawl	2019	North	181	1796	1102	900	17
Bottom trawl	2019	Center	1005	848	483	1049	12
Bottom trawl	2019	South	490	0	898	433	5
Bottom trawl	2020	North	697	502	1040	1055	16
Bottom trawl	2020	Center	467	655	894	991	10
Bottom trawl	2020	South	537	0	477	335	3
Bottom trawl	2021	North	1053	979	1146	1100	16
Bottom trawl	2021	Center	1067	974	552	465	12
Bottom trawl	2022	North	889	921	934	746	15
Bottom trawl	2022	Center	835	532	663	431	11
Bottom trawl	2023	North	651	629	921	721	13
Bottom trawl	2023	Center	587	757	816	772	13

Length-Based Spawning Potential Ratio (LBSPR)

Table 20. Biological parameters used in the different LBSPR scenarios for blue and red shrimp (ARA). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Model setting and results

Scenarios

Three different scenarios were applied for the sensitivity analysis for blue and red shrimp (Table 20). All scenarios used the same growth and natural mortality parameters. For scenario 1, maturity information was obtained from STECF and GFCM stock assessment data, for scenario 2, these data was obtained from the literature (Sardà et al., 2004) and for scenario 3, from ICATMAR data (ICATMAR, 24-05).

Table 20. Biological parameters used in the different LBSPR scenarios for blue and red shrimp (ARA). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Species	Scenario	L_{inf} (mm)	M/k	L_{mat50} (mm)	L_{mat95} (mm)
ARA	1	77	1.211	20.0	23.1
ARA	2	77	1.211	25.5	29.4
ARA	3	77	1.211	24.2	27.9

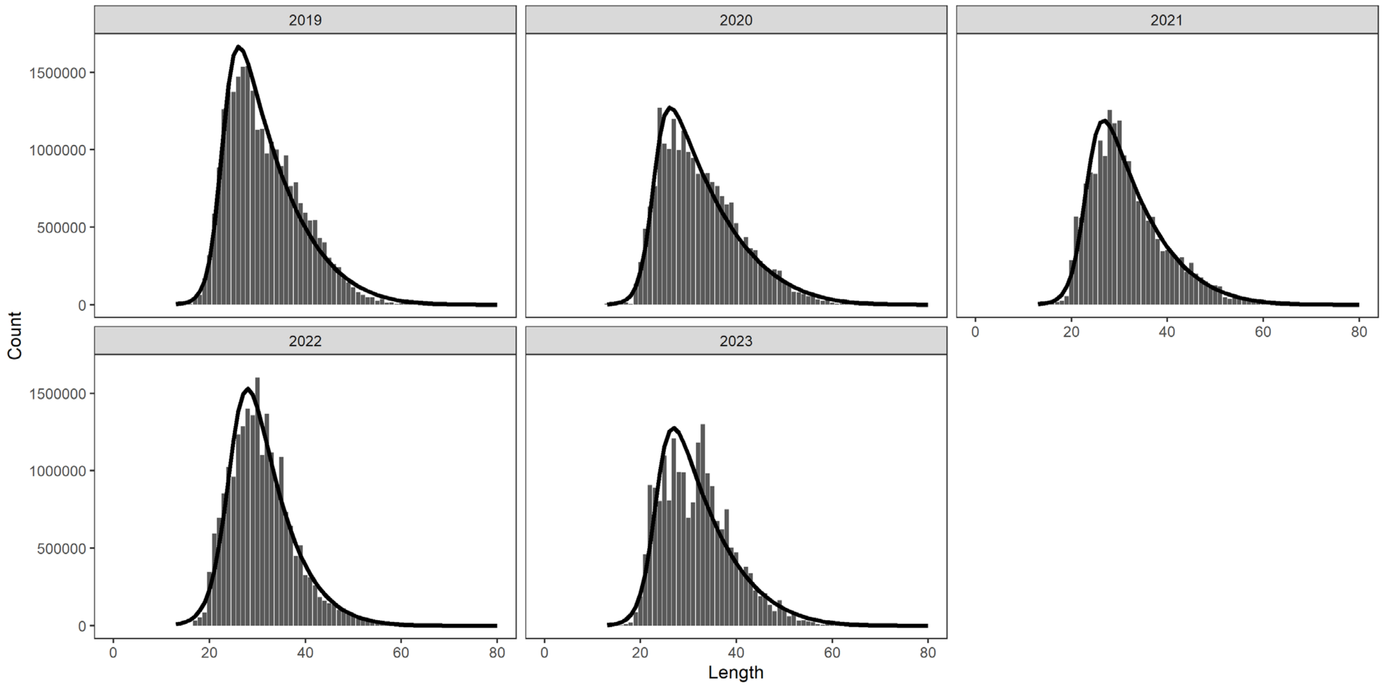


Figure 108. Fit of the data using the LBSPR model for blue and red shrimp for each studied year. Grey columns indicate length frequencies. Black lines indicate the fit of the model.

Fitted data

The length frequency distribution fit per year is shown in Figure 108. The model generally follows the mode for all years but overestimates some length classes in the middle mode part for all years.

Selectivity

The outputs of the model for the selectivity of the fishery are shown for each scenario in Table 21. The outputs are also plotted together with L_{mat50} and SL_{50} Figure 109. Each scenario provides different results. In detail, for scenario 1, the model reveals that the fishery is fishing above L_{mat50}, for scenario 2 the fishing is below L_{mat50} and for scenario 3, it is around L_{mat50}.

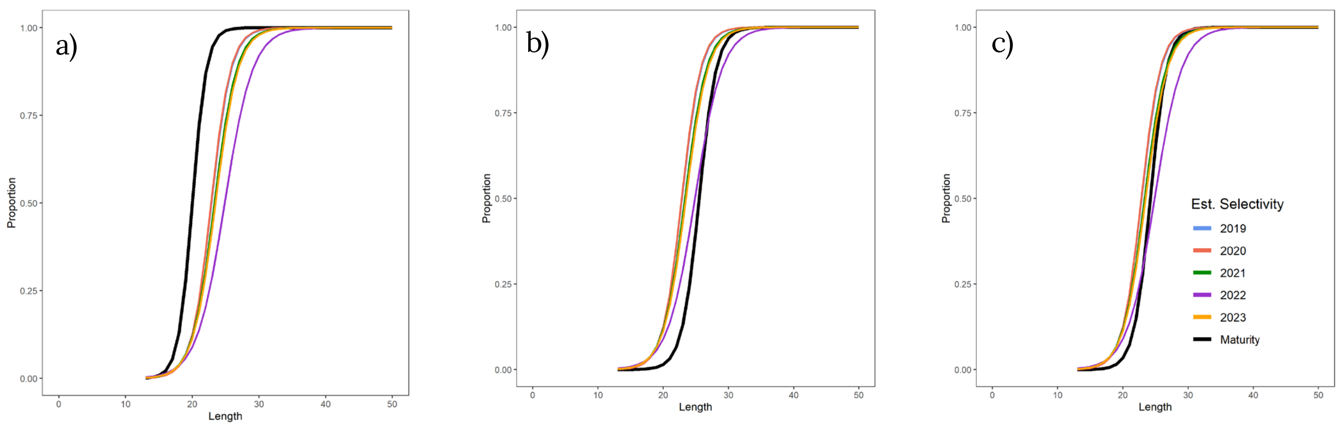


Figure 109. Length curves for blue and red shrimp. Black line shows the length curve at maturity. Colour lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (a), scenario 2 (b) and scenario 3 (c).

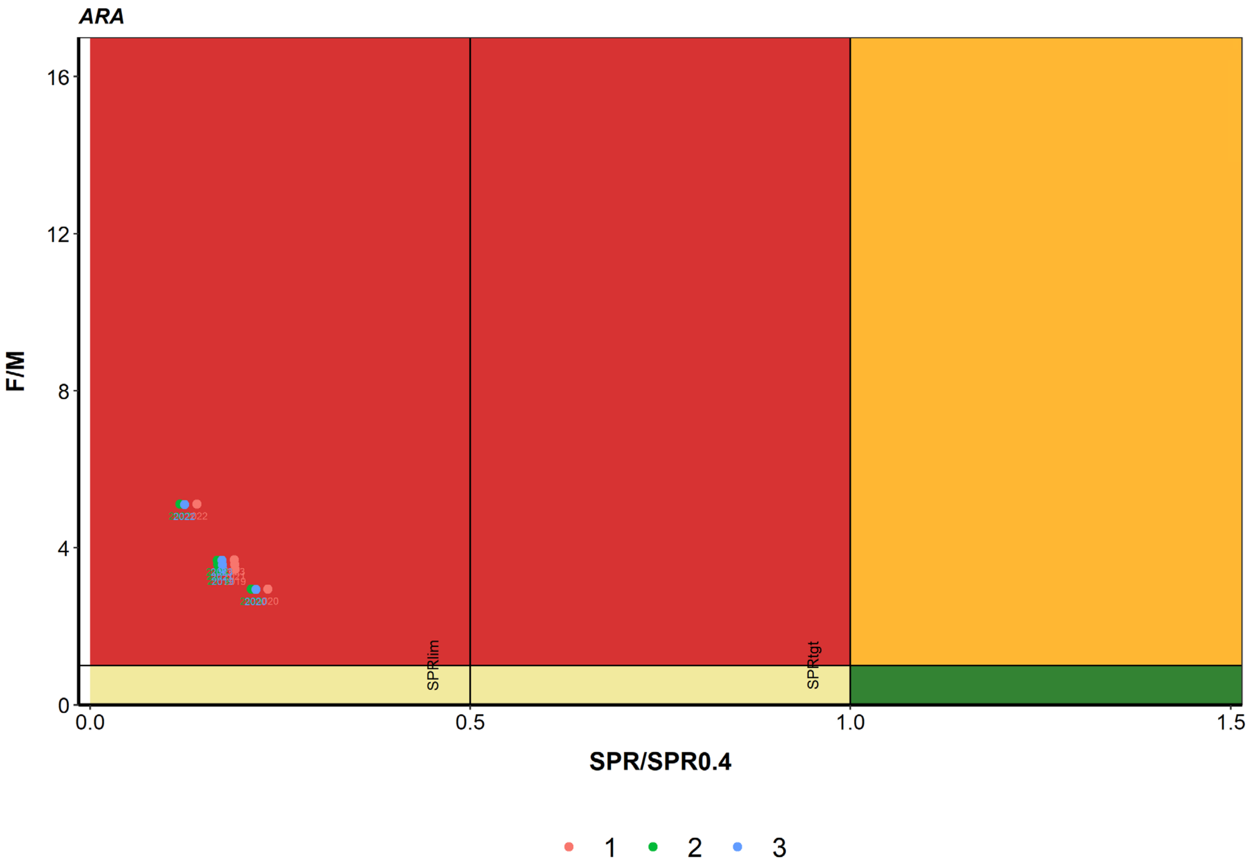
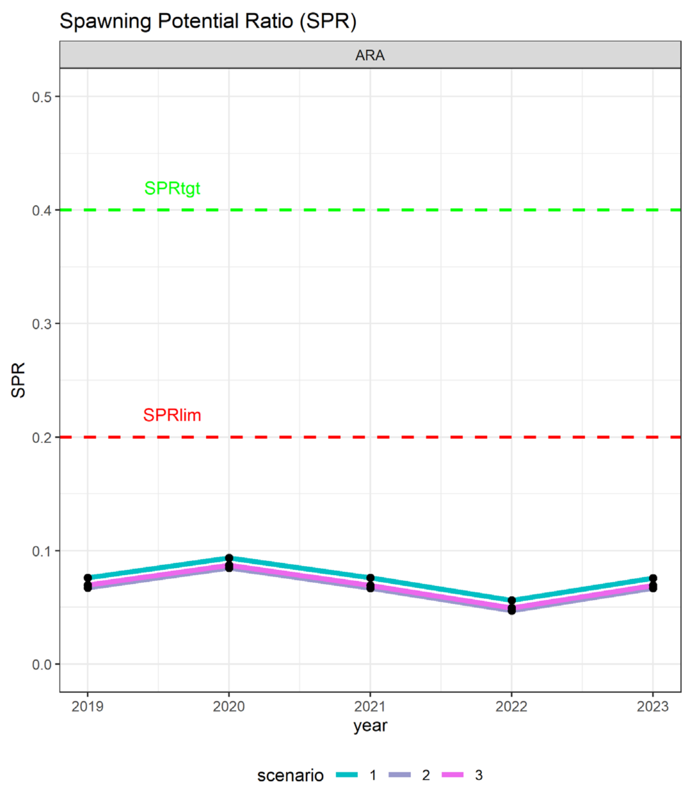


Figure 110. Kobe plot for blue and red shrimp by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.



Reference points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is below SPR_{lim} (=0.1)(Table 21 and Figure 111). The Kobe plot for blue and red shrimp (Figure 110) shows the stock status throughout the different years, with no clear trend. In all cases, the stock status is located in the red zone, meaning that the stock is overfished and under overfishing.

Figure 111. Spawning potential ratio (SPR) per year analysed for blue and red shrimp evaluated with LBSPR model. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio,SPR_{tgt}: target spawning potential ratio. Coloured lines show the results for each scenario.

Table 21. LBSPR model results for blue and red shrimp with the different scenarios tested for each year analysed. SL_{50}: Length where 50% of individuals are caught, SPR: spawning potential ratio and FM: fishing mortality. SD is the standard deviation calculated for each indicator.

Species	Scenario	Year	SL_{50}	SD	SPR	SD	FM	SD
ARA	**1**	**2019**	23.12	0.27	0.08	0.04	3.45	0.94
ARA	**1**	**2020**	23.09	0.31	0.09	0.05	2.95	0.85
ARA	**1**	**2021**	23.67	0.35	0.08	0.04	3.58	0.99
ARA	**1**	**2022**	25.34	0.41	0.06	0.03	5.12	1.33
ARA	**1**	**2023**	24.07	0.63	0.08	0.04	3.70	1.08
ARA	**2**	**2019**	23.11	0.26	0.07	0.04	3.46	0.95
ARA	**2**	**2020**	23.08	0.29	0.08	0.05	2.95	0.86
ARA	**2**	**2021**	23.66	0.33	0.07	0.04	3.58	0.99
ARA	**2**	**2022**	25.33	0.40	0.05	0.03	5.12	1.33
ARA	**2**	**2023**	24.04	0.60	0.07	0.04	3.69	1.08
ARA	**3**	**2019**	23.12	0.27	0.07	0.04	3.45	0.93
ARA	**3**	**2020**	23.09	0.30	0.09	0.05	2.95	0.84
ARA	**3**	**2021**	23.67	0.34	0.07	0.04	3.57	0.98
ARA	**3**	**2022**	25.34	0.41	0.05	0.03	5.11	1.32
ARA	**3**	**2023**	24.06	0.63	0.07	0.04	3.69	1.07

Final scenario

As LFD and L_{mat} originated from ICATMAR data, scenario three was selected to provide final advice for the LBSPR model.

Stochastic Production model in Continuous Time (SPiCT)

For blue and red shrimp data was taken from EU fleet register provided by the European Commission (Reg. EU 2017/218), GSA6 daily commercial fishing landings provided by the Spanish Ministry of Agriculture, Fisheries and Food, DCF and GFCM Stock Assessment Form (SAF) for ARA in GSA6 RY2022 (Figure 112)

Landings from 1996 to 2022 (Tons)

OTB CPUE from 1996 to 2022 (kg/vessel/day)

Index: MEDITS survey data from 1996 to 2022 (Biomass, kg/km2)

To compare input data, a double axis plot was presented in Figure 113. The MEDITS index is more or less constant since 2013. Catches and CPUE follow a similar trend, decreasing since 2013. Considering the data available, three scenarios were defined as follows:

Scenario 1: MEDITS + CPUE OTB

Scenario 2: MEDITS

Scenario 3: CPUE OTB

All the final scenarios end in 2022 because no MEDITS data for 2023 was available. Further work will be needed regarding the longest time series and standardized CPUE.

Settings for all final scenarios selected:

Catches from 1996 to 2022.

```
dat$stdevfacC = rep(1,length(dat$obsC))

ce = 0.05

dat$priors$logsdc <- c(log(ce), 0.3, 1)

dat$priors$logr <- c(log(0.66),0.05,1)

bk.pr=c(0.5,0.5,1)

dat$priors$logbkfrac <- c(log(bk.pr[1])-bk.pr[2]^2/2,bk.pr[2],bk.pr[3])

dat$ini$logn <- log(2)

dat$phases$logn <- -1

pe = c(0.1,0.5,1)

dat$priors$logsdb <- c(log(pe[1])-0.5*pe[2]^2, pe[2], pe[3])

fdevs=c(4,0.5,1)

dat$priors$logsdf <- c(log(fdevs[1])-0.5*fdevs[2]^2, fdevs[[2]], fdevs[3])

dat$priors$logalpha <- c(0,0,0)

dat$priors$logbeta <- c(0,0,0)

dat$dteuler = ¼
```

<u>Scenario 1 MEDITS + CPUE OTB</u>

The input data (Figure 114) consisted of a landings time series from 1996 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 1996 as for CPUE for OTB.

Indices were added considering the specific month each survey was carried out per year. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value of 0.3 was set for BK frac.

The observation error for the MEDITS survey was set SE=0.4 and CPUE: SE = 0.2, and CV = 0.3.

Figure 115 shows a summary of the scenario 1 fit. The relative biomass has been below 1 since 1996, and the estimated fishing mortality has been above 1 since 1996. It is important to consider the estimates uncertainty.

<u>Scenario 2 MEDITS</u>

The input data (Figure 116) consisted of a landings time series from 1996 onwards and a biomass index to tune the model. The biomass index data were derived from the MEDITS bottom trawl survey from 1996.

Indices were added considering the specific month each survey was carried out per year. In the case of MEDITS, the survey was carried out in the middle of June.

For this scenario, a final value of 0.3 was set for BK frac.

The observation error for MEDITS is SE=0.5 with CV = 0.3.

Figure 117 shows a summary of the scenario 2 fit. The relative biomass has been above 1 since 2015, and the estimated fishing mortality has been below 1 since 2007. It is important to consider the estimates uncertainty.

<u>Scenario 3 CPUE OTB</u>

The input data (Figure 118) consisted of a landings time series from 1996 onwards and a biomass index to tune the model. The biomass index data were derived from CPUE for OTB from 1996.

For this scenario, a final value of 0.5 was set for BK frac.

The observation error for CPUE, SE = 0.2, with CV = 0.3.

Figure 119 shows a summary of the scenario 3 fit. For the whole time series, the relative biomass was below 1 as is the case of estimated fishing mortality. It is important to consider the estimates uncertainty.

Finally, Figure 120 compares the three final scenarios. It is important to highlight the different perceptions of the stock status depending on the input data.

Scenario 2 was selected as the final one since the CPUE OTB index did not give contrast to the model.

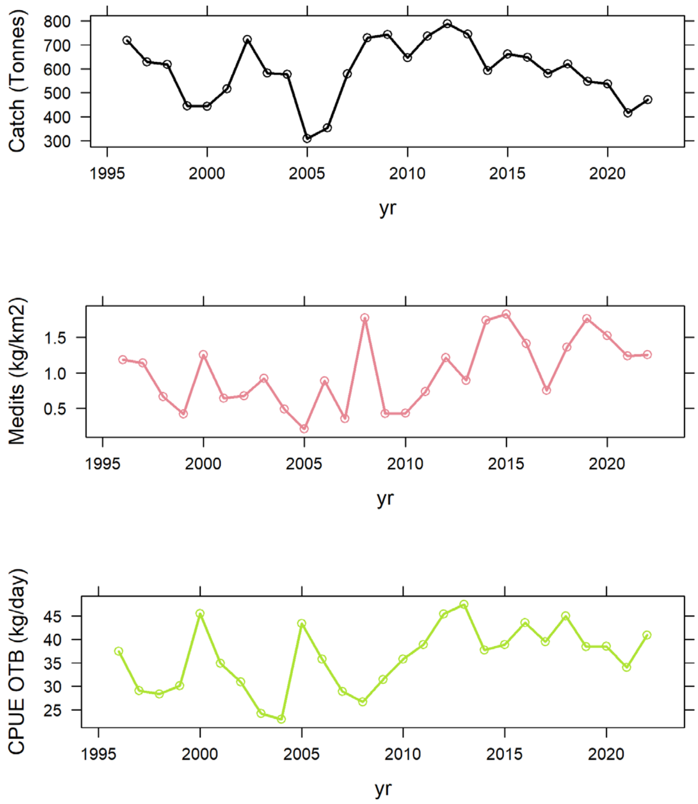


Figure 112. Data available for the assessment for blue and red shrimp in GSA6 to run SPiCT model. Top: catch data from 1996 to 2022. Centre: Medits survey data since 1996 to 2022. Bottom: CPUE for OTB data since 1996 to 2022.

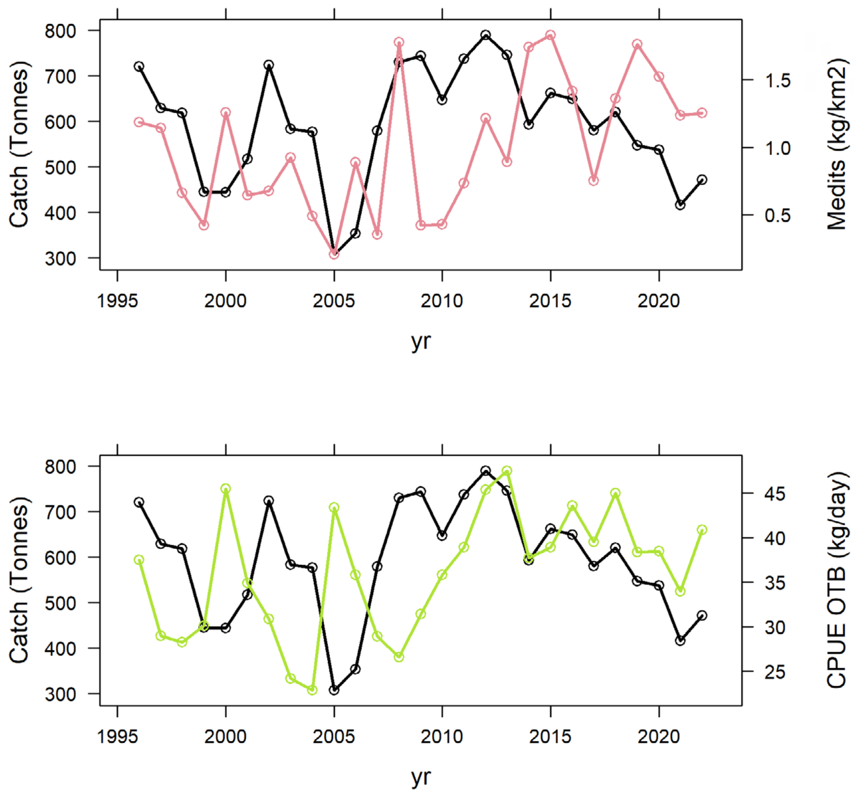


Figure 113. Double axis plot to compare trends between catch and Medits index (top) and catch and CPUE for OTB (bottom) for blue and red shrimp.

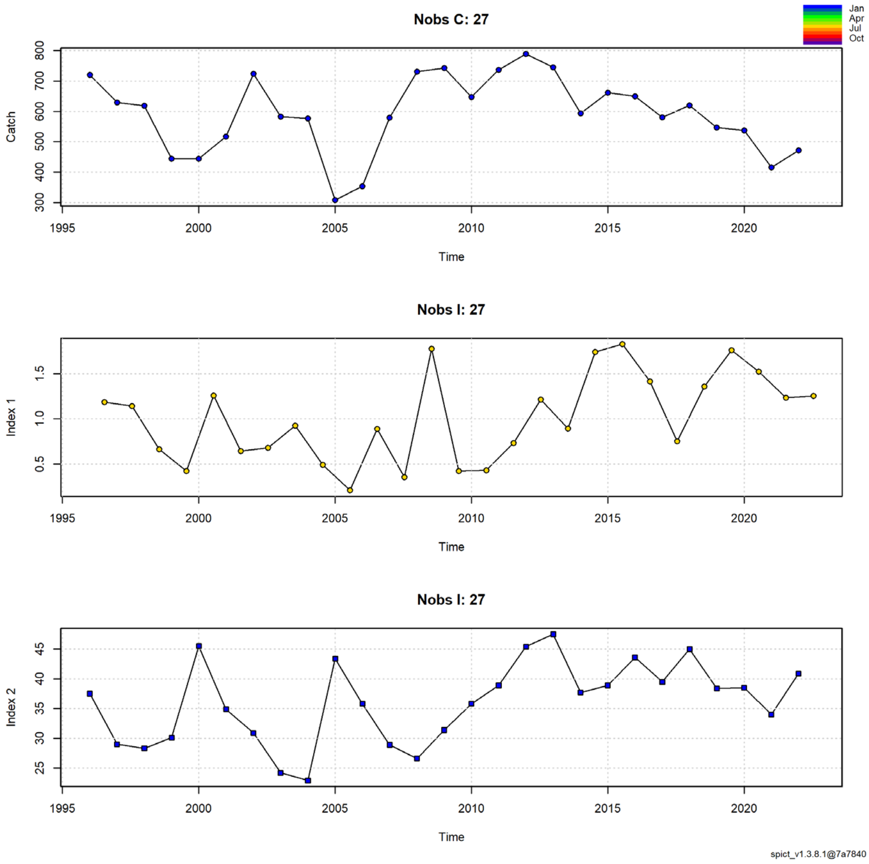


Figure 114. Input data for SPiCT model for blue and red shrimp in GSA6 for scenario 1. Top: catch in tones per year since 1996, centre: index data of biomass derived from MEDITS since 1996, and bottom: CPUE for OTB data since 1996 to 2022.

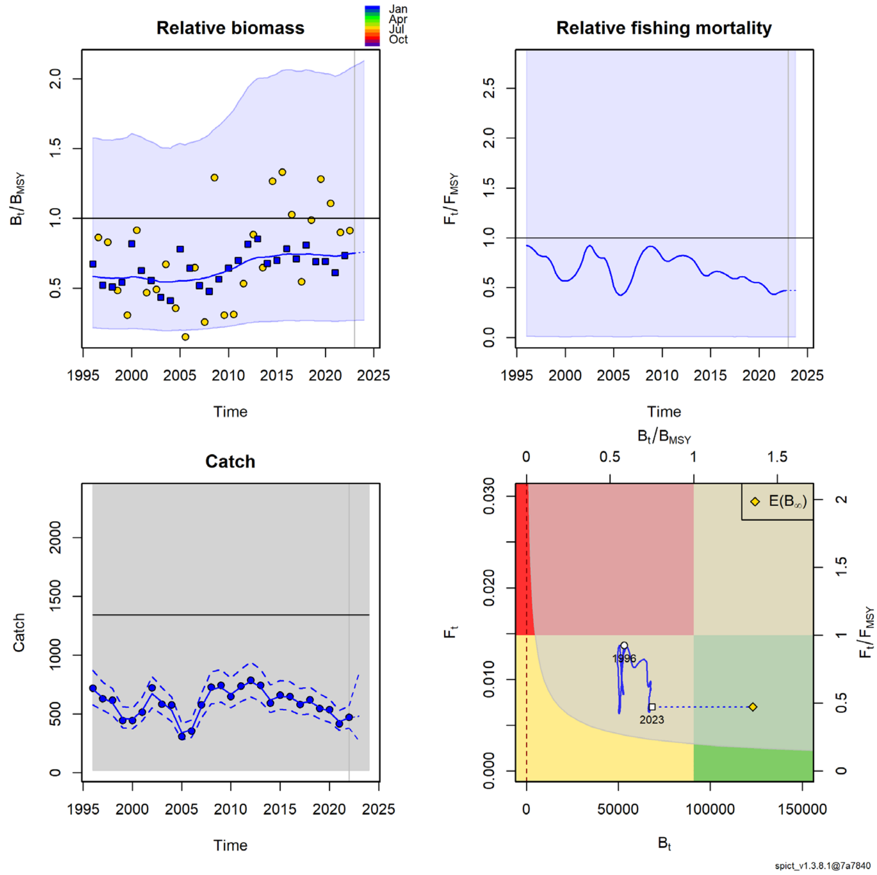


Figure 115. Stock assessment summary for SPiCT model for blue and red shrimp in GSA6 for scenario 1.

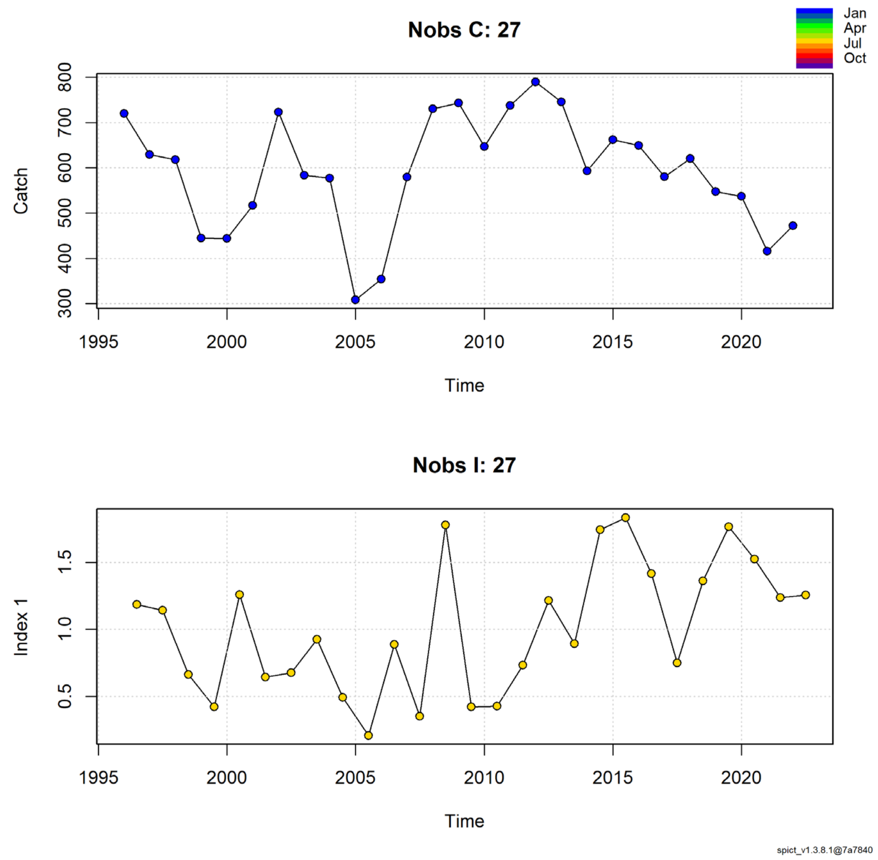


Figure 116. Input data for SPiCT model for blue and red shrimp in GSA6 for scenario 2. Top: catch in tones per year since 1996 and bottom: index data of biomass derived from MEDITS since 1996.

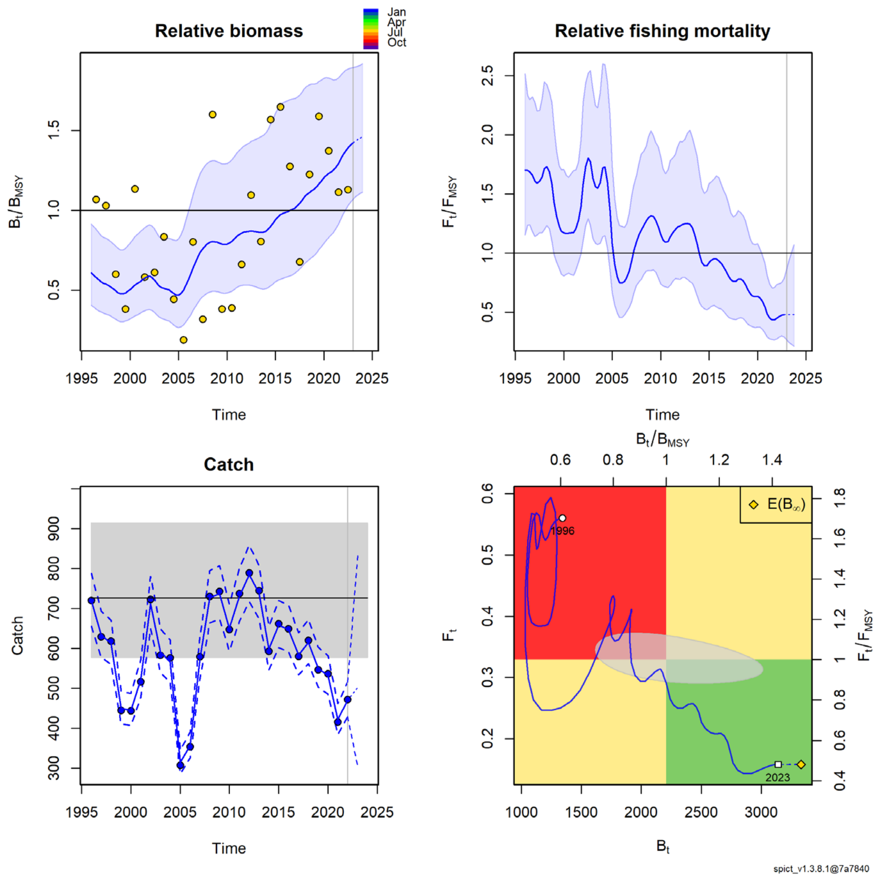


Figure 117. Stock assessment summary for SPiCT model for blue and red shrimp in GSA6 for scenario 2.

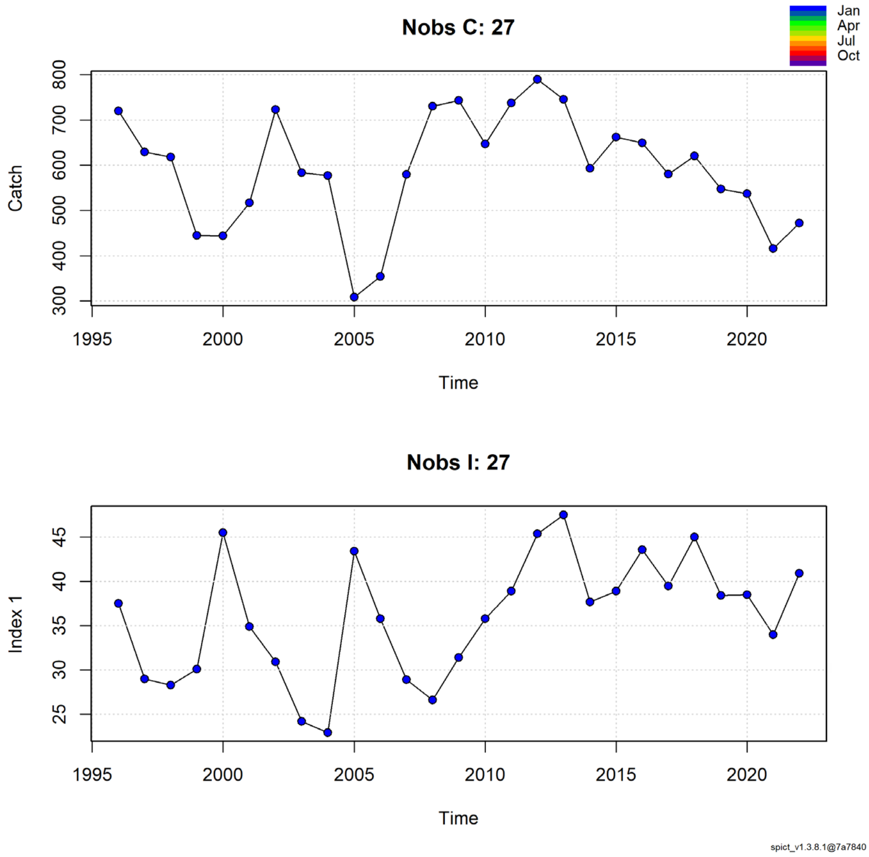


Figure 118. Input data for SPiCT model for blue and red shrimp in GSA6 for scenario 3. Top: catch in tones per year since 1996, bottom: CPUE data since 19969 to 2022.

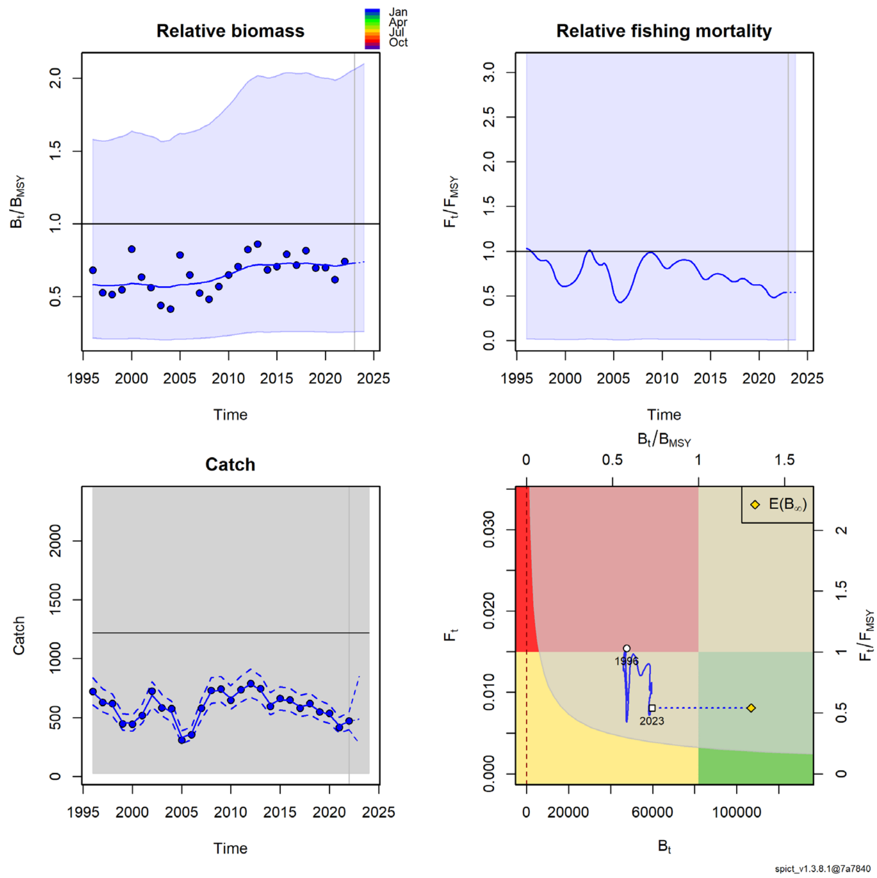


Figure 119. Stock assessment summary for SPiCT model for blue and red shrimp in GSA6 for scenario 3.

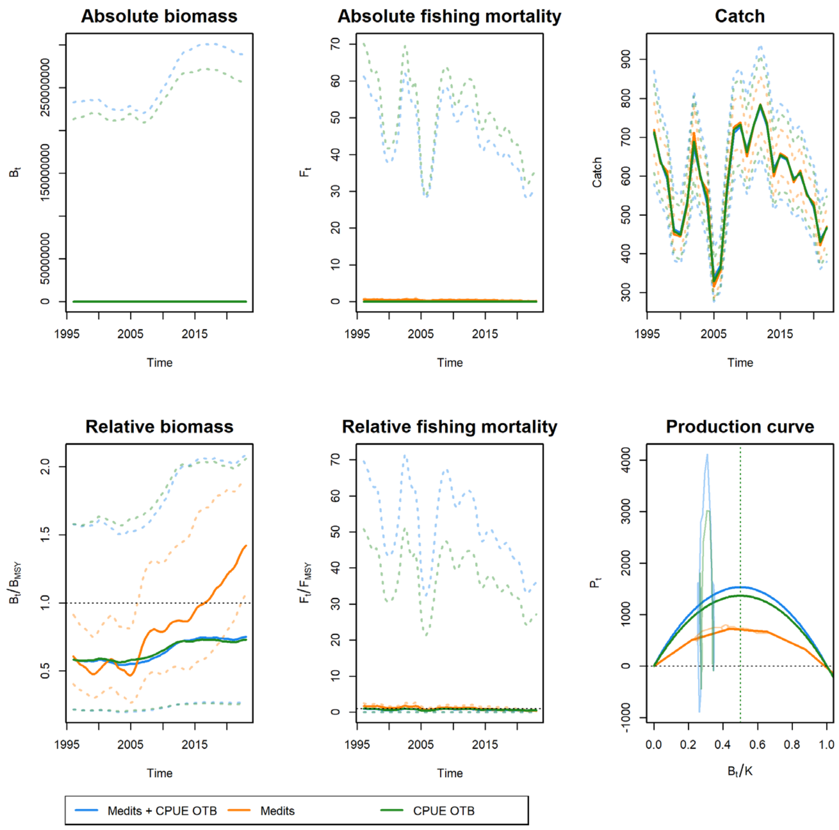


Figure 120. Scenarios comparison for blue and red shrimp in GSA6.

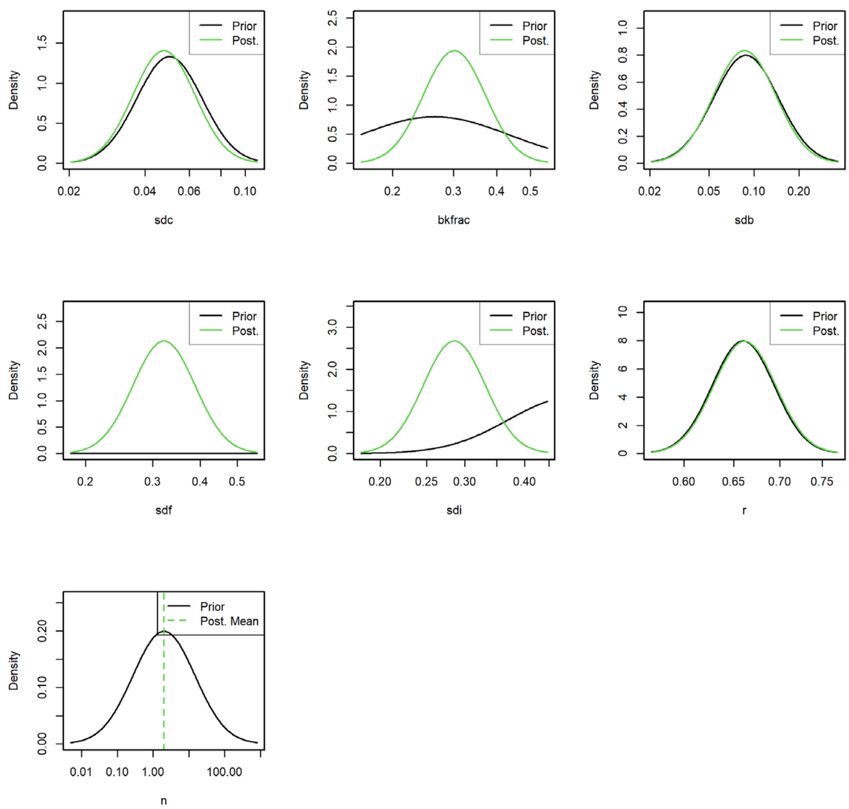


Figure 121. Estimated priors and posteriors for the updated assessment for blue and red shrimp in GSA6 for scenario 2.

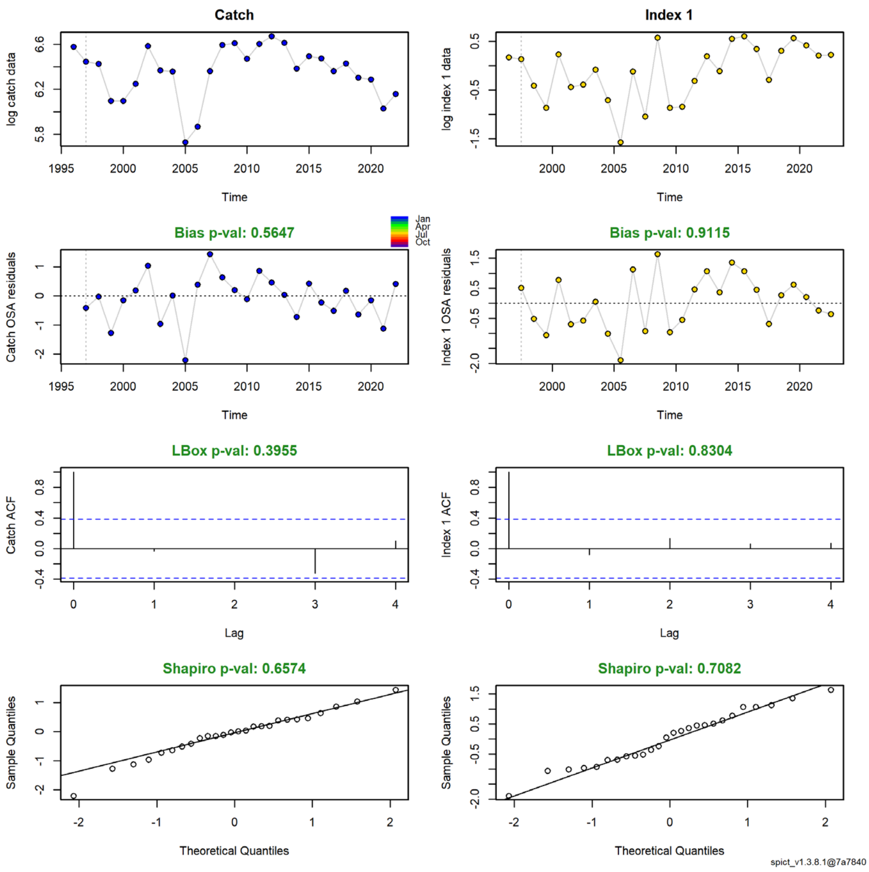


Figure 122. One-step-ahead residuals for the model for blue and red shrimp in GSA6 for scenario 2.

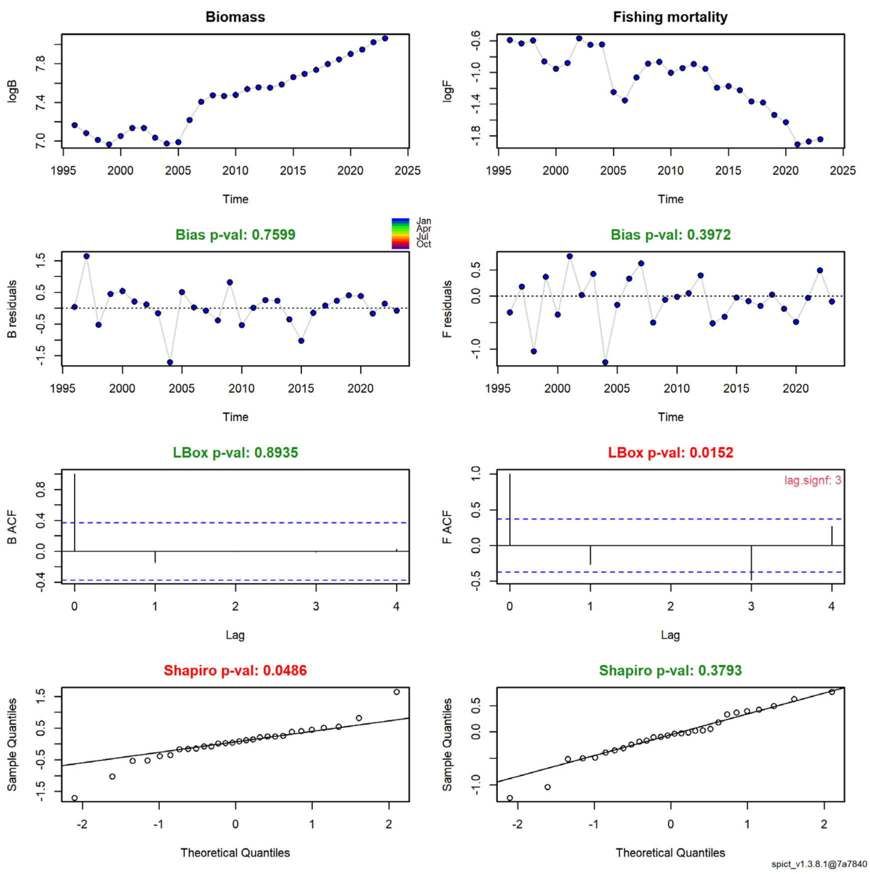


Figure 123. Process error deviations for the model for blue and red shrimp in GSA6 for scenario 2.

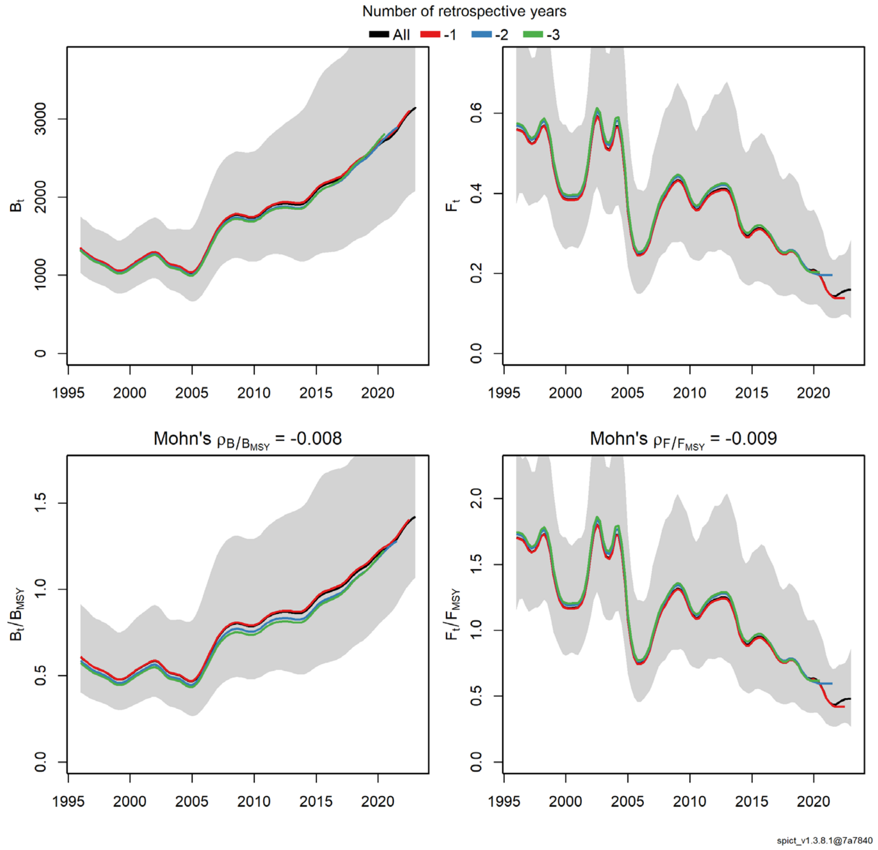


Figure 124. Retrospective analysis for blue and red shrimp in GSA6 for scenario 2.

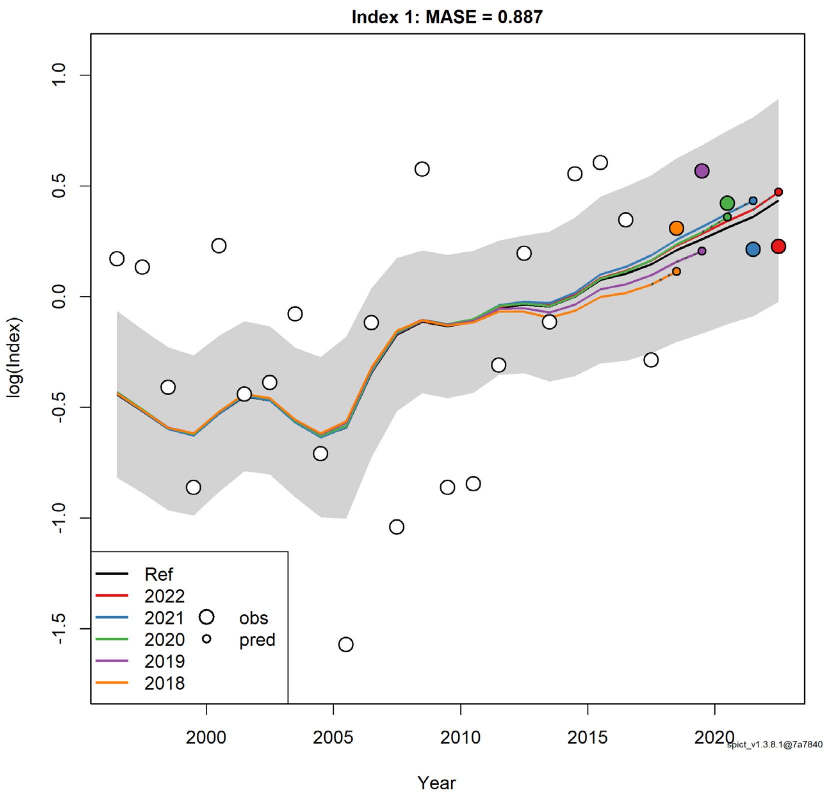


Figure 125. Hindcasting for the model for blue and red shrimp in GSA6 for scenario 2.

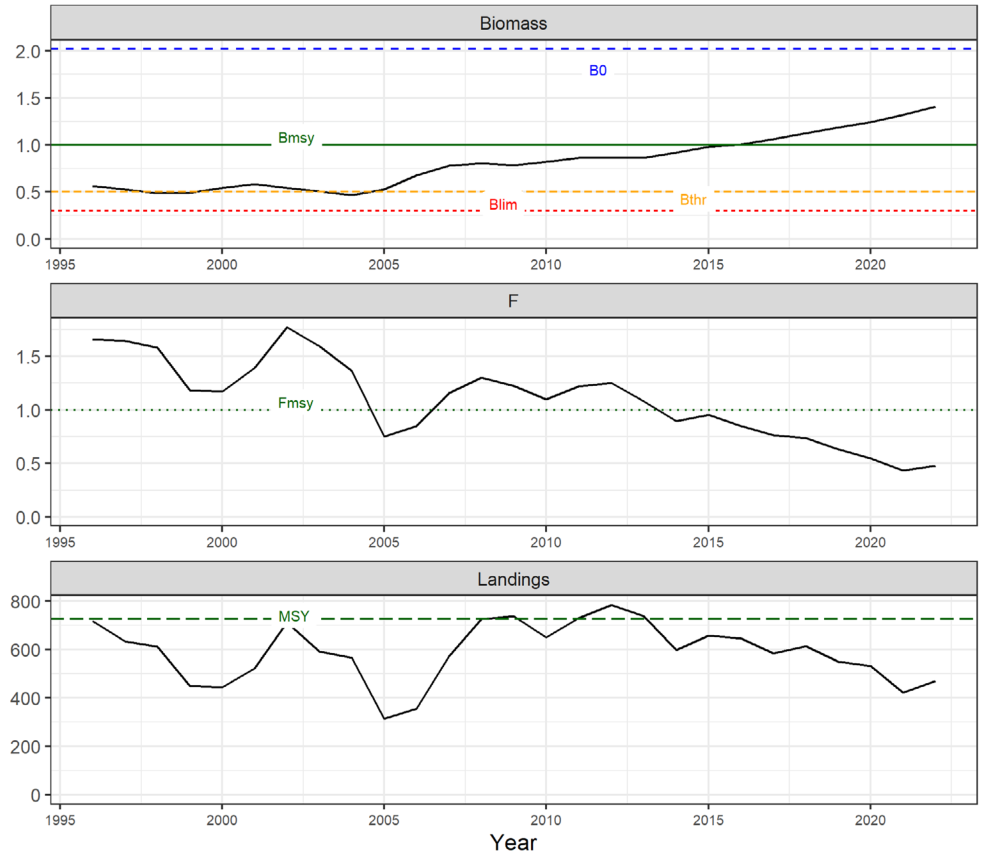


Figure 126. Advice for scenario 2 for blue and red shrimp in GSA6: Historical and current stock status regarding F_{msy}, B_{msy} and B_{lim}.

Table 22. Indicators in 2022 from SPiCT for blue and red shrimp in GSA6.

Species	Year	Catch (t)	FFmsy	BBmsy	BBpa	BBlim
ARA	**2022**	470.36	0.48	1.41	2.82	4.7

Final scenarios diagnostics

Diagnostics for the final scenario selected (i.e., Scenario 2) were shown below (Figure 121, Figure 122, Figure 123, Figure 124, Figure 125). The chosen scenario met most of the model diagnostics and provided good retrospective analysis and hindcasting diagnostics.

The annexes contain all the diagnostics for scenario 1 (Annex 57, Annex 59, Annex 60, Annex 61) and scenario 3 (Annex 62, Annex 63, Annex 64, Annex 65, Annex 66).

Also, a sensitivity analysis for scenario 2 was performed, testing r prior (Annex 67), bkfrac (Annex 68), process error (Annex 69Annex 41), and observation error (Annex 70) to see how robust the model is within these priors.

Final scenarios advice

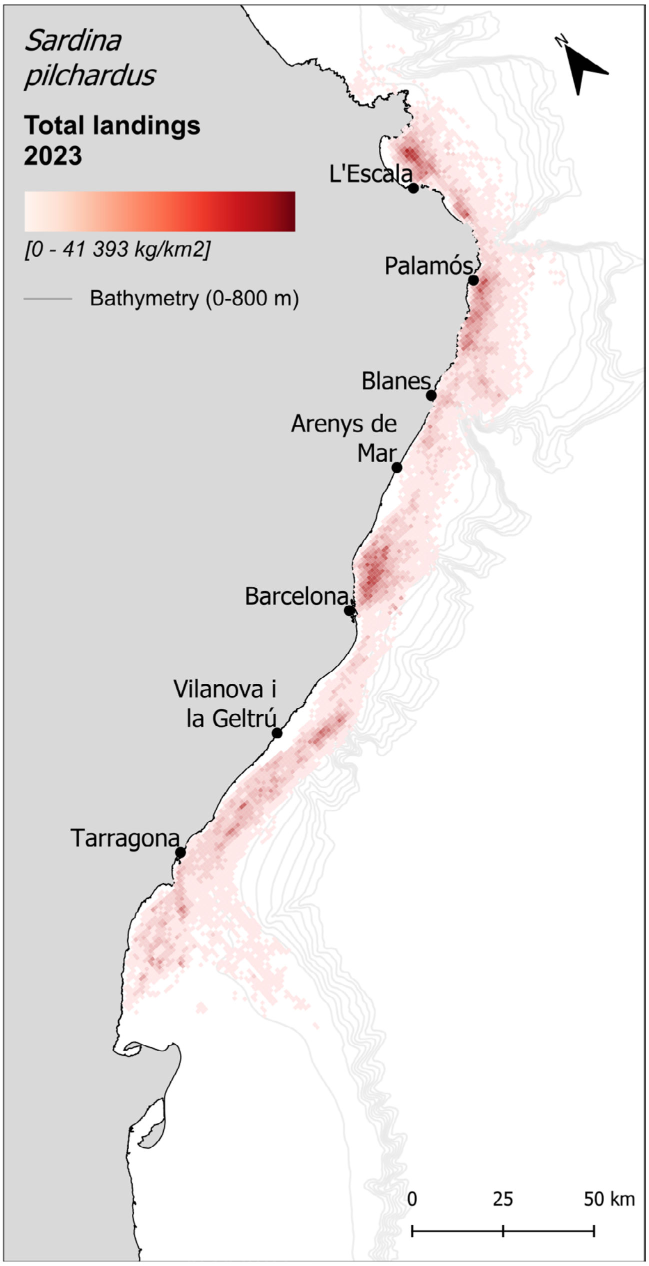
Figure 126 represents the stock assessment for the final scenario (i.e., scenario 2) (advice framework) using MEDITS as a biomass index. Table 22 shows indicators in 2022 for scenario 2 for blue and red shrimp in GSA6.

SECTION 4
Results by stock

Small pelagic fishes

Stock assessment results for species in the GSA6

European sardine (*Sardina pilchardus*) PIL



The reproduction of the European sardine occurs between November and February (ICATMAR, 24-05), and recruitment is observed afterwards, in spring and summer.

Input data

The spatial distribution of total landings for European sardine in the Catalan fishing grounds (Figure 127) is located, mainly, in lower coastal areas along the Catalan coast, with no occurrence in the Delta area (the southernmost area of the coast).

Historical European sardine landings in Catalonia from 2002 to 2023 are shown in Figure 128. The total catch peaked in 2007 with a great decrease from 2008 to 2010. The historical minimum landings were observed in 2023.

Figure 127. Spatial distribution of landings per unit of effort (LPUE) for European sardine in the Catalan fishing grounds (North GSA6) in the year analysed.

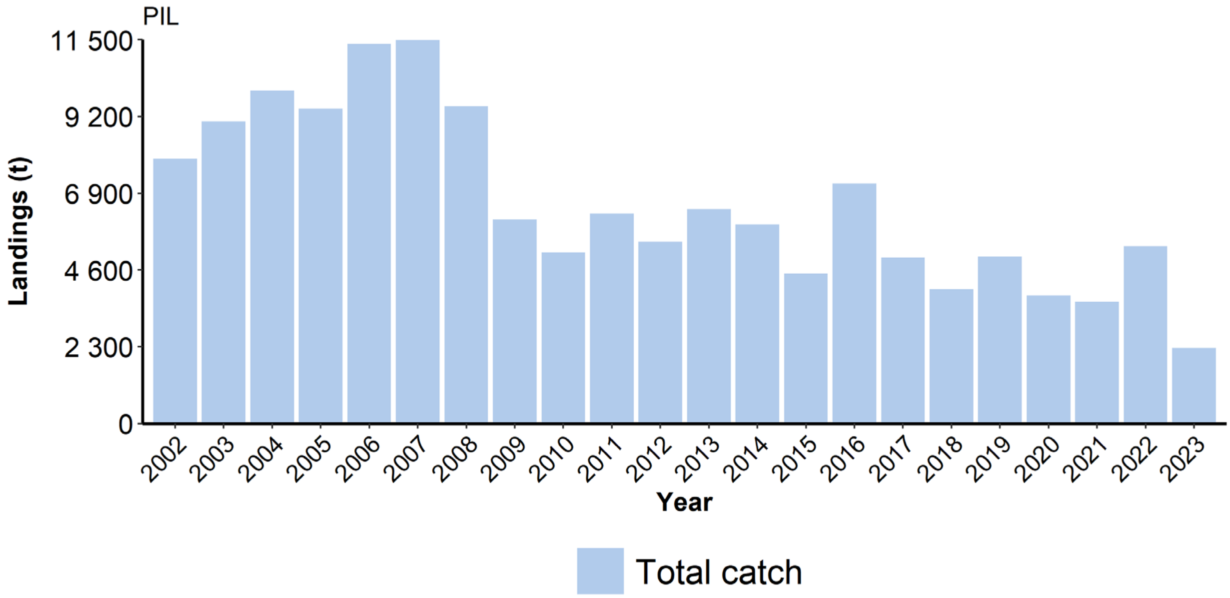


Figure 128. Historical landings (t) for European sardine in Catalonia.

Annual LFD

After raising the length frequencies obtained with the monitoring program from commercial landings (Table 23), the annual length frequency of European sardine in Catalonia is plotted in Figure 129. The size classes with greater frequencies are about 125 - 130 mm in total length. Although for some bottom trawling metiers in the delta shelf discards of small pelagic fishes were important (Blanco et al. 2023) its biomasses were residual compared to purse seine landings.

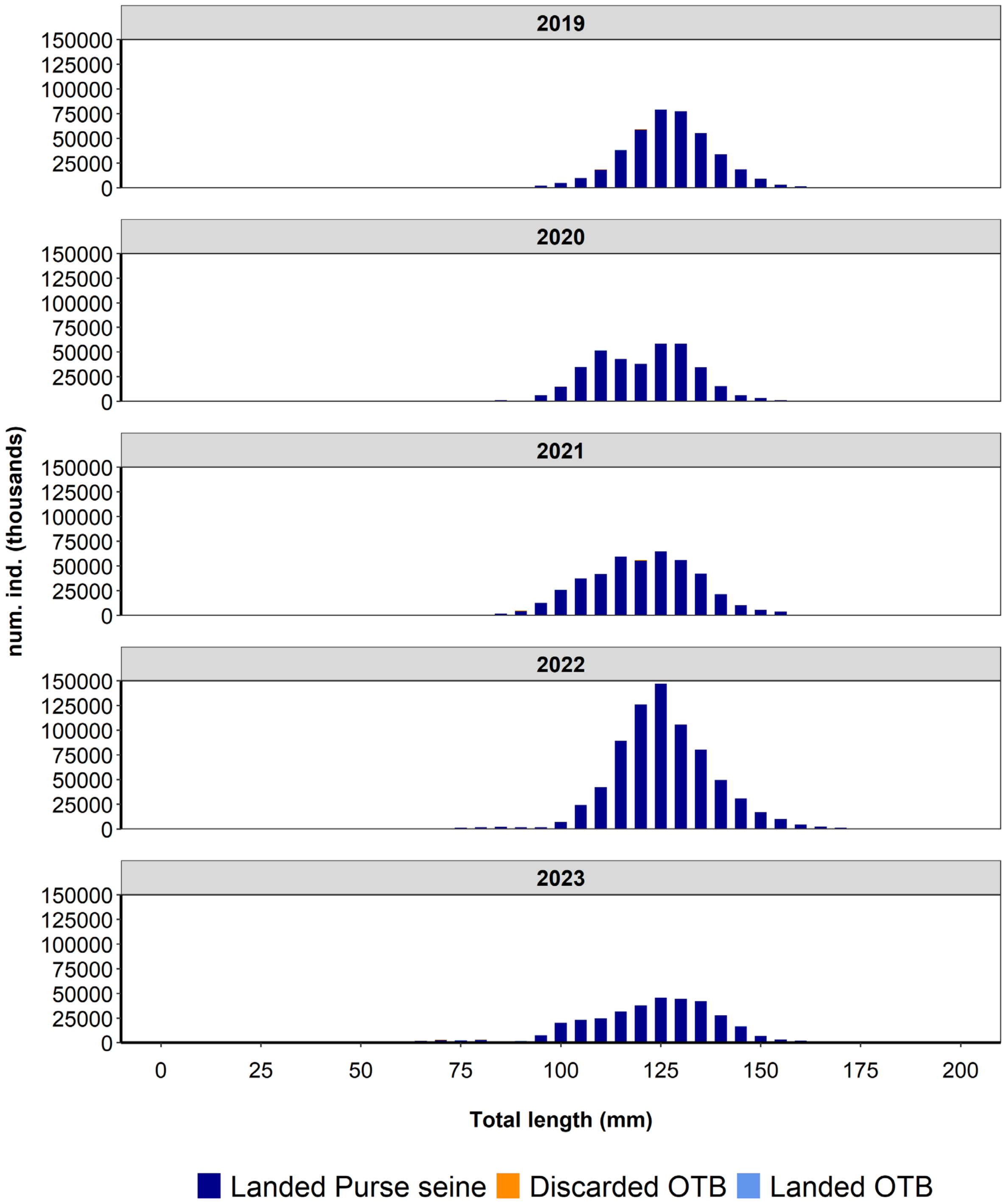


Figure 129. Annual length frequency distributions of European sardine from bottom trawling and small-scale fisheries. The data from bottom trawling is raised from ICATMAR data and details landed and discarded European sardine. The data from small-scale fisheries is obtained from DCF (Data Collection Framework) dataset.

Table 23. Number of European sardine individuals sampled by zone and season from ICATMAR monitoring data used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N sampling
			Number individuals sampled				
Artisanal fisheries	2019	North	0	0	1	0	1
Artisanal fisheries	2019	Center	32	3	0	0	2
Artisanal fisheries	2021	North	1	0	0	0	1
Bottom trawl	2019	South	38	122	404	53	18
Bottom trawl	2020	North	0	0	3	1	2
Bottom trawl	2020	Center	0	0	30	1	2
Bottom trawl	2020	South	7	96	132	94	14
Bottom trawl	2021	North	4	0	4	0	4
Bottom trawl	2021	Center	9	1	15	11	6
Bottom trawl	2021	South	16	85	352	191	17
Bottom trawl	2022	North	0	5	2	1	4
Bottom trawl	2022	Center	4	0	0	38	2
Bottom trawl	2022	South	0	31	182	166	12
Bottom trawl	2023	North	0	8	2	3	3
Bottom trawl	2023	Center	0	70	31	0	2
Bottom trawl	2023	South	7	247	294	29	18
Purse seine (fish market)	2019	North	826	990	724	610	22
Purse seine (fish market)	2019	Center	800	861	725	690	19
Purse seine (fish market)	2020	North	722	393	936	681	18
Purse seine (fish market)	2020	Center	354	465	817	836	15
Purse seine (fish market)	2021	North	867	878	925	557	21
Purse seine (fish market)	2021	Center	623	370	921	526	17
Purse seine (fish market)	2022	North	979	785	500	407	17
Purse seine (fish market)	2022	Center	699	905	663	561	19
Purse seine (fish market)	2023	North	470	394	485	130	10
Purse seine (fish market)	2023	Center	570	463	598	431	15
Purse seine (on board)	2022	North	581	497	750	11	17
Purse seine (on board)	2022	Center	0	267	193	0	4
Purse seine (on board)	2023	North	1058	780	970	144	22
Purse seine (on board)	2023	Center	78	332	0	0	4
Purse seine (on board)	2023	South	0	0	1	0	1

Length-Based Spawning Potential Ratio (LBSPR)

Model setting and results

Scenarios

Three scenarios were applied considering different growth parameters and natural mortality from GFCM working groups (Table 24). In scenarios 3, L_{mat50} correspond to ICATMAR data (ICATMAR, 24-05).

Table 24. Biological parameters used in the different LBSPR scenarios for European sardine (PIL). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Species	Scenario	Linf (mm)	M/k	Lmat50 (mm)	Lmat95 (mm)
PIL	1	184	1.367	113.0	135.0
PIL	2	209	1.483	113.0	135.0
PIL	3	184	1.367	103.0	123.1
PIL	4	209	1.483	103.0	123.1

Fitted data

The length frequency distribution fit per year is shown in Figure 130. The model generally follows the mode for all years but it overestimates some length classes in the middle mode part and underestimates small individuals in 2020 and 2021. Also, in 2020, there was a decrease in the number of individuals, mainly for medium-length classes.

Selectivity

The outputs of the model for the selectivity of the fishery are shown for each scenario in Table 25. The outputs are also plotted together with L_{mat50} and SL_{50} for scenarios 1, 2 and 3 in Figure 131. In all scenarios, the fishery is fishing above or similar to L_{mat50}.

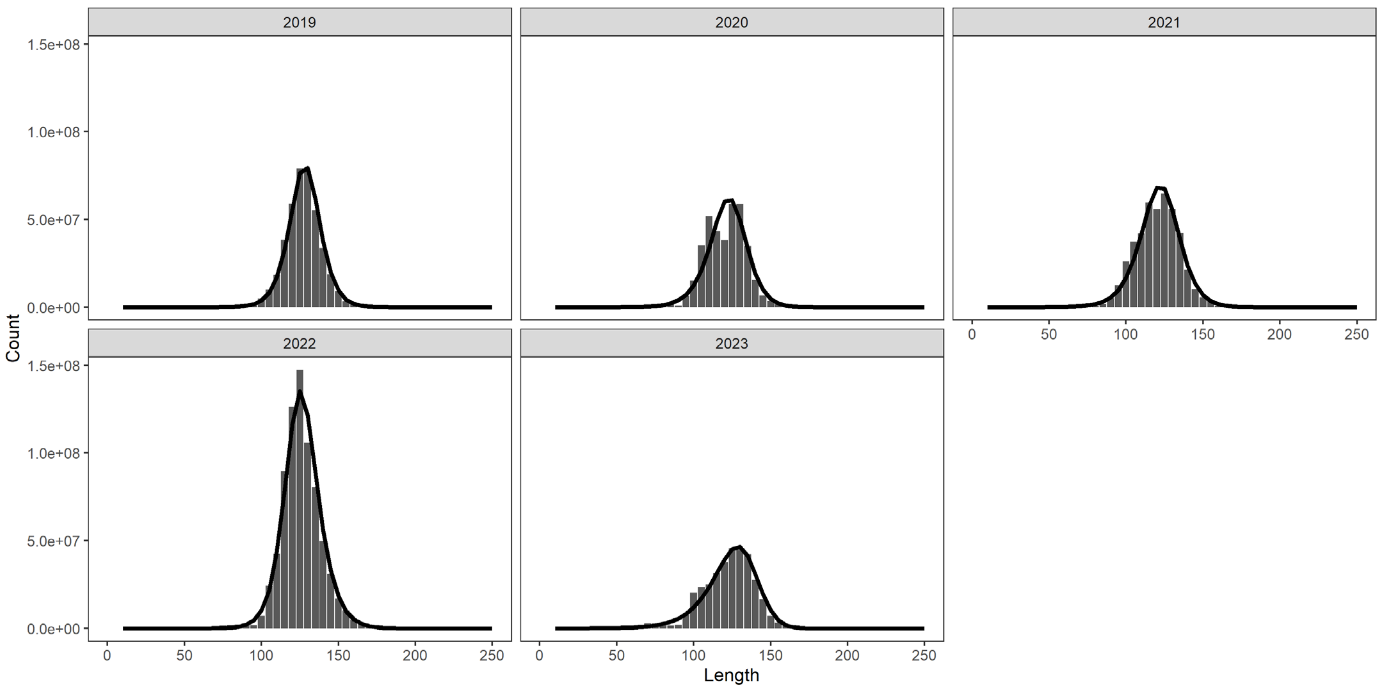


Figure 130. Fit of the data using the LBSPR model for European sardine for each studied year. Grey columns indicate length frequencies. Black lines indicate the fit of the model.

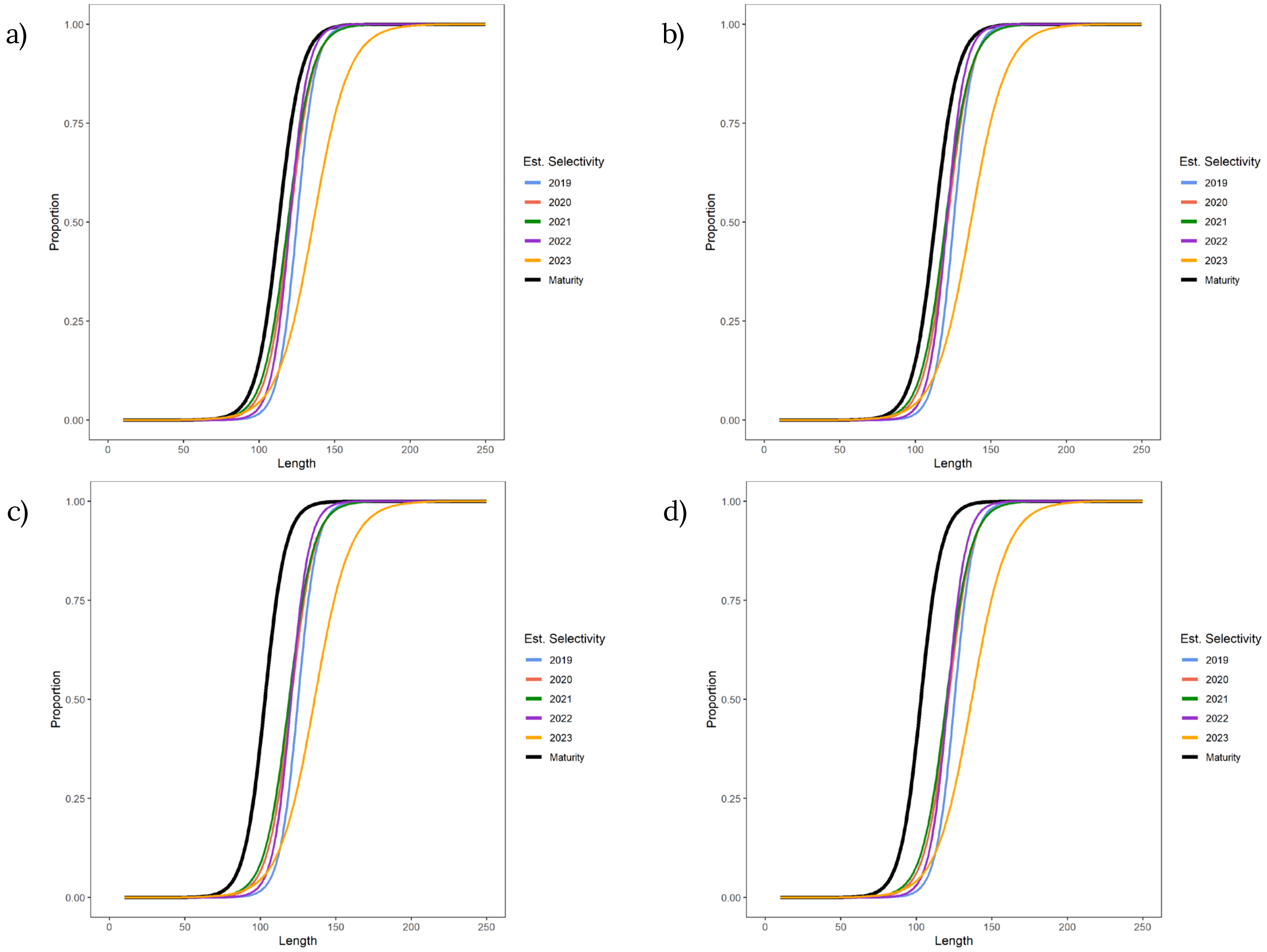


Figure 131. Length curves for European sardine. Black line shows the length curve at maturity. Colour lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (a), scenario 2 (b) scenario 3 (c) and (d) scenario 4.

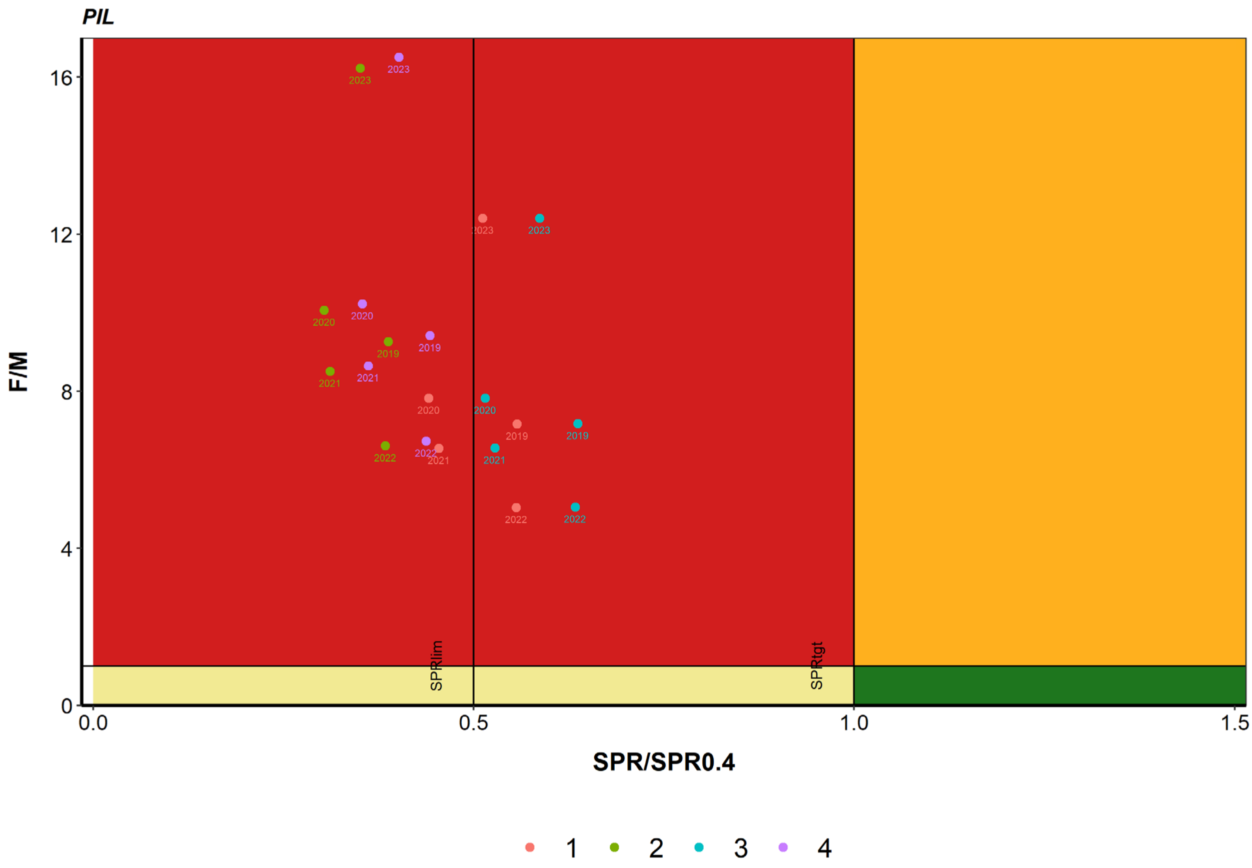


Figure 132. Kobe plot for European sardine by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

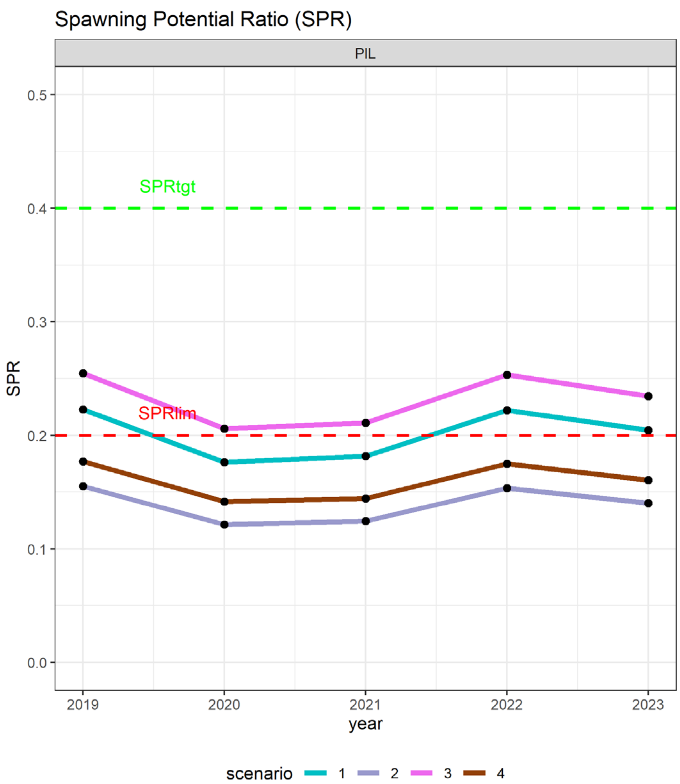


Figure 133. Spawning potential ratio (SPR) per year analysed for European sardine evaluated with LBSPR model. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. Coloured lines show the results for each scenario.

Reference points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is below SPR_{tgt} (=0.4) (Table 25 and Figure 133. For scenarios 2, 4 and 5, the stock is below SPR_{lim}. For scenarios 1 and 3, the stock is around SPR_{lim}. For scenario 5, the stock has the same value or is above SPR_{lim}, depending on each year. The Kobe plot for European sardine (Figure 132) shows the stock status through the years, with no clear trend. The stock is, in all cases, located in the red zone, meaning that it is overfished and under overfishing.

Final scenario

As LFD and L_{mat} originated from ICATMAR data, scenario three was selected to provide final advice for the LBSPR model.

Table 25. LBSPR model results for European sardine with the different scenarios tested for each year analysed. SL_{50}: Length where 50% of individuals are caught, SPR: spawning potential ratio and FM: fishing mortality. SD is the standard deviation calculated for each indicator.

Species	Scenario	Year	SL_{50}	SD	SPR	SD	FM	SD
PIL	**1**	**2019**	126.84	1.00	0.22	0.14	7.17	2.76
PIL	**1**	**2020**	123.63	1.87	0.18	0.13	7.83	3.12
PIL	**1**	**2021**	122.34	1.91	0.18	0.13	6.55	2.65
PIL	**1**	**2022**	122.09	1.01	0.22	0.15	5.04	2.00
PIL	**1**	**2023**	139.98	2.41	0.20	0.14	12.41	5.56
PIL	**2**	**2019**	126.88	0.84	0.16	0.10	9.27	2.91
PIL	**2**	**2020**	123.89	1.45	0.12	0.09	10.07	3.26
PIL	**2**	**2021**	122.66	1.48	0.12	0.09	8.51	2.78
PIL	**2**	**2022**	122.23	0.82	0.15	0.10	6.62	2.11
PIL	**2**	**2023**	140.46	1.87	0.14	0.10	16.23	5.76
PIL	**3**	**2019**	126.82	0.95	0.25	0.14	7.18	2.63
PIL	**3**	**2020**	123.60	1.77	0.21	0.13	7.83	2.96
PIL	**3**	**2021**	122.32	1.82	0.21	0.13	6.56	2.52
PIL	**3**	**2022**	122.07	0.96	0.25	0.14	5.05	1.90
PIL	**3**	**2023**	140.00	2.30	0.23	0.14	12.41	5.29
PIL	**4**	**2019**	126.90	0.80	0.18	0.10	9.42	2.86
PIL	**4**	**2020**	123.93	1.38	0.14	0.09	10.24	3.20
PIL	**4**	**2021**	122.69	1.42	0.14	0.09	8.65	2.73
PIL	**4**	**2022**	122.25	0.79	0.17	0.10	6.73	2.08
PIL	**4**	**2023**	140.52	1.79	0.16	0.10	16.51	5.67

Stochastic Production model in Continuous Time (SPiCT)

The GFCM working group on small pelagics in 2023 has already completed the stock assessment for GSA6 for small pelagics. For this report, data available in the Stock Assessment Form was used to reproduce the SPiCT model within the same settings but using a shorter time series.

For European sardine, input data for catches were from 1996 to 2022. Two different indexes were used: ECOMED, an autumn acoustic survey from 1996 to 2009, and MEDIAS, a summer acoustic survey from 2009 to 2022 (Figure 134). As for the other species, a double-axis plot (Figure 135) was presented to compare trends between catches and indices.

Only one scenario was presented, using the same input data as in the GFCM report (Figure 136).

The results (Figure 137) show a decreasing trend of biomass, with all the time series below the reference point. For fishing mortality, the estimated values remain above 1 for the whole time series. These results are comparable with those using the longest time series.

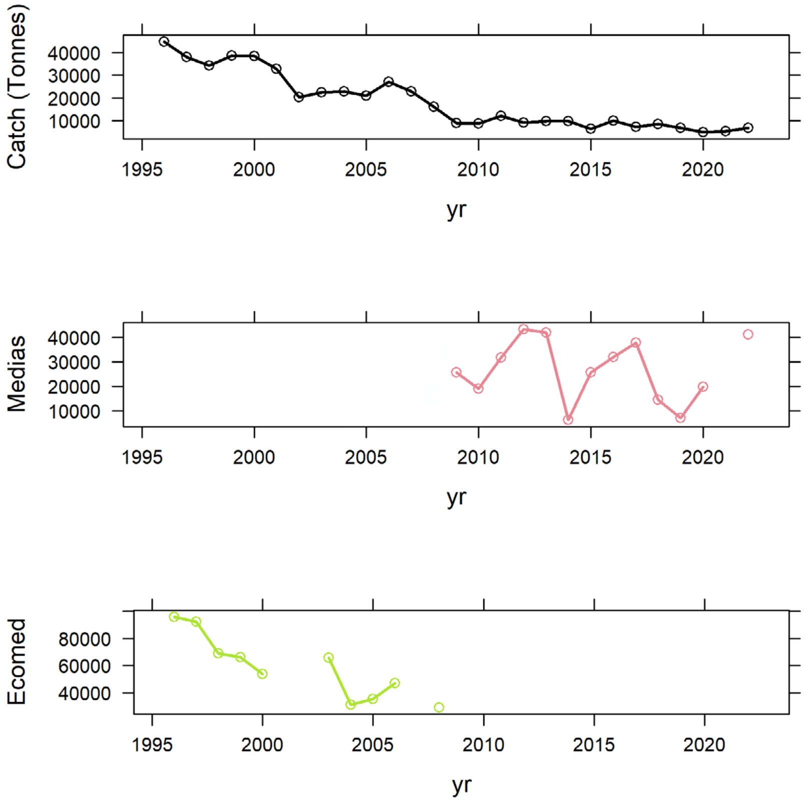


Figure 134. Data available for the assessment for European sardine in GSA6 to run SPiCT model. Top: catch data from 1996 to 2022. Centre: Ecomed acoustic survey data since 1994 to 2008 and Medias acustic survey since 2009 to 2022.

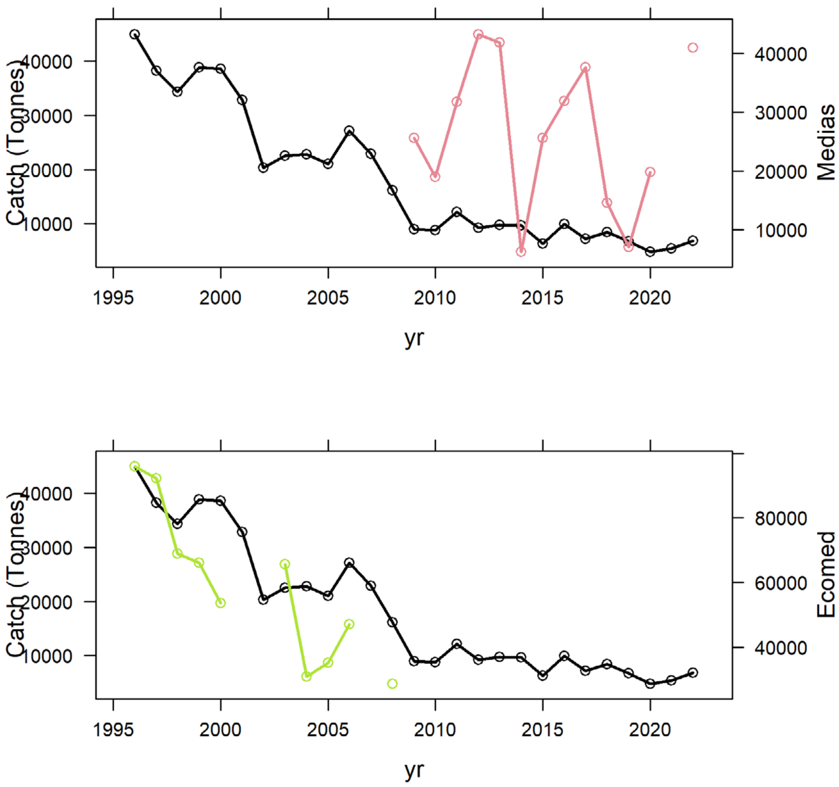


Figure 135. Double axis plot to compare trends between catch and Ecomed index (top) and catch and Medias index (bottom) for European sardine.

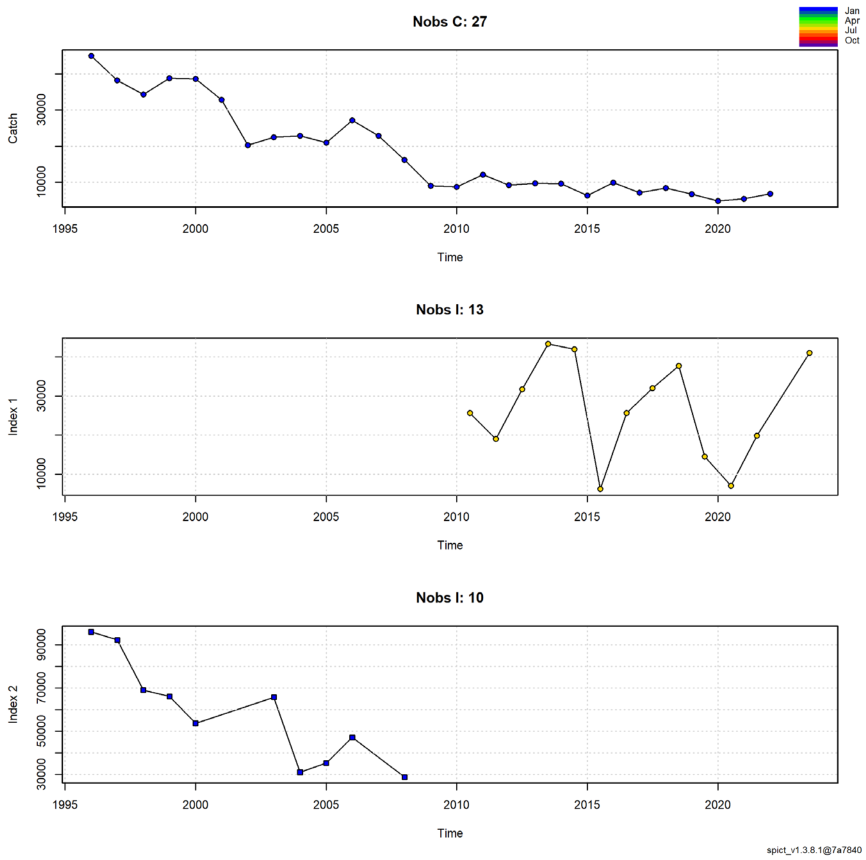


Figure 136. Input data for SPiCT model for European sardine in GSA6. Top: catch in tones per year since 1996, centre: index data of biomass derived from Medias survey since 2009 to 2022, and bottom: Ecomed survey since 1994 to 2008.

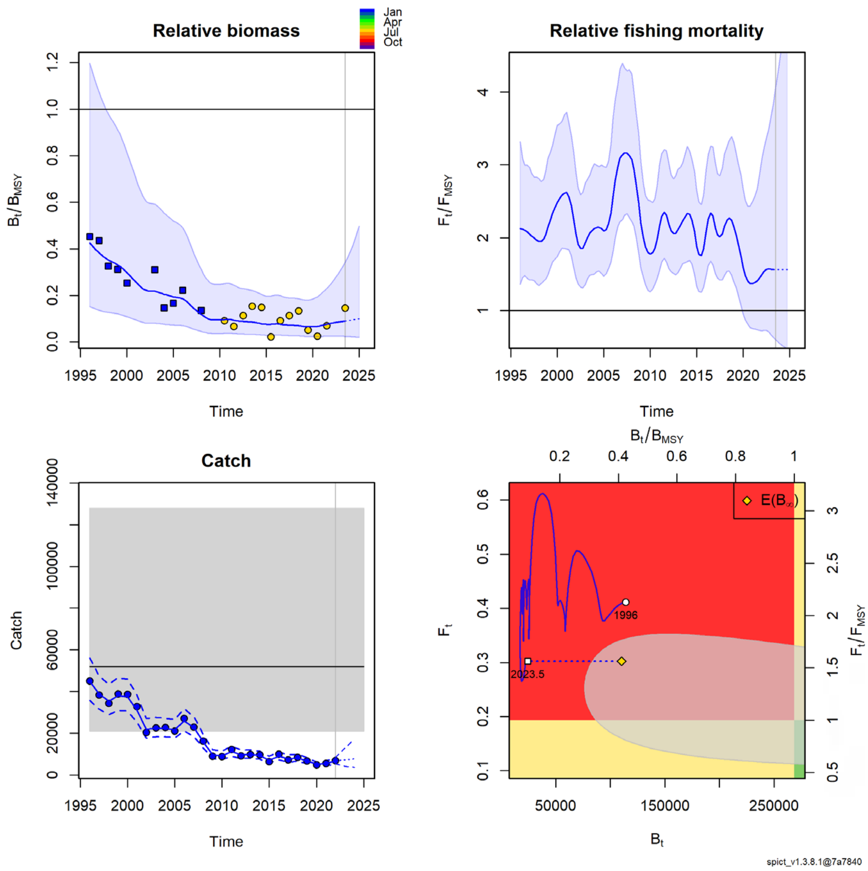


Figure 137. Stock assessment summary for SPiCT model for European sardine in GSA6.

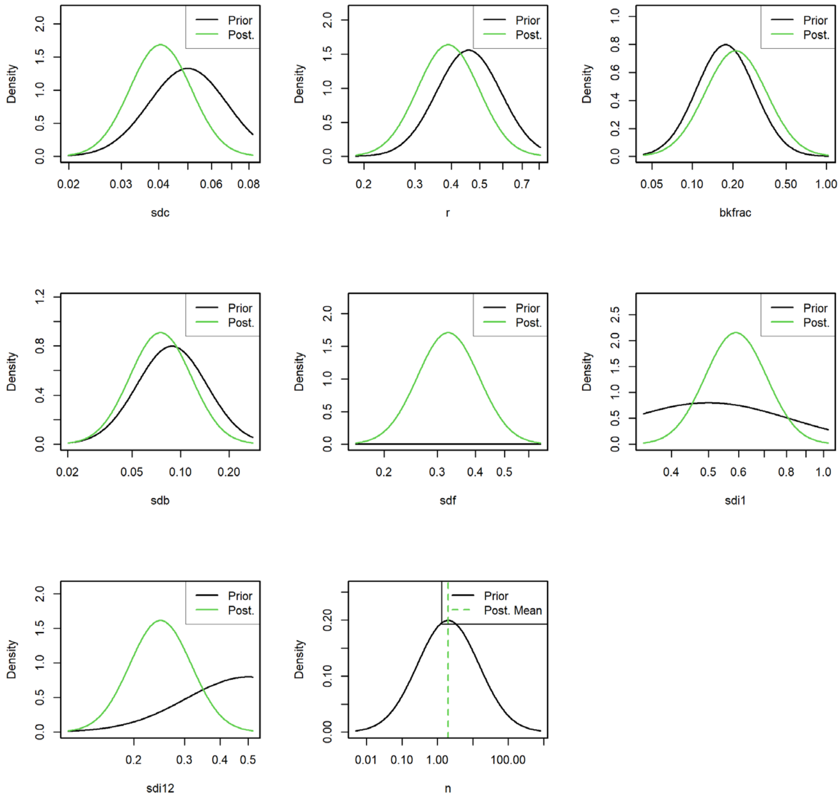


Figure 138. Estimated priors and posteriors for the updated assessment for European sardine in GSA6 for scenario 1.

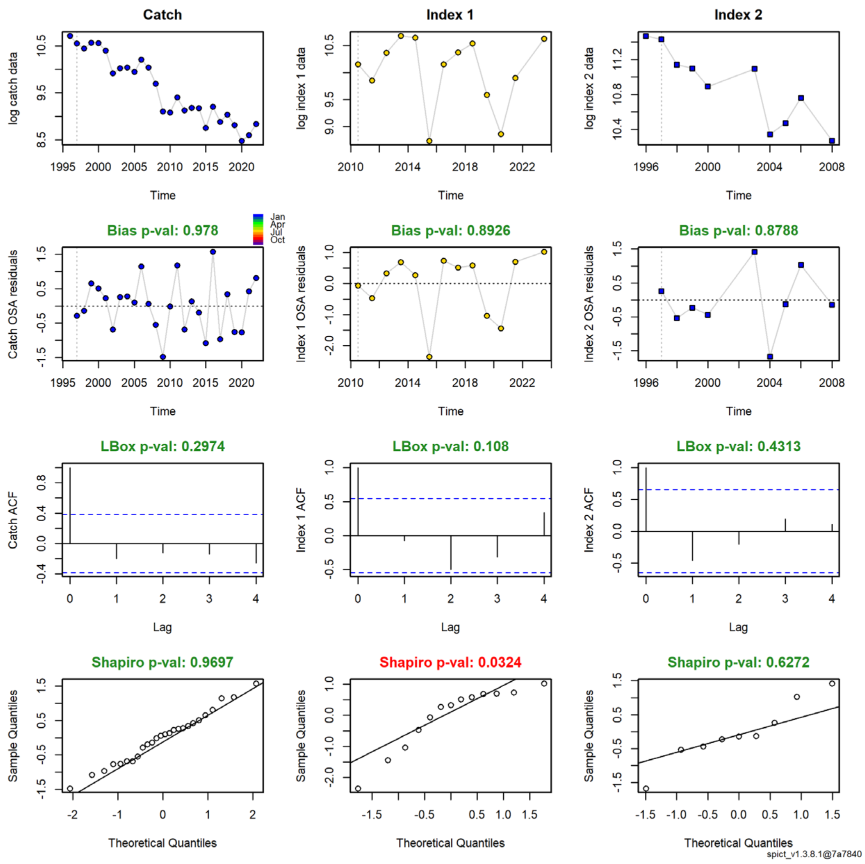


Figure 139. One-step-ahead residuals for the model for European sardine in GSA6.

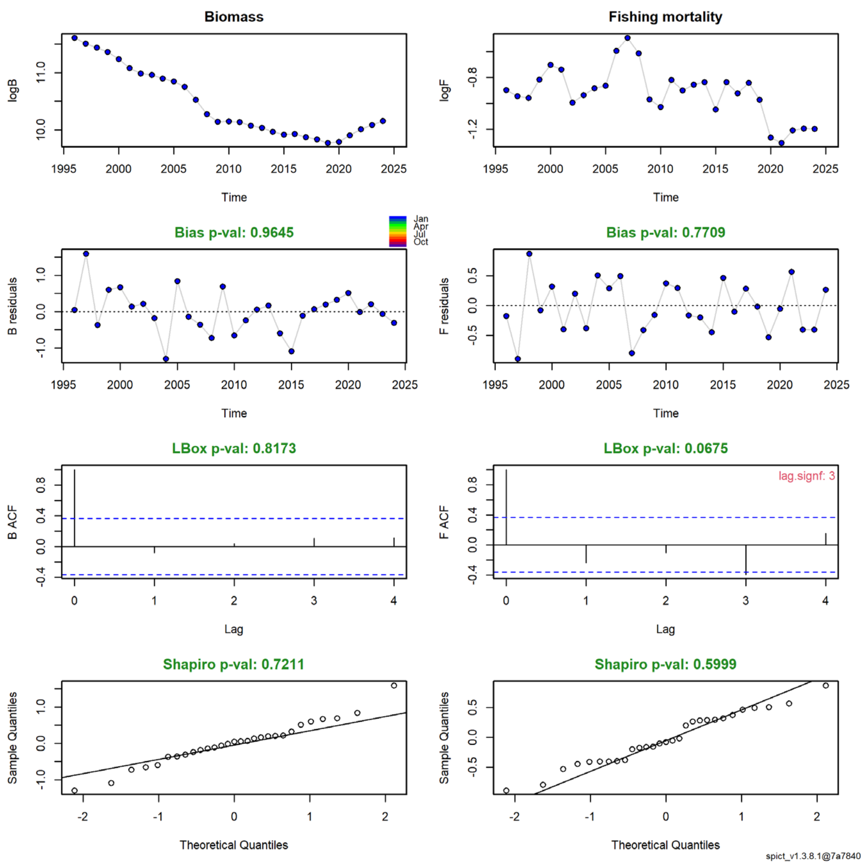


Figure 140. Process error deviations for the model for European sardine in GSA6.

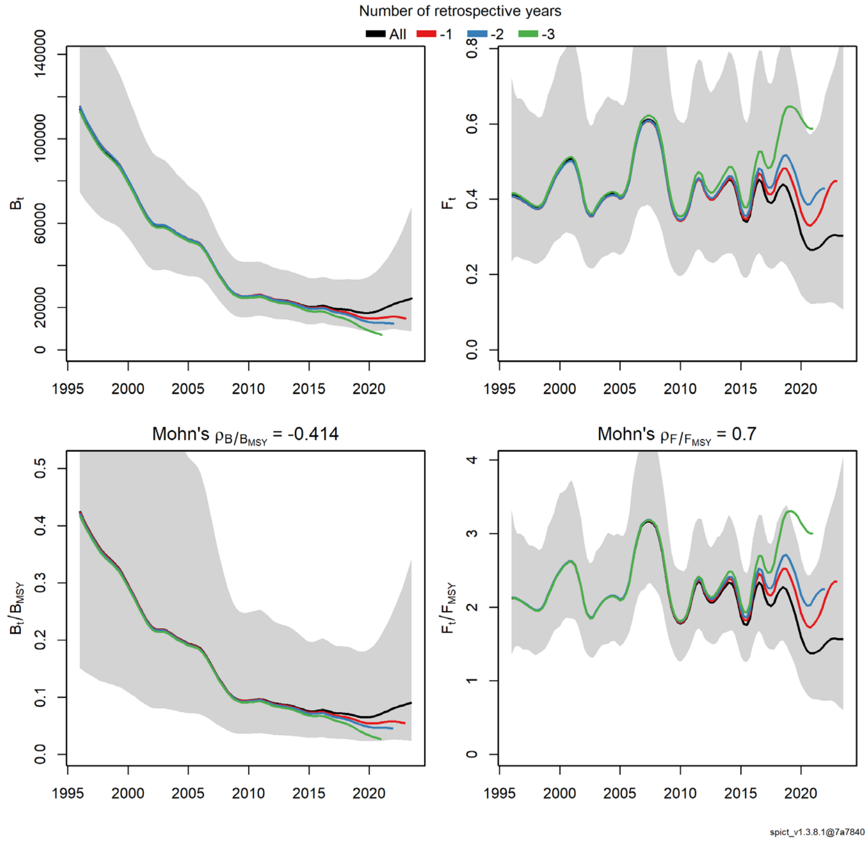


Figure 141. Retrospective analysis for European sardine in GSA6.

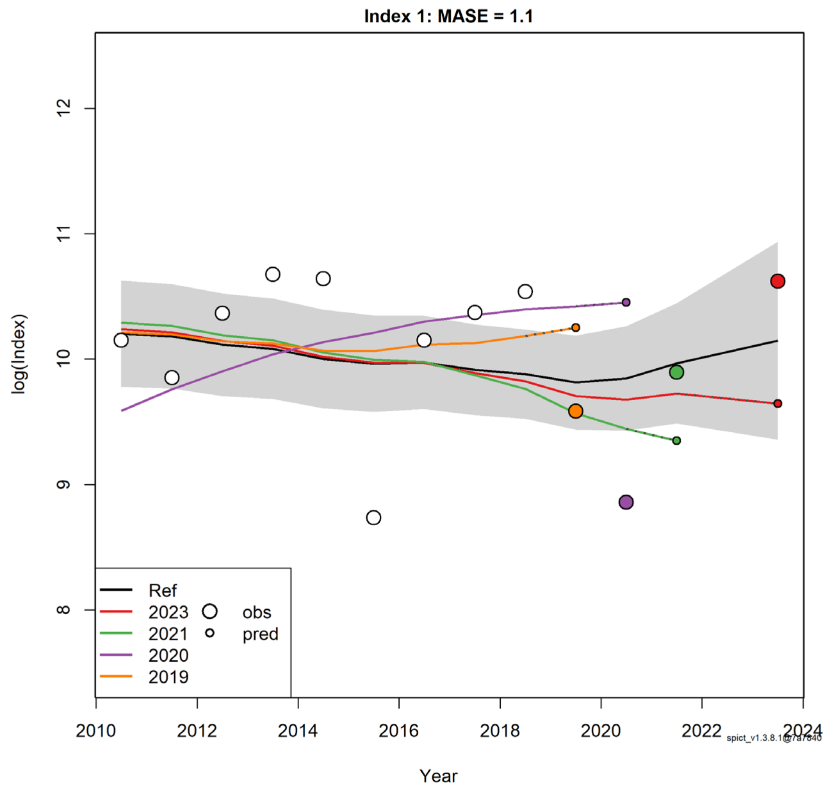


Figure 142. Hindcasting for the model for European sardine in GSA6.

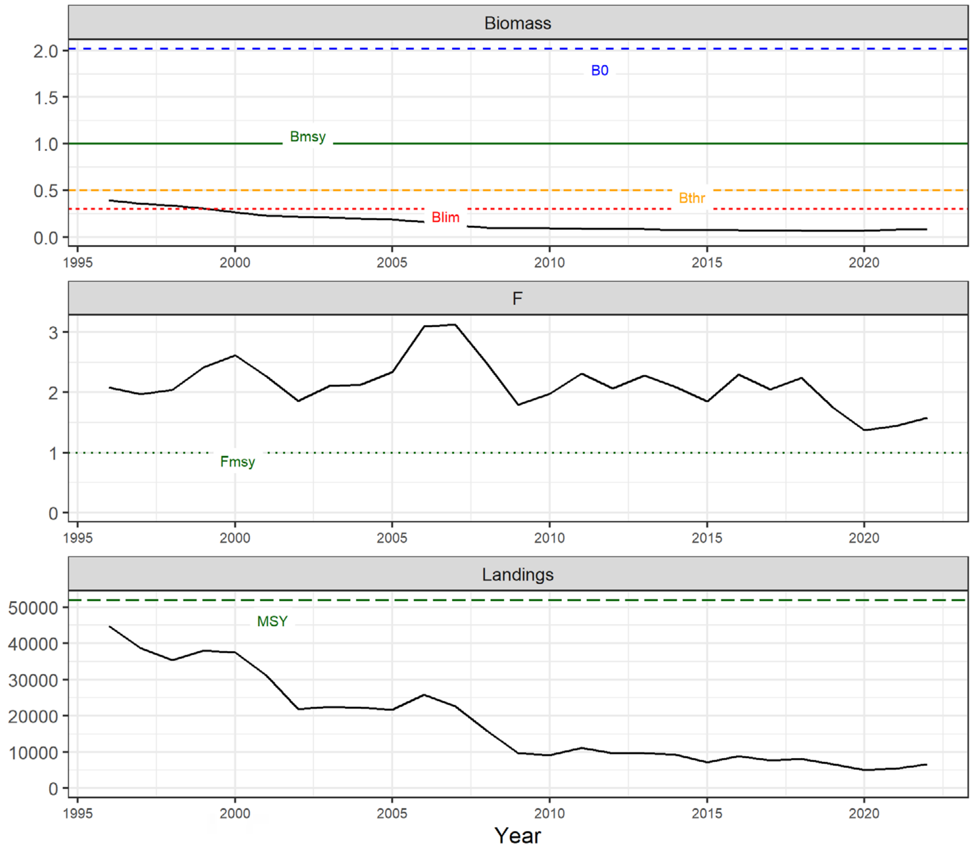


Figure 143. Advice for European sardine in GSA6: Historical and current stock status regarding F_{msy}, B_{msy} and B_{lim}.

Table 26. Indicators in 2022 from SPiCT for European sardine in GSA6.

Species	Year	Catch (t)	FFmsy	BBmsy	BBpa	BBlim
PIL	**2022**	6654.41	1.58	0.09	0.17	0.29

Final scenarios diagnostics

Diagnostics for the scenario (i.e., Scenario 1) were shown below (Figure 138, Figure 139, Figure 140, Figure 141, Figure 142). The chosen scenario met most of the model diagnostics and provided good retrospective analysis and hindcasting diagnostics.

A sensitivity analysis for scenario 1 was performed, testing r prior (Annex 71), bkfrac (Annex 72), process error (Annex 73), and observation error (Annex 74) to see how robust the model is within these priors.

Final scenarios advice

Figure 143 represents the stock assessment for the final scenario (i.e., scenario 1) (advice framework) using ECOMED and MEDIAS as a biomass index. Table 26 shows indicators in 2022 for scenario 2 for European sardine in GSA6.

Anchovy (*Engraulis encrasicolus*) ANE

The reproduction of the European anchovy occurs between May and September (ICATMAR, 24-05), and recruitment is observed afterwards, in fall and winter.

Input data

The spatial distribution of total landings for anchovy in the Catalan fishing grounds (Figure 144) is located, mainly, in lower coastal areas along the Catalan coast, with no occurrence in the Delta area (the southernmost area of the coast).

Historical anchovy landings in Catalonia from 2002 to 2023 are shown in Figure 145. From 2002 to 2008, there was a decrease in landings. Afterwards, the landings increased until 2018, when they inverted the trend and decreased again.

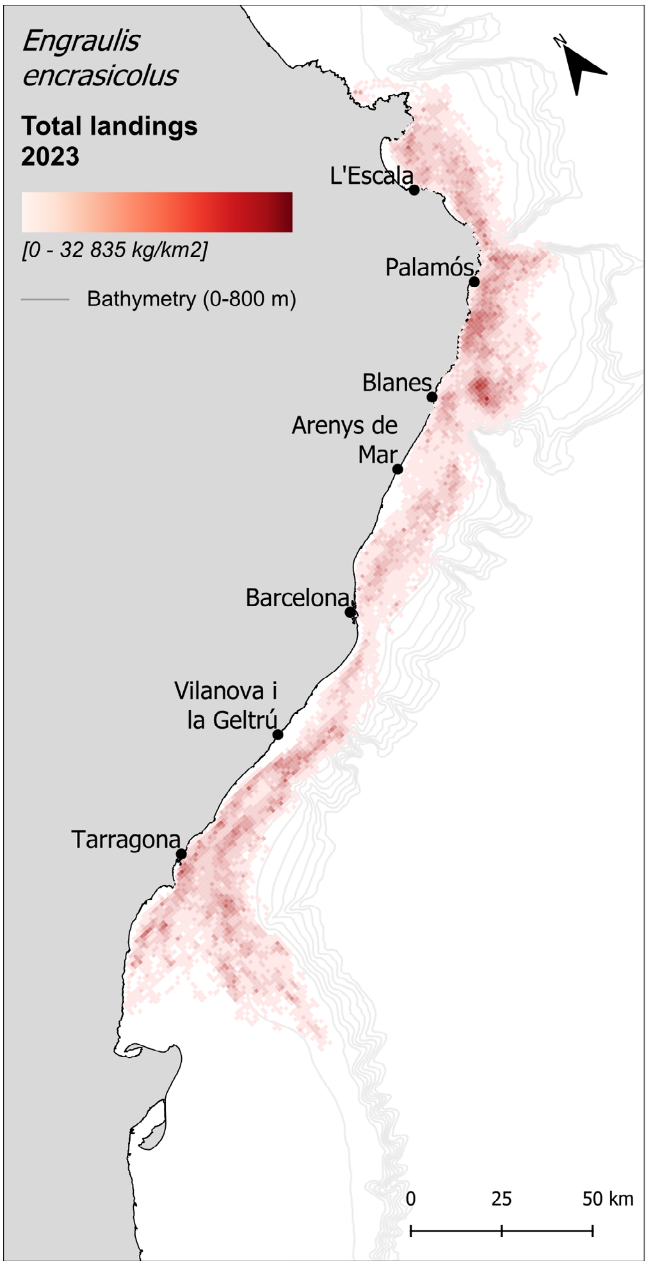


Figure 144. Spatial distribution of landings per unit of effort (LPUE) for anchovy in the Catalan fishing grounds (North GSA6) in the year analysed.

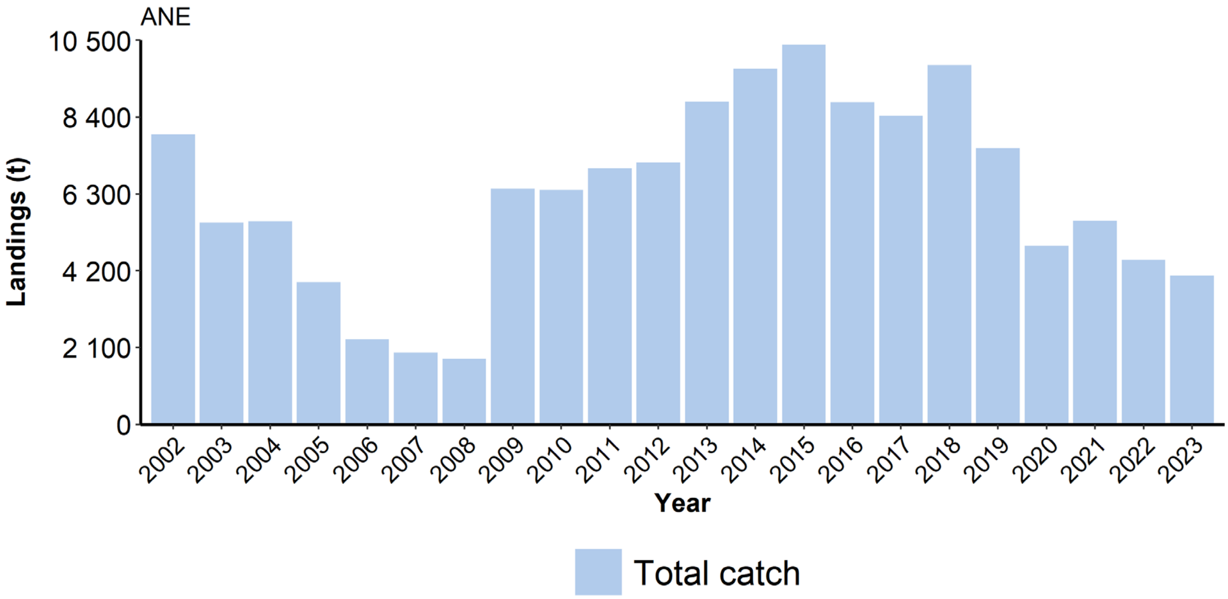


Figure 145. Historical landings (t) for anchovy in Catalonia.

Annual LFD

After raising the length frequencies obtained with the monitoring program from commercial landings (Table 27), the annual length frequency of anchovy in Catalonia is plotted in Figure 146. There is no clear consistency in the length frequency of small and big individuals; as a general observation, in 2022 there are fewer small individuals than in 2020 and 2021. Although for some bottom trawling metiers in the delta shelf discards of small pelagic fishes were important (Blanco et al. 2023) its biomasses were residual compared to purse seine landings.

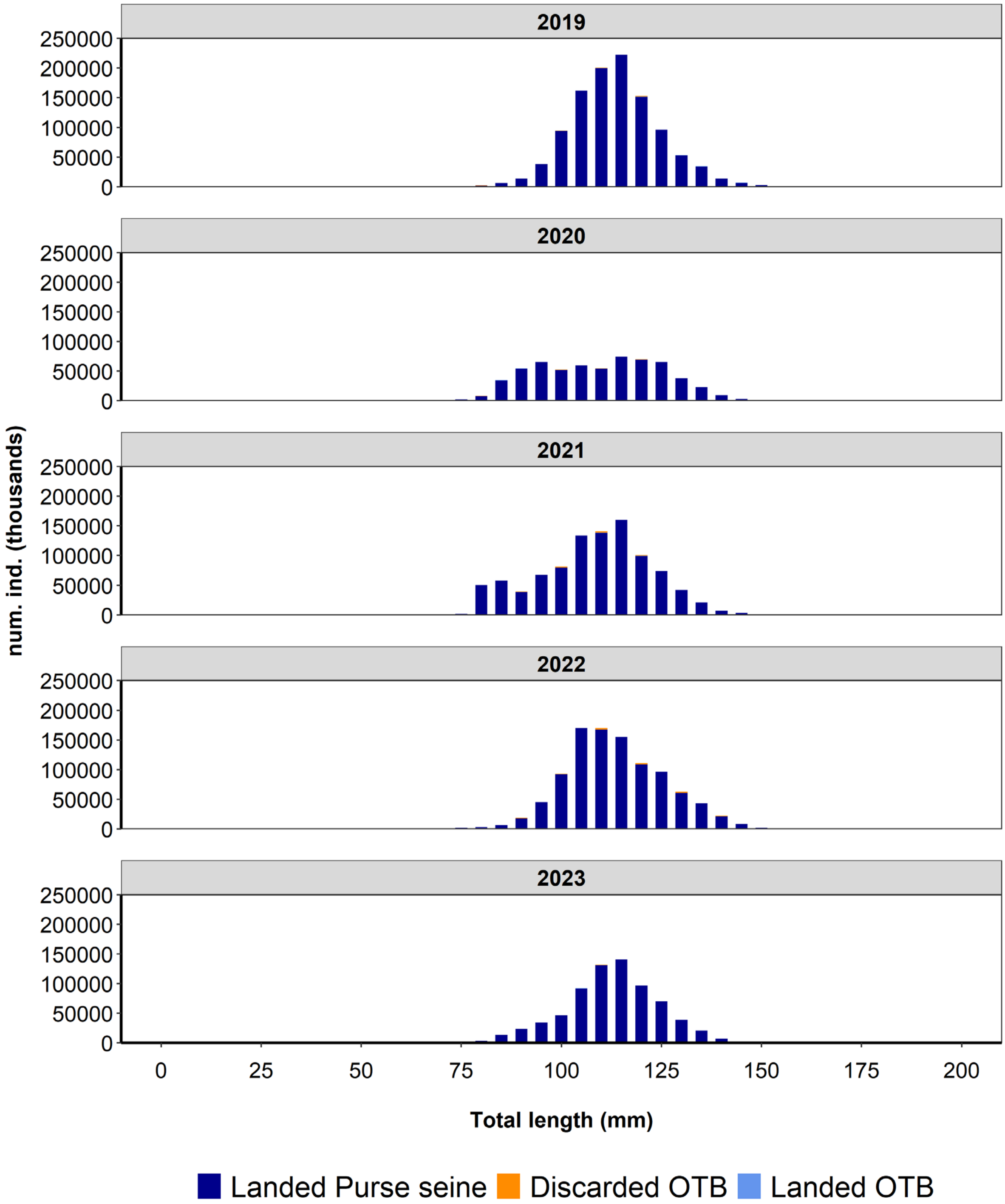


Figure 146. Annual length frequency distributions of anchovy from bottom trawling and small-scale fisheries. The data from bottom trawling is raised from ICATMAR data and details landed and discarded anchovy. The data from small-scale fisheries is obtained from DCF (Data Collection Framework) dataset.

Table 27. Number of anchovy individuals sampled by zone and season from ICATMAR monitoring data used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N sampling
			Number individuals sampled				
Artisanal fisheries	2019	Center	0	1	0	0	1
Artisanal fisheries	2020	North	0	0	0	19	1
Artisanal fisheries	2021	North	0	3	0	1	2
Artisanal fisheries	2021	Center	105	0	0	0	3
Artisanal fisheries	2022	Center	0	13	0	0	1
Artisanal fisheries	2023	North	0	0	0	30	1
Artisanal fisheries	2023	Center	39	0	0	0	1
Bottom trawl	2019	North	0	2	81	0	3
Bottom trawl	2019	Center	1	0	163	25	4
Bottom trawl	2019	South	428	372	582	238	27
Bottom trawl	2020	North	0	0	5	0	3
Bottom trawl	2020	Center	0	1	1	51	3
Bottom trawl	2020	South	10	273	266	177	14
Bottom trawl	2021	North	3	52	5	0	8
Bottom trawl	2021	Center	56	6	30	47	4
Bottom trawl	2021	South	72	143	192	297	19
Bottom trawl	2022	North	3	40	91	0	4
Bottom trawl	2022	Center	0	13	0	0	1
Bottom trawl	2022	South	8	259	155	180	17
Bottom trawl	2023	North	0	2	1	0	2
Bottom trawl	2023	Center	0	31	0	0	1
Bottom trawl	2023	South	60	277	109	1	17
Purse seine (fish market)	2019	North	1052	1729	1282	929	20
Purse seine (fish market)	2019	Center	929	1278	944	1078	17
Purse seine (fish market)	2020	North	1333	649	1562	1129	17
Purse seine (fish market)	2020	Center	1008	496	677	854	13
Purse seine (fish market)	2021	North	1307	1100	1416	565	19
Purse seine (fish market)	2021	Center	778	1037	1302	968	19
Purse seine (fish market)	2022	North	576	1637	867	752	16
Purse seine (fish market)	2022	Center	710	1337	1135	399	16
Purse seine (fish market)	2023	North	986	551	697	387	12
Purse seine (fish market)	2023	Center	907	1327	384	269	13
Purse seine (on board)	2022	North	1755	153	939	573	15
Purse seine (on board)	2022	Center	430	383	471	834	9
Purse seine (on board)	2023	North	967	185	887	525	13
Purse seine (on board)	2023	Center	254	193	0	0	2
Purse seine (on board)	2023	South	0	0	221	398	3

Length-Based Spawning Potential Ratio (LBSPR)

Model setting and results:

Scenarios

Three scenarios were applied considering different growth parameters and natural mortality from GFCM working groups (Table 28). In scenario 3, L_{mat50} correspond to ICATMAR data (ICATMAR, 24-05).

Table 28. Biological parameters used in the different LBSPR scenarios for anchovy (ANE). L_{inf}: asymptotic length at which growth is zero, k: growth rate, M: natural mortality, L_{mat50}: length where 50% of individuals are mature, L_{mat95}: length where 95% of individuals are mature.

Species	Scenario	Linf (mm)	M/k	Lmat50 (mm)	Lmat95 (mm)
ANE	1	155	1426	99.0	117.0
ANE	2	155	1426	96.0	114.0
ANE	3	155	1426	82.0	97.4

Fitted data

The length frequency distribution fit per year is shown in Figure 147. The model generally follows the mode for all years but, in some length classes, the observed data is not under the limits of the simulated data.

Selectivity

The outputs of the model for the selectivity of the fishery are shown for each scenario in Table 29. The outputs are also plotted together with L_{mat50} and SL_{50} for scenarios 1, 2 and 3 in Figure 148. In all scenarios, the fishery is fishing above L_{mat50}.

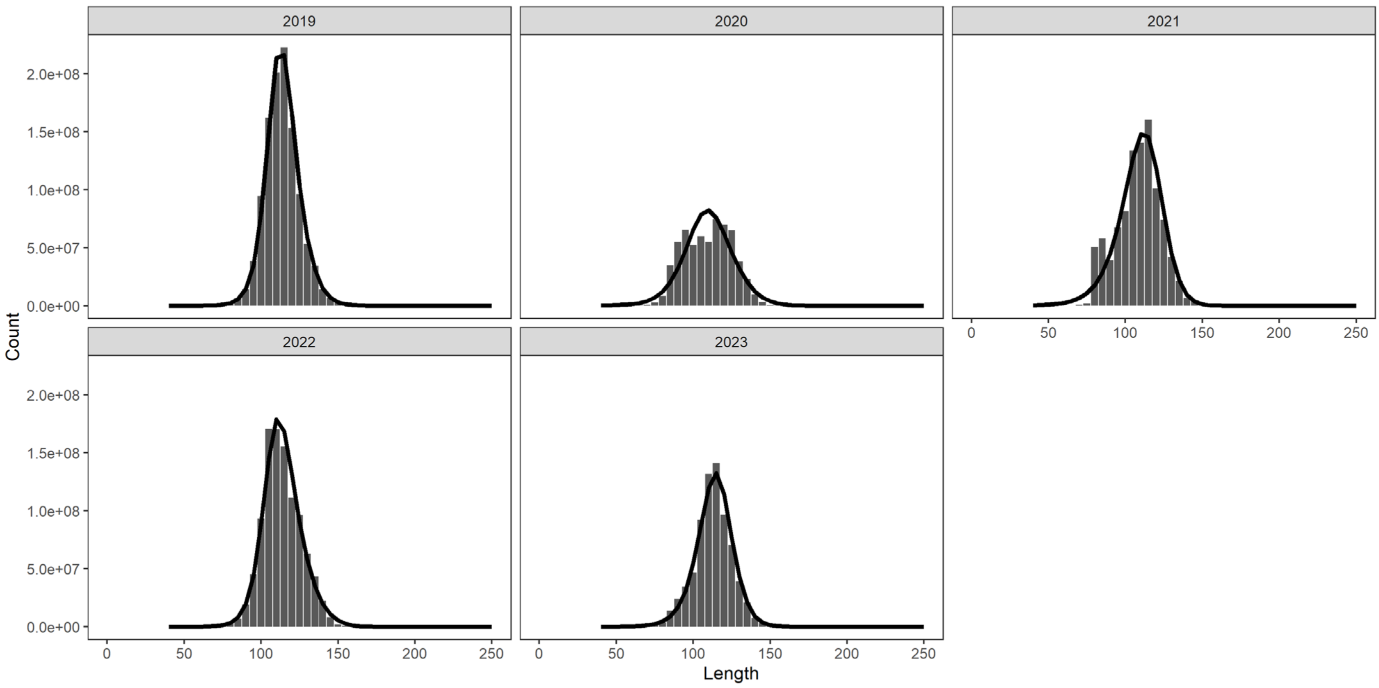


Figure 147. Fit of the data using the LBSPR model for anchovy for each studied year. Grey columns indicate length frequencies. Black lines indicate the fit of the model.

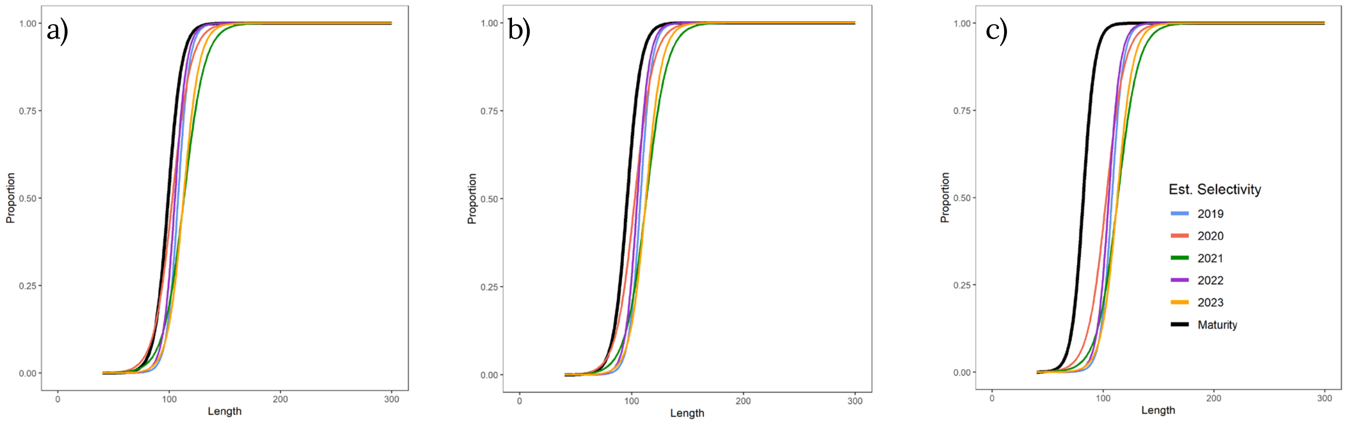


Figure 148. Length curves for anchovy. Black line shows the length curve at maturity. Colour lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (a), scenario 2 (b) and scenario 3 (c).

Reference points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is below SPR_{tgt} (=0.4) but nearby this value to in 2020 and 2022 for scenario 3 (Table 29 and Figure 150). The Kobe plot for anchovy (Figure 149) shows the stock status throughout the years, with no clear trend. The stock is, in all cases, located in the red zone. Despite that it is approaching to a sustainable reference point, it is still overfished and under overfishing.

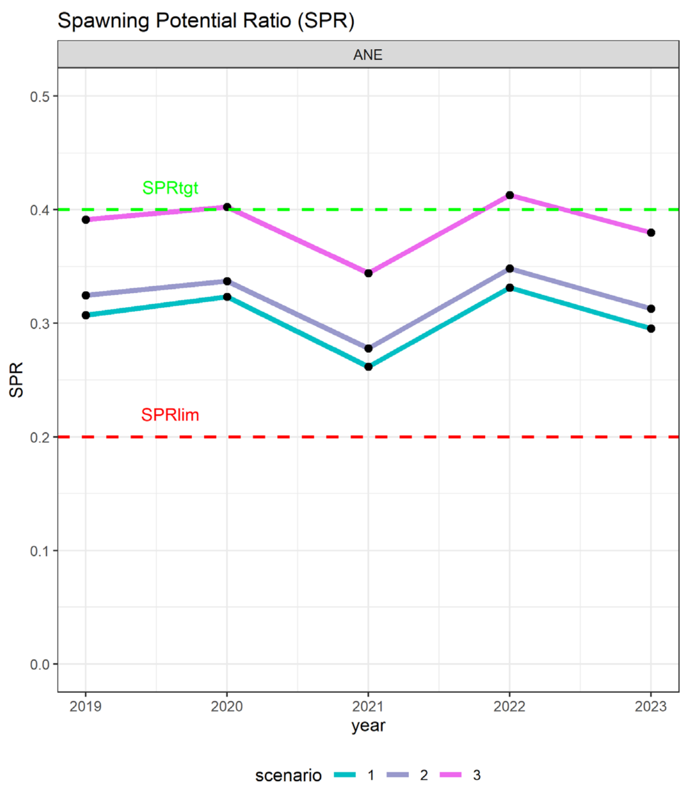


Figure 149. Kobe plot for anchovy by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

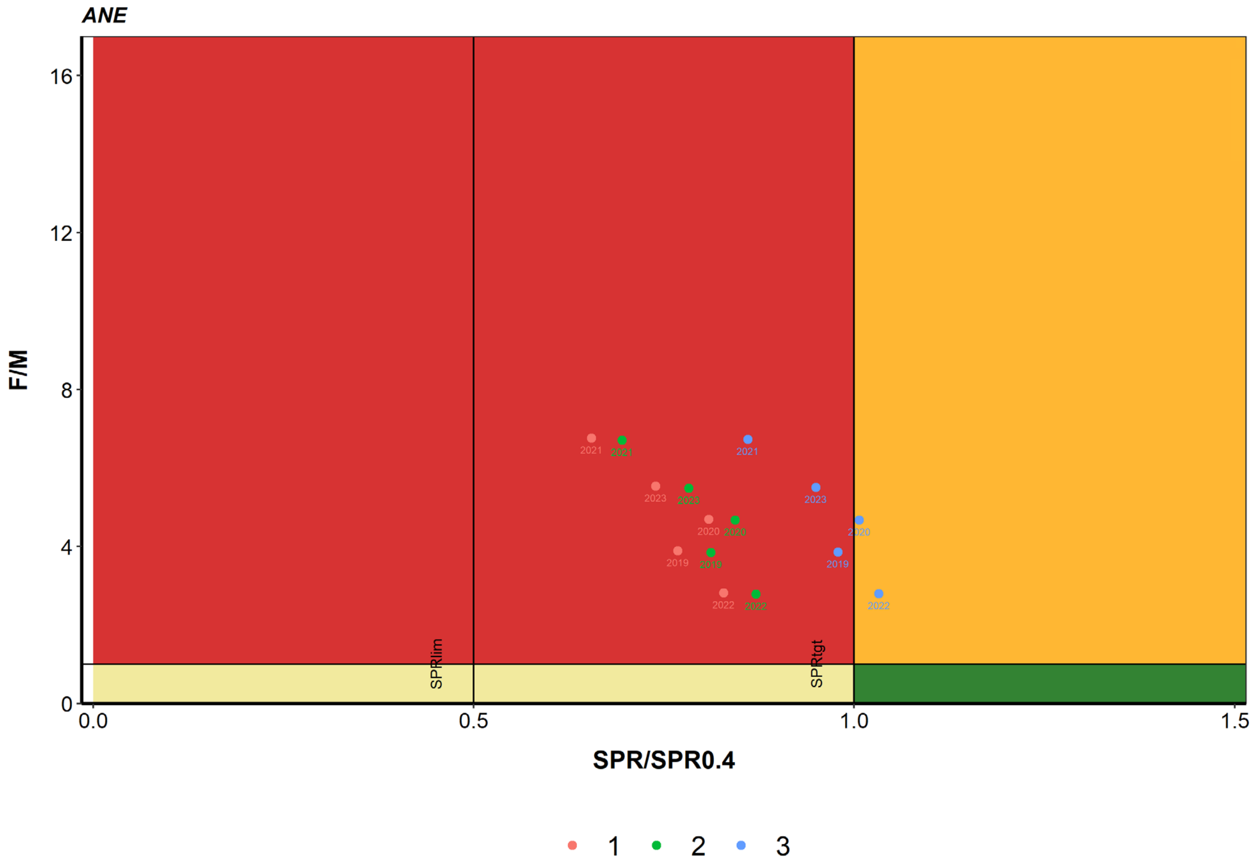


Figure 150. Spawning potential ratio (SPR) per year analysed for anchovy evaluated with LBSPR model. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio, SPR_{tgt}: target spawning potential ratio. Coloured lines show the results for each scenario.

Final scenario

As LFD and L_{mat} originated from ICATMAR data, scenario three was selected to provide final advice for the LBSPR model.

Table 29. LBSPR model results for anchovy with the different scenarios tested for each year analysed. SL_{50}: Length where 50% of individuals are caught, SPR: spawning potential ratio and FM: fishing mortality. SD is the standard deviation calculated for each indicator.

Species	Scenario	Year	SL_{50}	SD	SPR	SD	FM	SD
ANE	**1**	**2019**	109.72	1.06	0.31	0.19	3.89	1.82
ANE	**1**	**2020**	113.98	8.2	0.32	0.25	4.7	3.14
ANE	**1**	**2021**	116.81	2.31	0.26	0.18	6.76	3.36
ANE	**1**	**2022**	107.29	1.38	0.33	0.21	2.82	1.46
ANE	**1**	**2023**	115.03	1.24	0.3	0.19	5.54	2.56
ANE	**2**	**2019**	109.78	1.03	0.32	0.18	3.86	1.71
ANE	**2**	**2020**	114.34	7.94	0.34	0.23	4.67	2.95
ANE	**2**	**2021**	116.94	2.23	0.28	0.17	6.71	3.16
ANE	**2**	**2022**	107.36	1.37	0.35	0.2	2.79	1.38
ANE	**2**	**2023**	115.1	1.21	0.31	0.18	5.49	2.42
ANE	**3**	**2019**	109.73	1.11	0.39	0.18	3.87	1.82
ANE	**3**	**2020**	113.89	8.47	0.4	0.23	4.68	3.16
ANE	**3**	**2021**	116.83	2.43	0.34	0.18	6.73	3.36
ANE	**3**	**2022**	107.31	1.41	0.41	0.2	2.8	1.46
ANE	**3**	**2023**	115.04	1.3	0.38	0.18	5.51	2.56

Stochastic Production model in Continuous Time (SPiCT)

The GFCM working group on small pelagics in 2023 has already completed the stock assessment for GSA6 for small pelagics. For this report, data available in the Stock Assessment Form was used to reproduce the SPiCT model within the same settings but using a shorter time series.

For anchovy, input data for catches were from 1996 to 2022. Two indexes were used: ECOMED, an autumn acoustic survey from 1996 to 2009, and MEDIAS, a summer acoustic survey from 2009 to 2022 (Figure 151). As for the other species, a double-axis plot (Figure 152) was presented to compare trends between catches and indices.

Only one scenario was presented, using the same input data as in the GFCM report (Figure 153).

The results (Figure 154) show an increasing trend of biomass below the reference point since 2015. For fishing mortality, the estimated values have remained below 1 since 2005. These results are comparable with those using the longest time series.

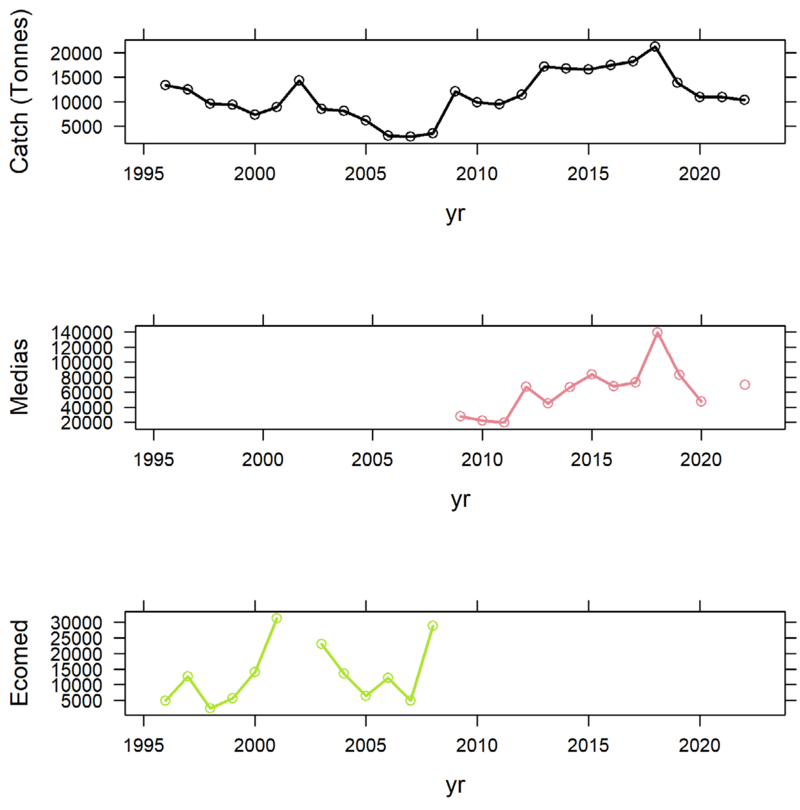


Figure 151. Data available for the assessment for Anchovy in GSA6 to run SPiCT model. Top: catch data from 1996 to 2022. Centre: Ecomed acustic survey data since 1994 to 2008 and Medias acustic survey since 2009 to 2022.

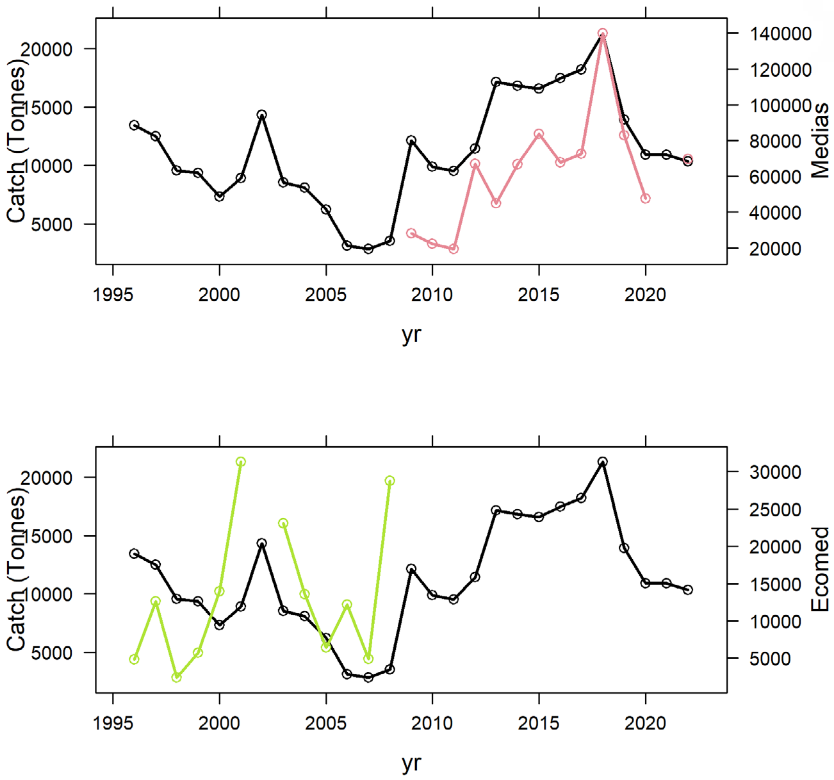


Figure 152. Double axis plot to compare trends between catch and Ecomed index (top) and catch and Medias index (bottom) for Anchovy.

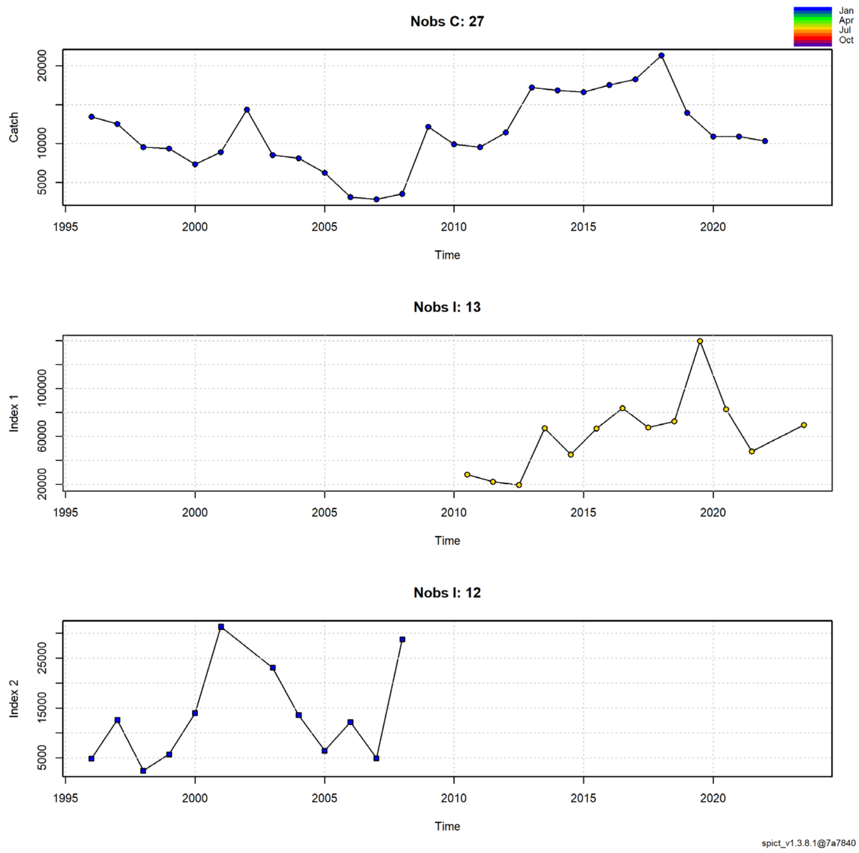


Figure 153. Input data for SPiCT model for Anchovy in GSA6. Top: catch in tonnes per year since 1996, centre: index data of biomass derived from Medias survey since 2009 to 2022, and bottom: Ecomed survey since 1994 to 2008.

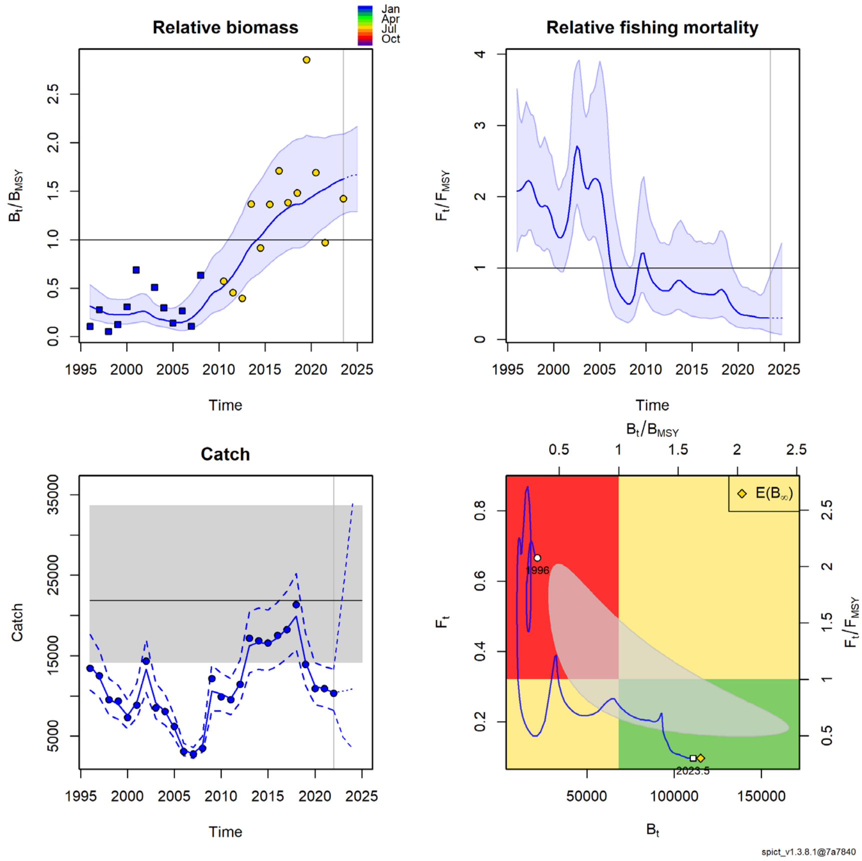


Figure 154. Stock assessment summary for SPiCT model for Anchovy in GSA6.

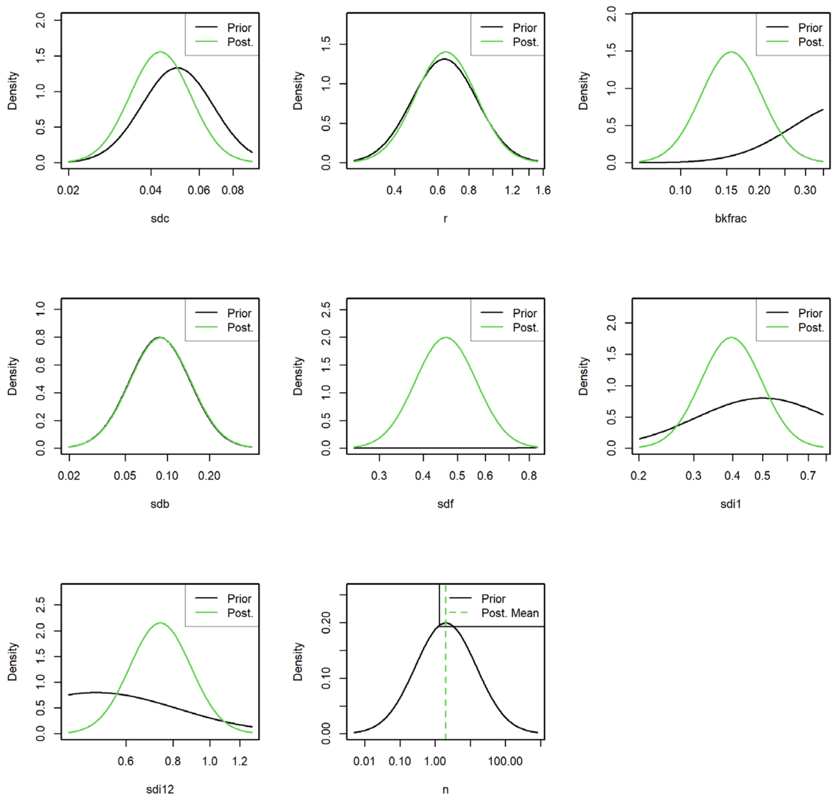


Figure 155. Estimated priors and posteriors for the updated assessment for Anchovy in GSA6 for scenario 1.

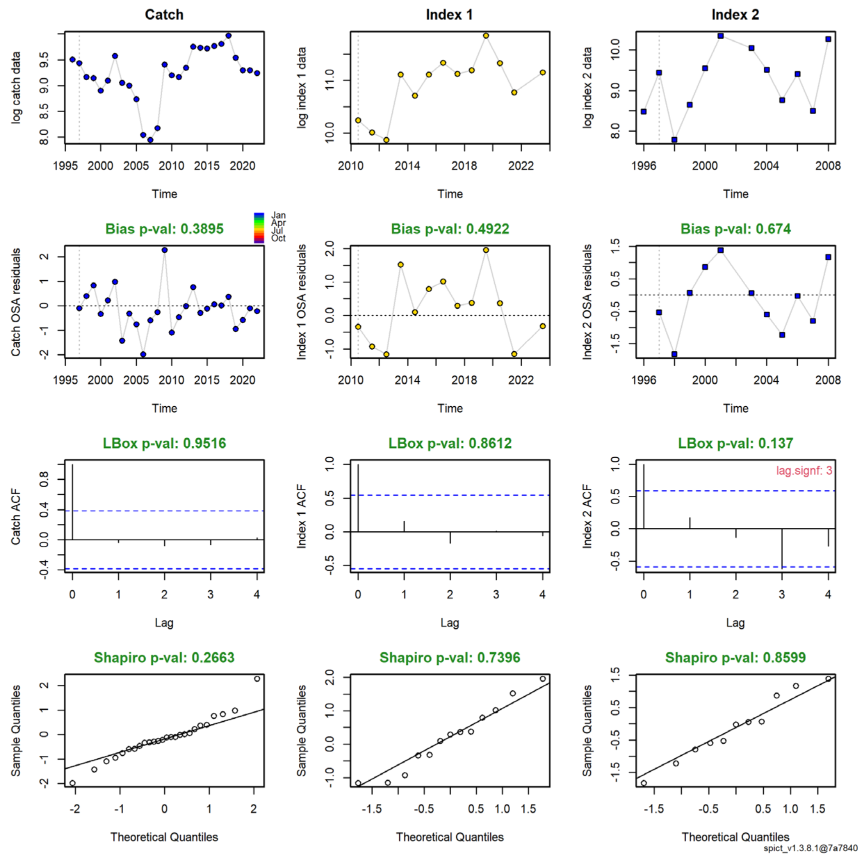


Figure 156. One-step-ahead residuals for the model for Anchovy in GSA6.

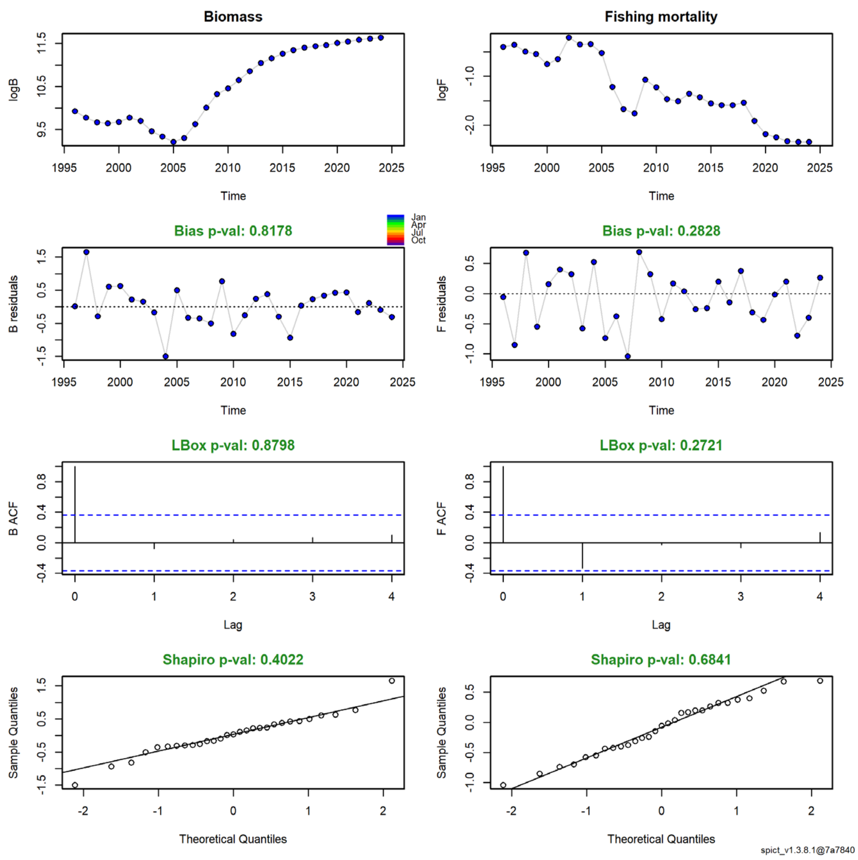


Figure 157. Process error deviations for the model for Anchovy in GSA6.

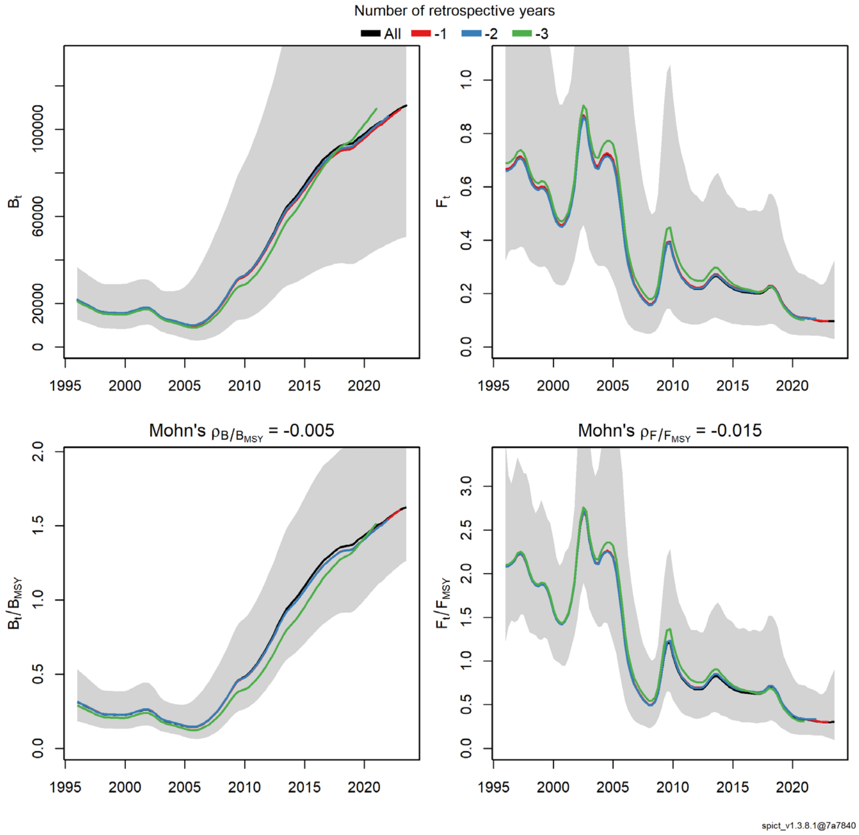


Figure 158. Retrospective analysis for Anchovy in GSA6.

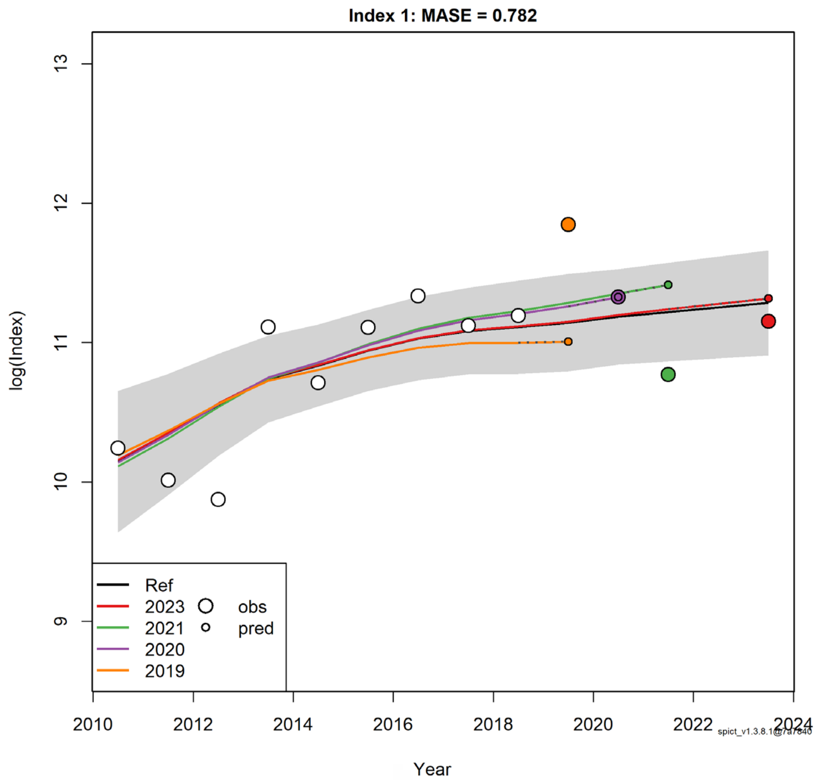


Figure 159. Hindcasting for the model for Anchovy in GSA6.

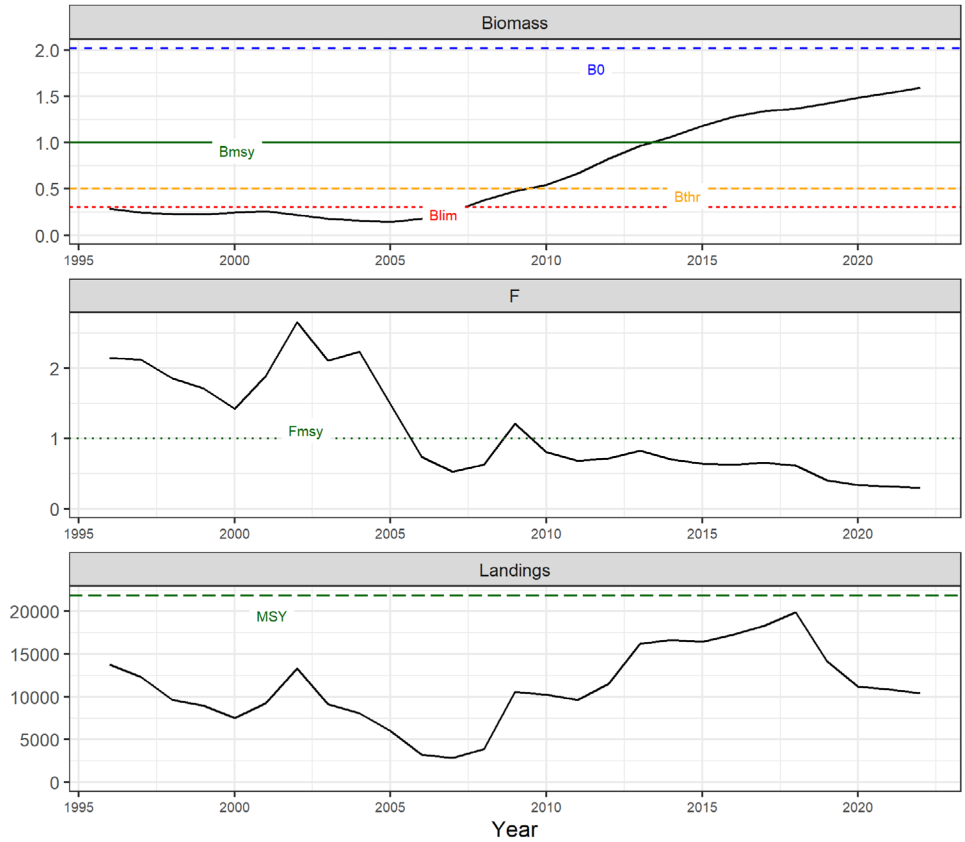


Figure 160. Advice for Anchovy in GSA6: Historical and current stock status regarding F_{msy}, B_{msy} and B_{lim}.

Table 30. Indicators in 2022 from SPiCT for Anchovy in GSA6.

Species	Year	Catch (t)	FFmsy	BBmsy	BBpa	BBlim
ANE	2022	10441.78	0.3	1.6	3.19	5.32

Final scenarios diagnostics

Diagnostics for the scenario (i.e., Scenario 1) are shown below (Figure 155, Figure 156, Figure 157, Figure 158, Figure 159). The chosen scenario met most of the model diagnostics and provided good retrospective analysis and hindcasting diagnostics.

A sensitivity analysis for scenario 1 was performed, testing r prior (Annex 75), bkfrac (Annex 76), process error (Annex 77), and observation error (Annex 78) to see how robust the model is within these priors.

Final scenarios advice

Figure 160 represents the stock assessment for the final scenario (i.e., scenario 1) (advice framework) using ECOMED and MEDIAS as a biomass index. Table 30 shows indicators in 2022 for scenario 2 for anchovy in GSA6.

SECTION 5
Conclusions and comments

Methodological Remarks

This report incorporates two different stock assessment models to assess all the priority demersal species (i.e., red mullet, hake, deep-water rose shrimp, Norway lobster and blue and red shrimp) and small pelagic species (i.e., European sardine and anchovy). Also, north GSA6 and GSA6 stocks were evaluated.

LBSPR, a length-based model, was chosen to perform the stock assessment for the priority demersal species, and for sardine and anchovy, with ICATMAR's data for the north GSA6. SPiCT, a surplus production model, was applied to test the influence of a long-term data series, such as landings and biomass index, for the species selected in the GSA6. Both models are based on different assumptions and use different input data, giving different perspectives of stock status and types of advice (Reference points for LBSPR: SPR, for SPiCT: B_{msy} and F_{msy}). SPiCT reference points are comparable with the ones used for age-structured models (i.e., a4a) or integrated models (i.e., SS3).

In LBSPR, SPR estimations are conditioned to the L_{mat50} parameter and F/M estimations are conditioned to growth parameters. This model is very sensitive to the input parameters, meaning that it could be unstable. Also, the M/K ratio could affect the importance of the adults' contribution. In contrast to LBSPR, SPiCT does not use length structure but biomass. Therefore, the model cannot consider whether the population is more or less truncated. On the other hand, this model's advantage is the possibility to use landings time series, which is much longer and allows a wider view of the species' history.

To update the LBSPR with 2023 data, landings data were assigned to *métiers* following the same machine-learning methodology used in the previous report (ICATMAR 23-08), and then combined with discard data to raise the LFD. Moreover, new calculations of L_{mat50} with ICATMAR data were considered for the scenarios for some species. LBSPR mainly considers the stock's length structure and is more affected by truncated stocks, such as that for hake. This can be explained, for example, because the life history parameters (i.e. L_{inf}) may have been estimated with data taken a long time ago and may not represent the current population anymore.

Concerning SPiCT, new data was used to estimate normal and standardize CPUE to test different model scenarios for each of the demersal species. The biomass index (MEDITS, ECOMED, and MEDIAS) for the whole GSA6 was considered in SPiCT model scenarios. The SPiCT outputs belong to 2022 because data from 2023 is not yet available.

Different sensitivity analyses were applied for both LBSPR and SPiCT because the models had assumptions and limitations, and uncertainty was considered in the calculations. For SPiCT, the different diagnostics regarding the good performance of the model were also taken into account.

Conclusions

The models used in this report are based on different assumptions and use different input data. However, the results from both LBSPR and SPiCT models should be coherent and this is not the case for all the species. Therefore, all the information provided by the models needs to be carefully evaluated when giving advice to science-based management practitioners.

For LBPSR, different scenarios were performed for each species. The model results vary greatly, highlighting the importance of re-estimating the biological parameters of the species to have up-to-date data and obtain more realistic results. The final scenarios for each species were based on parameters (i.e., L_{mat50} and catch-at-length) updated with ICATMAR data.

Three of the five priority demersal species are below SPR_{lim} (i.e., hake, red mullet, and blue and red shrimp), one is on SPR_{lim} (i.e., deep-water rose shrimp), and another species is above SPR_{lim} (i.e., Norway lobster). For small pelagic stocks, one stock is above SPR_{lim} (i.e., European sardine), whereas the other is near SPR_{tgt} (i.e., anchovy).

For SPiCT, MEDITS data provided the best model outputs in many cases because the CPUE is non-informative. However, the model was not always able to understand the stock dynamics, especially when the biomass index remains stable but the catches greatly decrease. For small pelagic fish, the assessment was performed following the same settings as in the GFCM stock assessment, achieving similar results. Overall, the assessments should be updated with the 2023 biomass index data, and further data should be explored as potential inputs for all stocks, such as including the standardization of the CPUE from different gears used for a same species (e.g., GNS for red mullet), to better inform and understand the models and reduce uncertainty.

Results for the SPiCT model estimate that demersal stock biomass for red mullet, hake, and Norway lobster is above the B_{thr}, for deep-water rose shrimp and blue and red shrimp is above B_{msy}. Accordingly, fishing mortality varies for each species. For example, red mullet and blue and red shrimp are below F_{msy}, hake and Norway lobster values remain around F_{msy}, and deep-water rose shrimp fishing mortality is above F_{msy}, indicating a high fishing mortality value.

The estimates for small pelagic fish biomass indicate that European sardine is below B_{lim}, and anchovy is above B_{msy}. Accordingly, European sardine fishing mortality value is high, above F_{msy}, whereas anchovy is below F_{msy}.

The monitoring program from ICATMAR will continue the long-term data collection program to be able to apply more complex models, such as integrated stock assessment models (i.e. stock synthesis model SS3). This type of models could help consider relevant information on gear selectivity for different time periods, use historical catch and effort data with length frequency distributions together and consider the different sex-related characteristics. It is also recommended to provide the uncertainty information along with the model outputs whenever possible.

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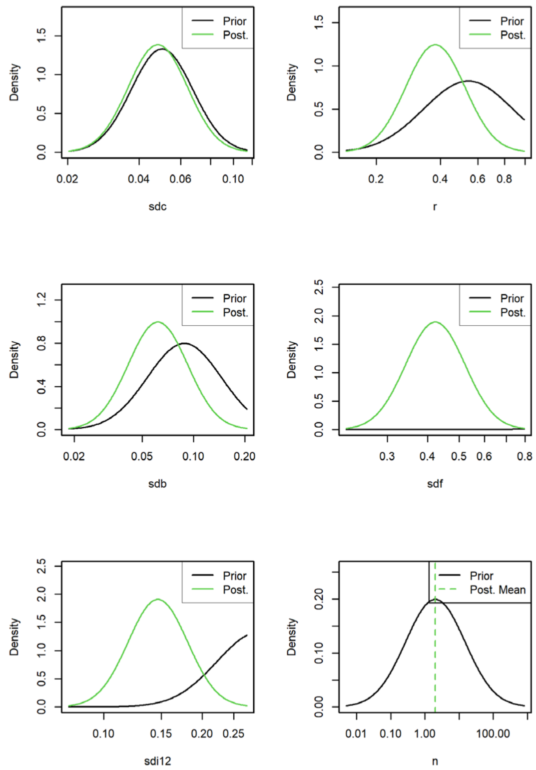
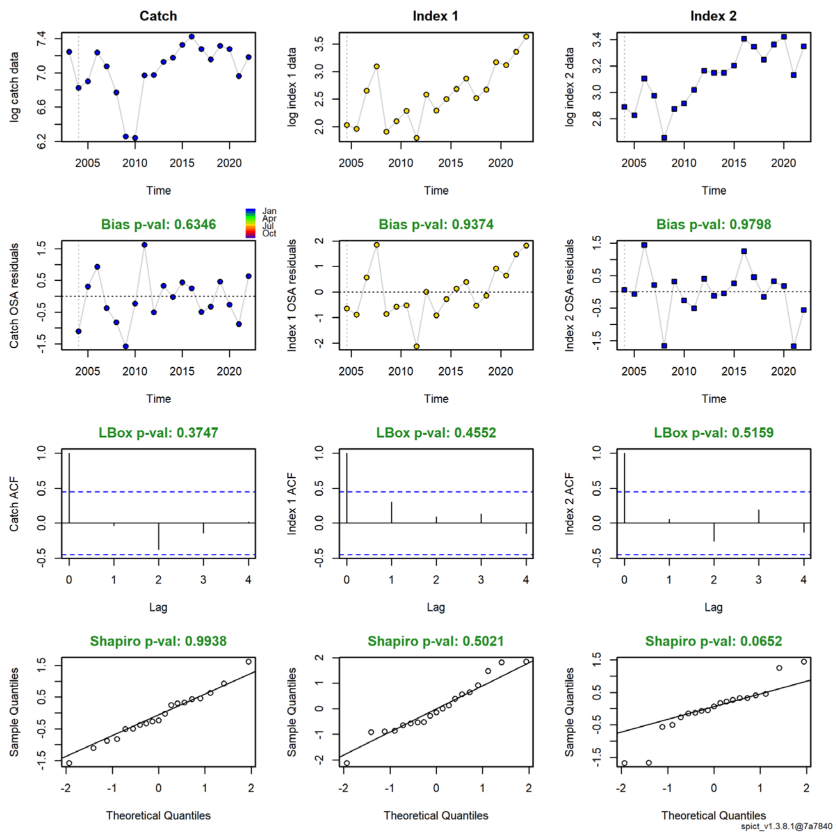
Annexes

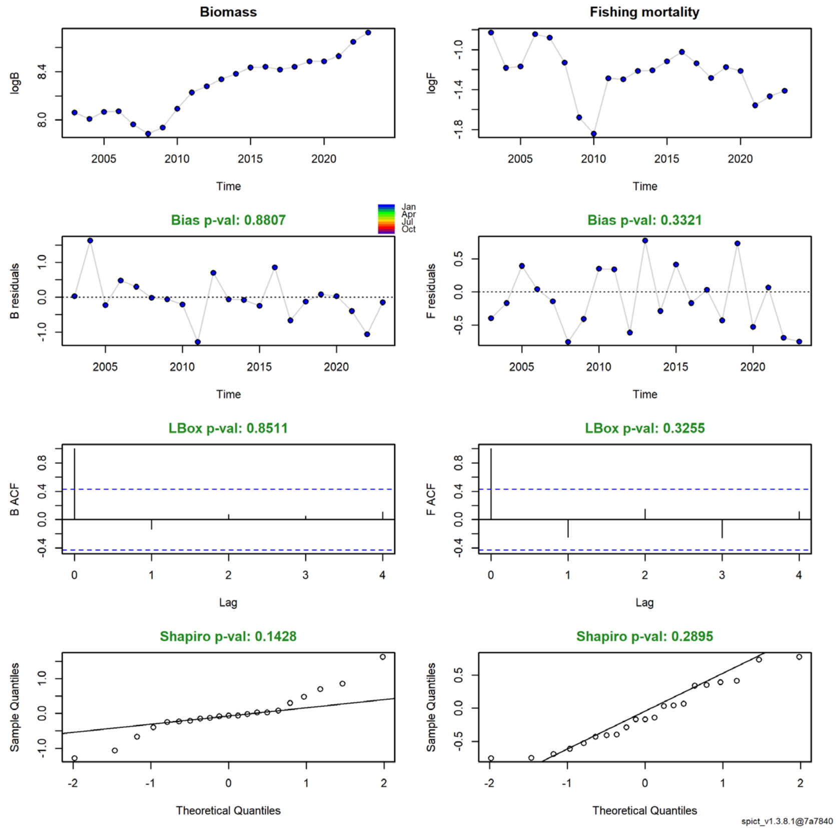
Red mullet (*Mullus barbatus*) MUT



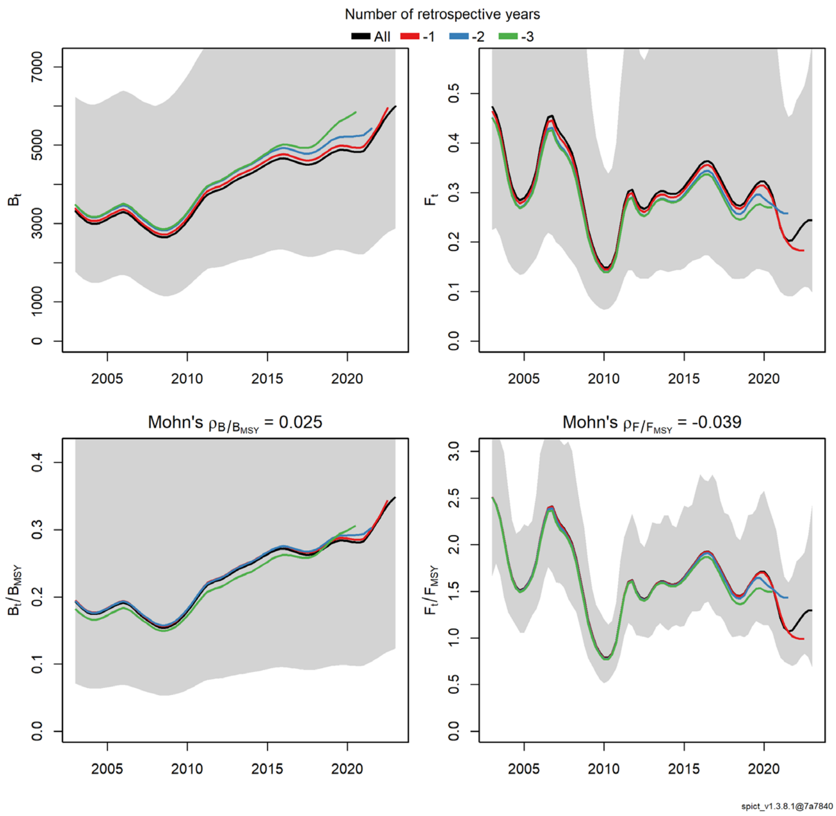
Annex 1. Estimated priors and posteriors for the updated assessment for red mullet in GSA6 for scenario 1.



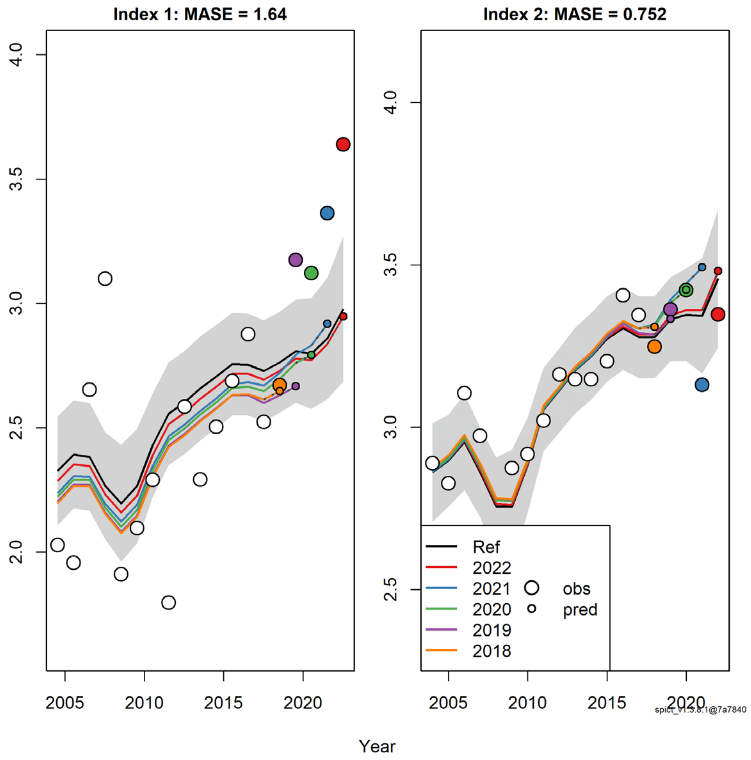
Annex 2. One-step-ahead residuals for the model for red mullet in GSA6 for scenario 1.



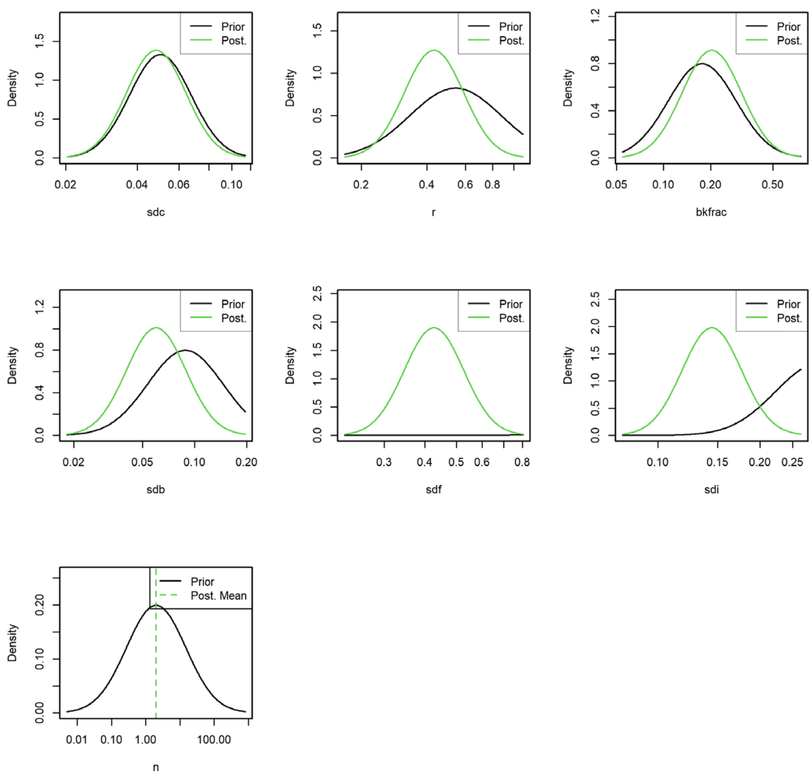
Annex 3. Process error deviations for red mullet model in GSA6 for scenario 1.



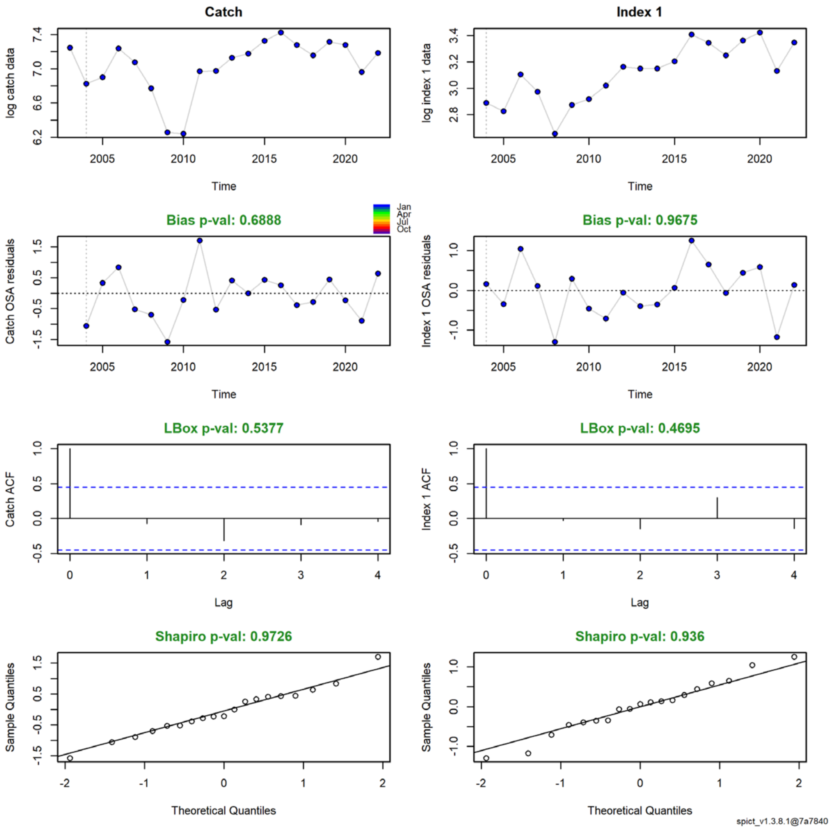
Annex 4. Retrospective analysis for red mullet in GSA6 for scenario 1.



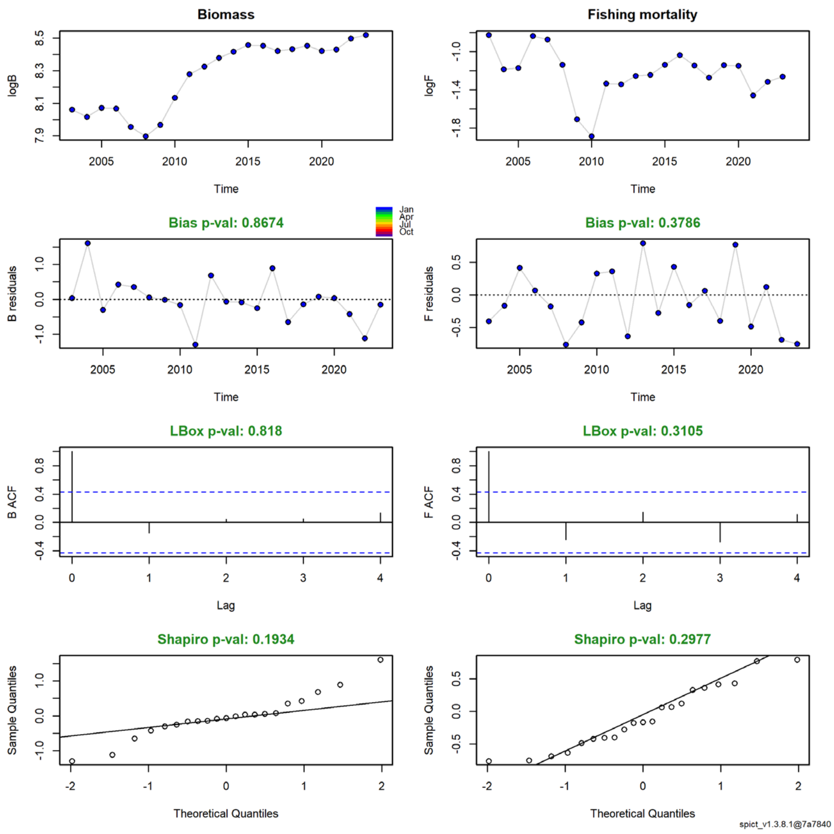
Annex 5. Hindcasting for red mullet model in GSA6 for scenario 1.



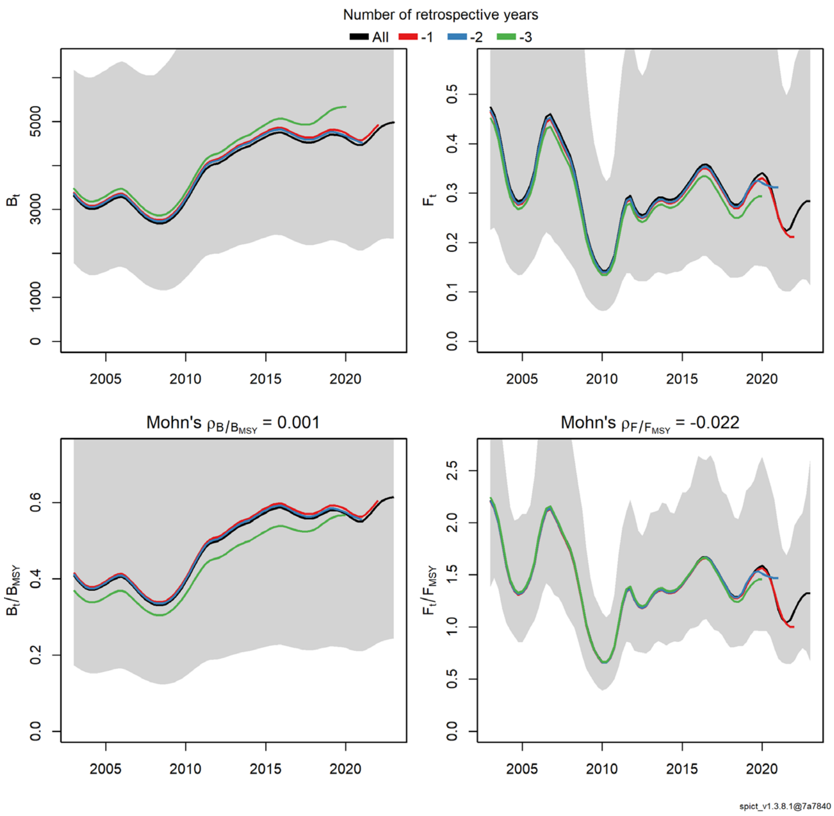
Annex 6. Estimated priors and posteriors for the updated assessment for red mullet in GSA6 for scenario 3.



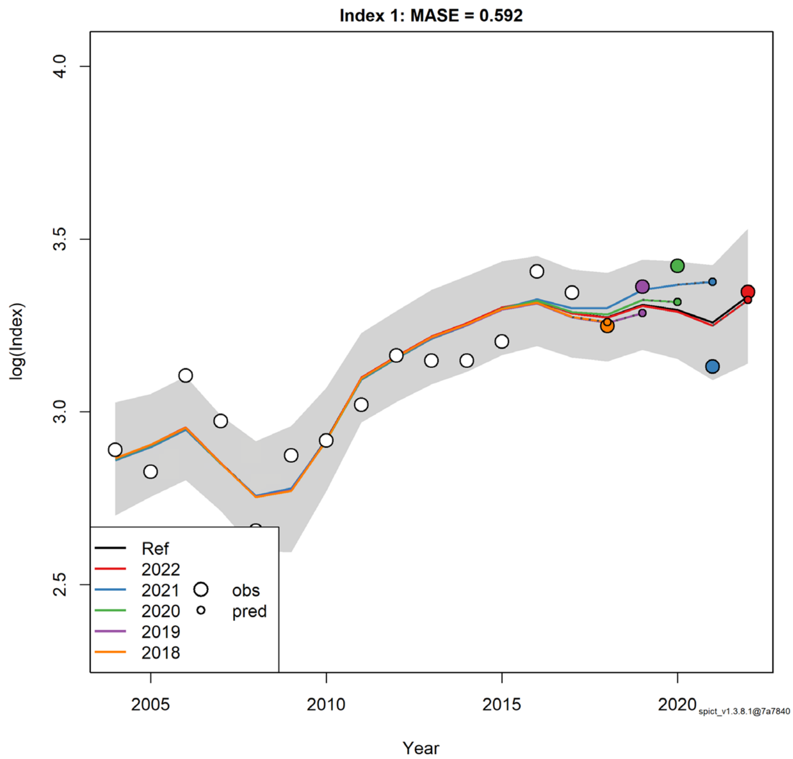
Annex 7. One-step-ahead residuals for the model for red mullet in GSA6 for scenario 3.



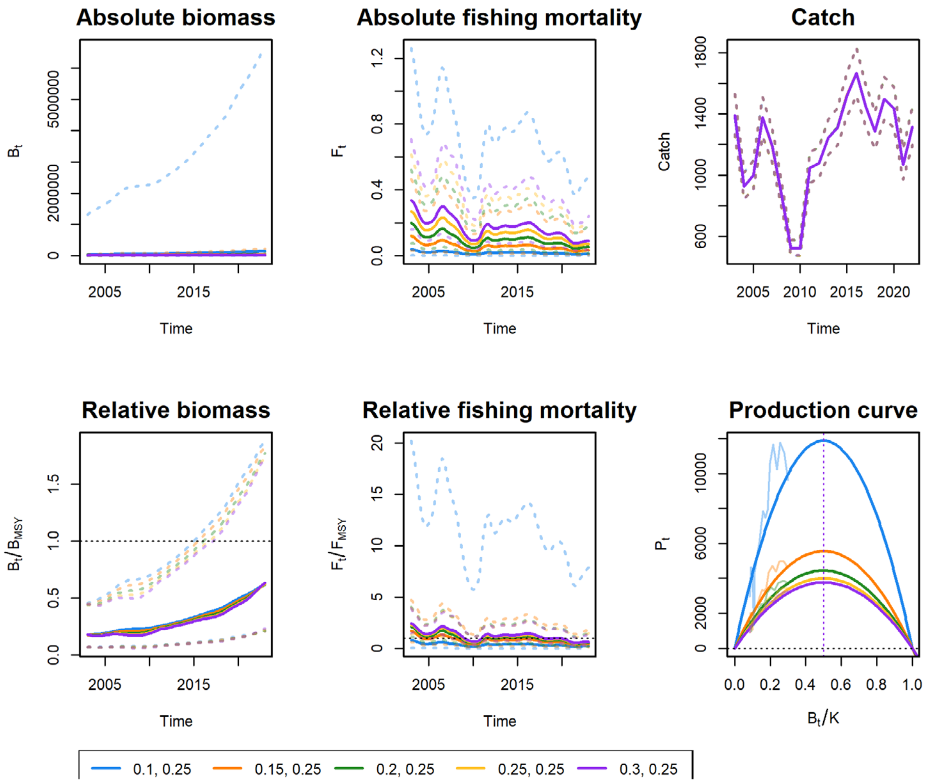
Annex 8. Process error deviations for the model for red mullet in GSA6 for scenario 3.



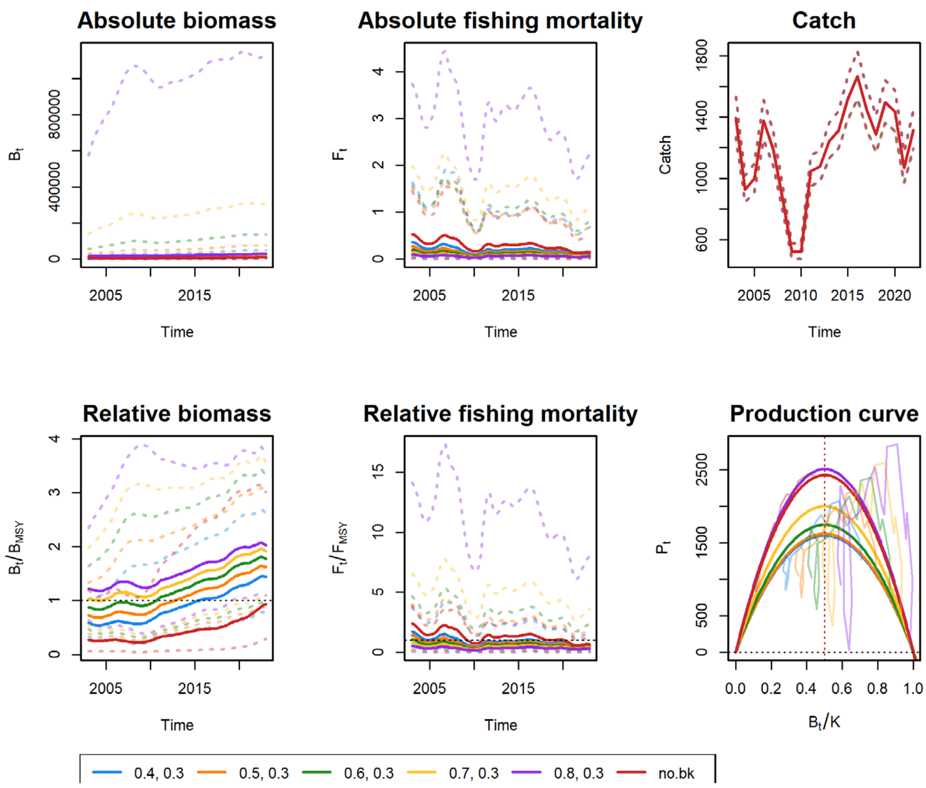
Annex 9. Retrospective analysis for red mullet in GSA6 for scenario 3.



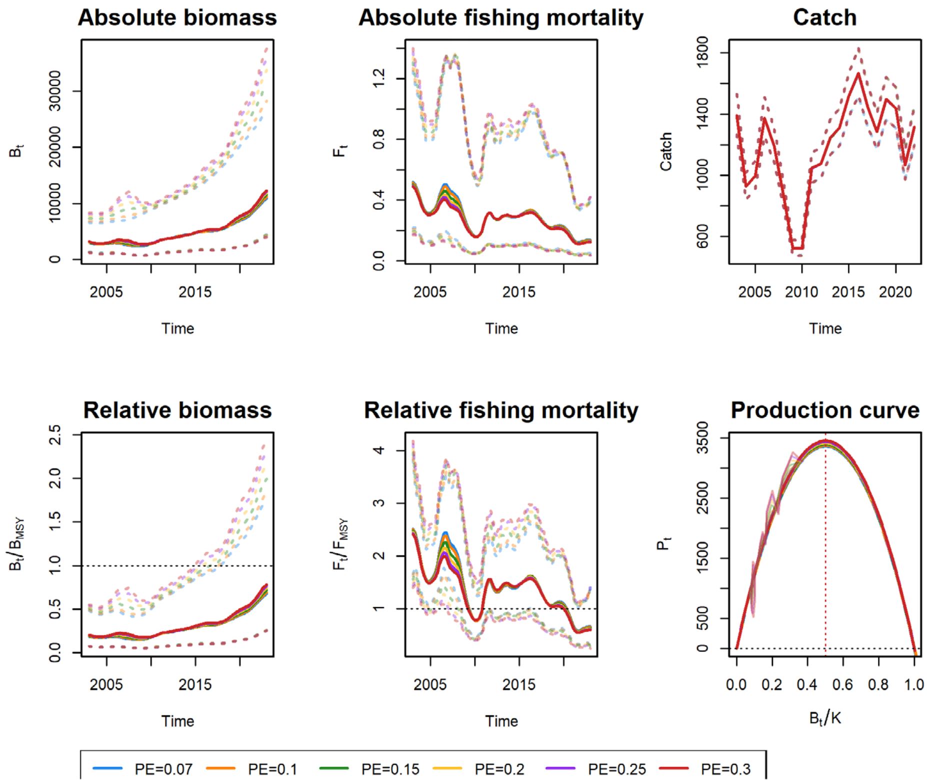
Annex 10. Hindcasting for the model for red mullet in GSA6 for scenario 3.



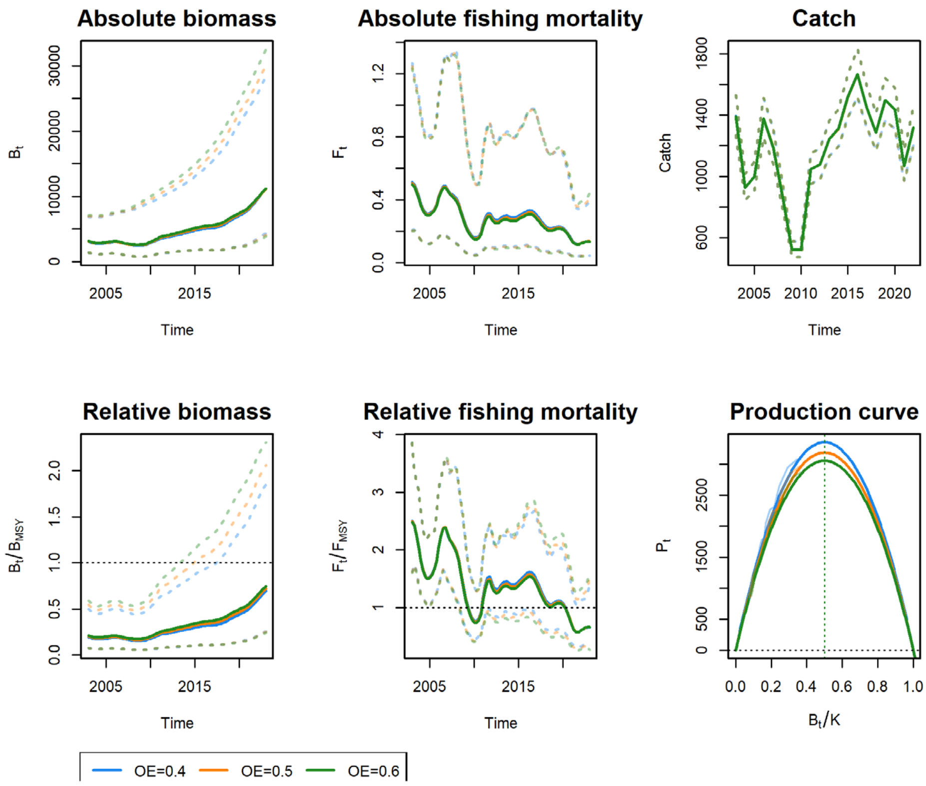
Annex 11. Scenario 2 r prior sensitivity for red mullet in GSA6.



Annex 12. Scenario 2 BKfrac sensitivity for red mullet in GSA6.

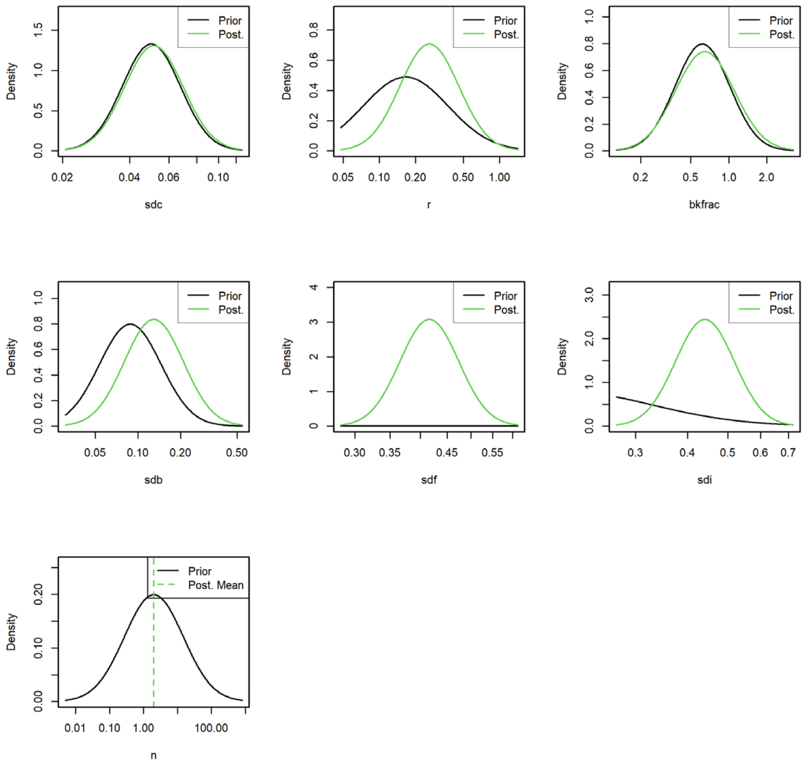


Annex 13. Scenario 2 Process error prior sensitivity for red mullet in GSA6.

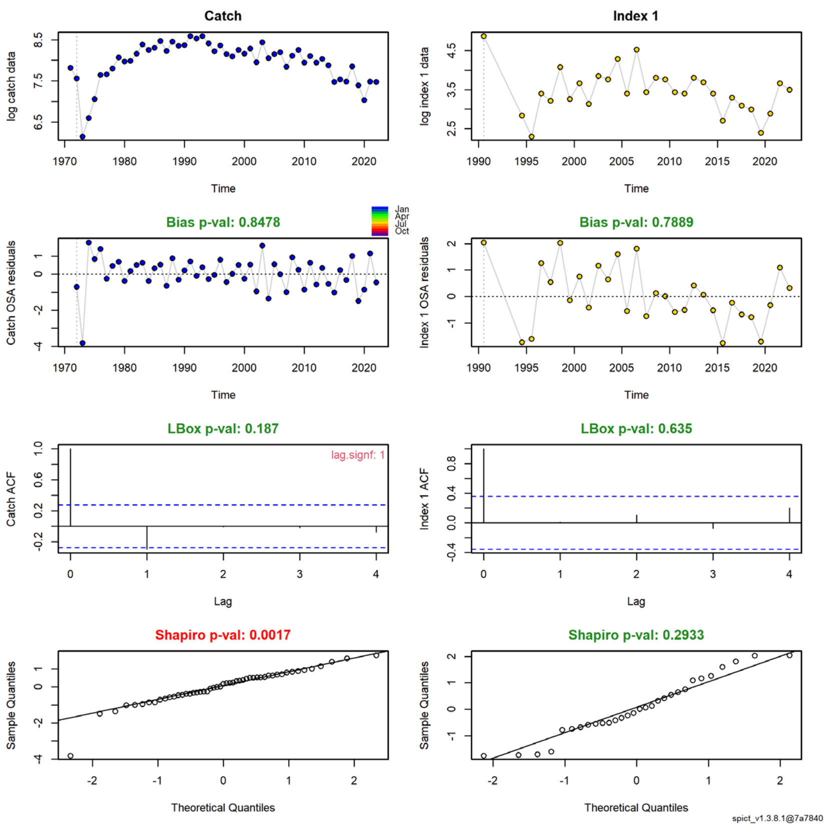


Annex 14. Scenario 2 Observation error sensitivity for red mullet in GSA6.

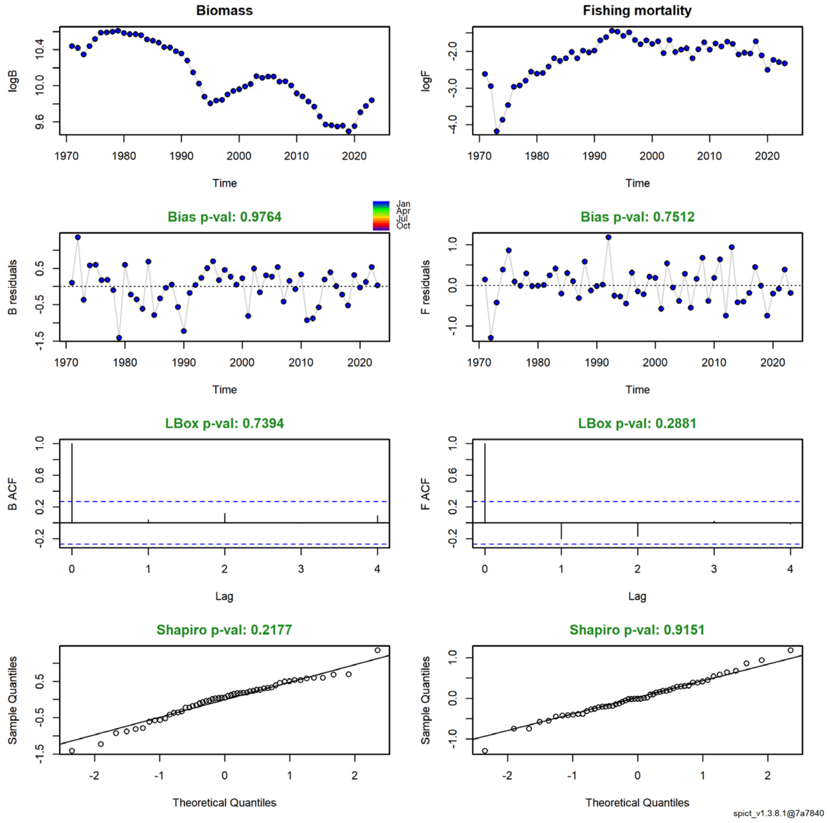
Hake (*Merluccius merluccius*) HKE



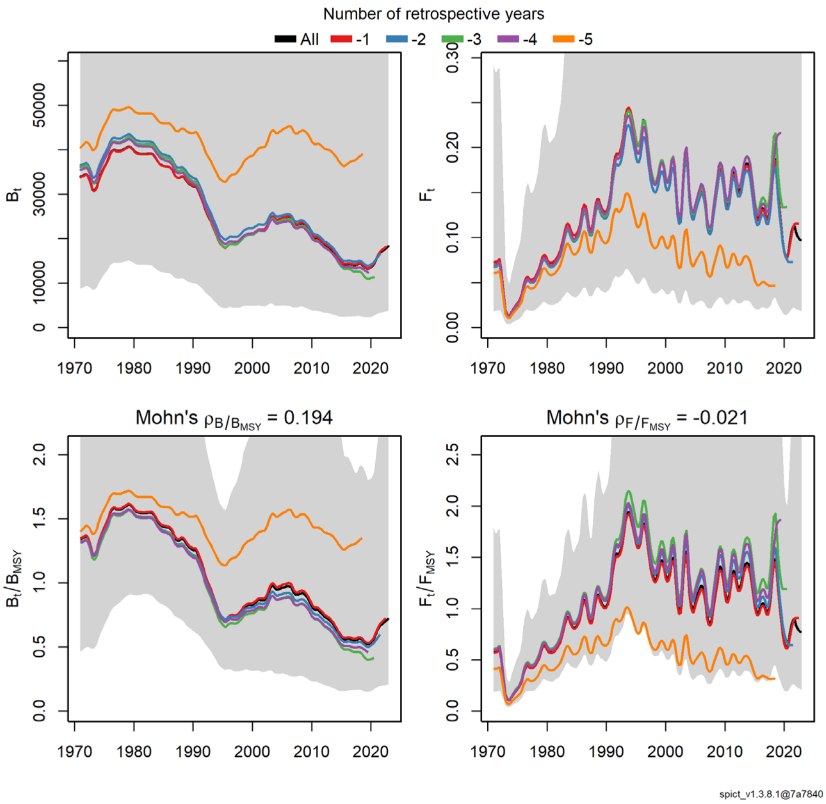
Annex 15. Estimated priors and posteriors for the updated assessment for hake in GSA6 for scenario 1.



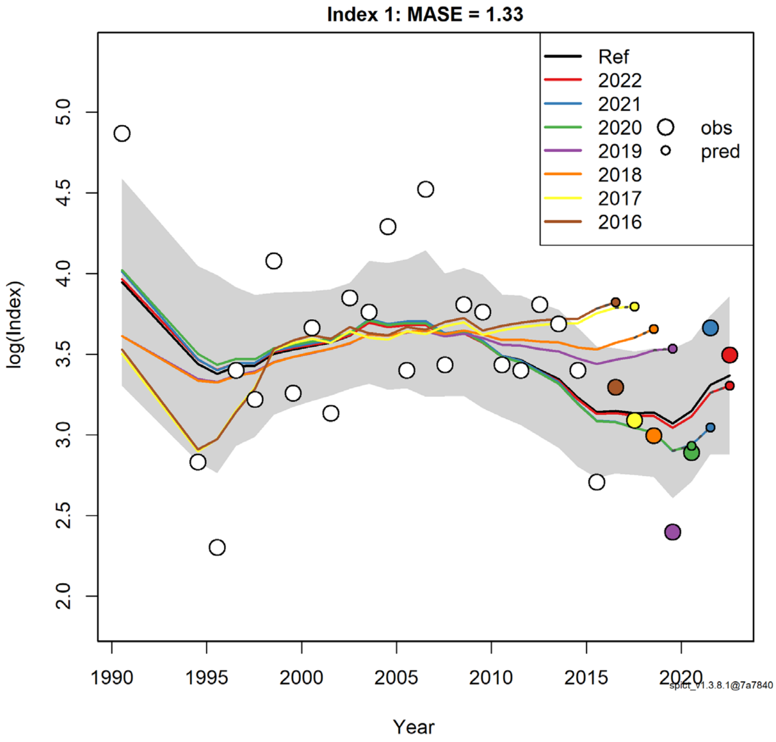
Annex 16. One-step-ahead residuals for the model for hake in GSA6 for scenario 1.



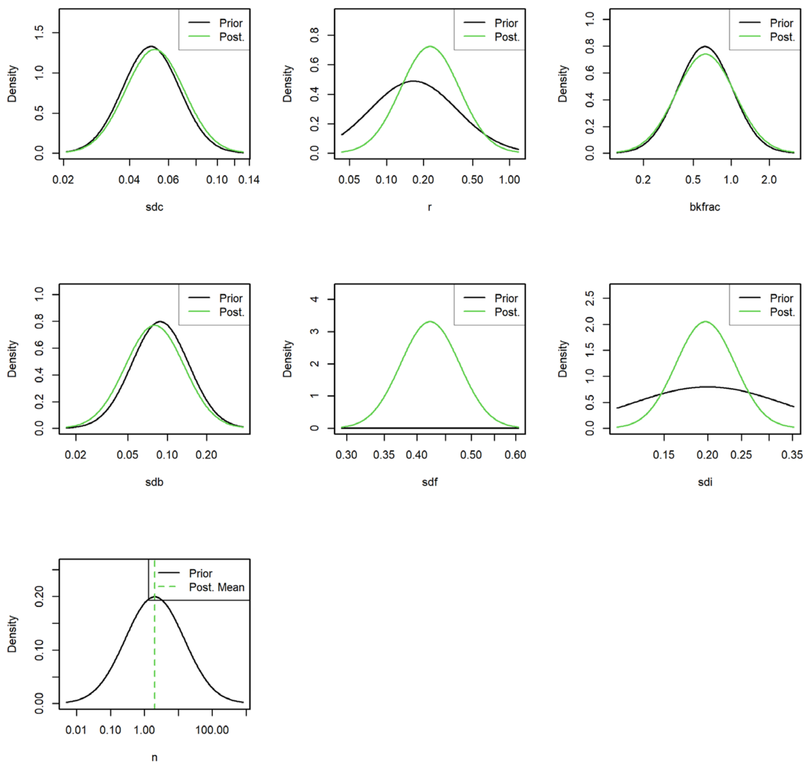
Annex 17. Process error deviations for the model for hake in GSA6 for scenario 1.



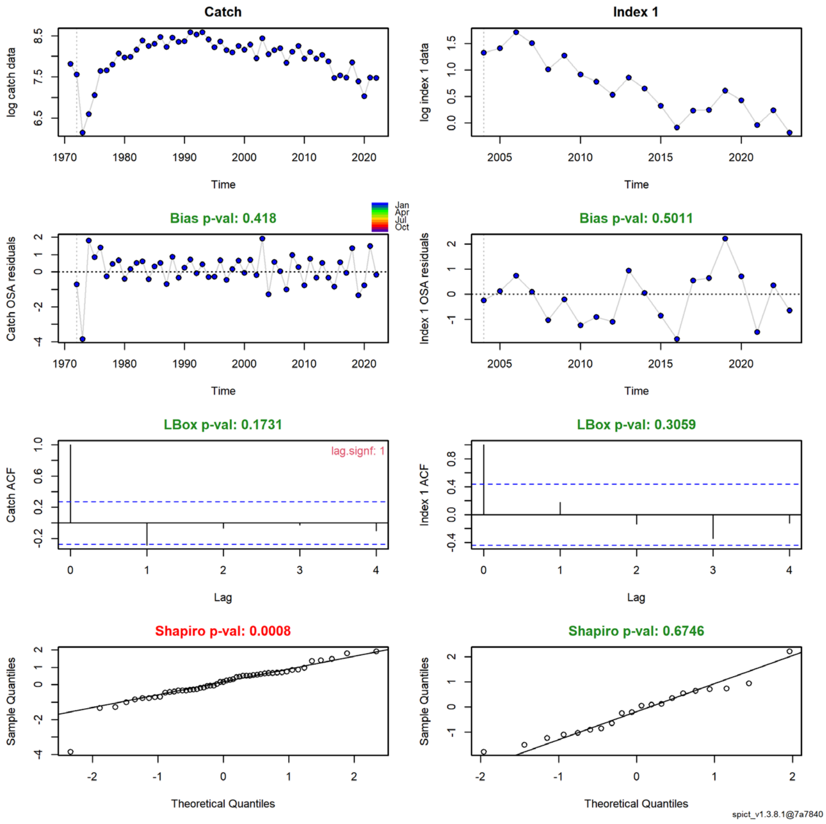
Annex 18. Retrospective analysis for hake in GSA6 for scenario 1.



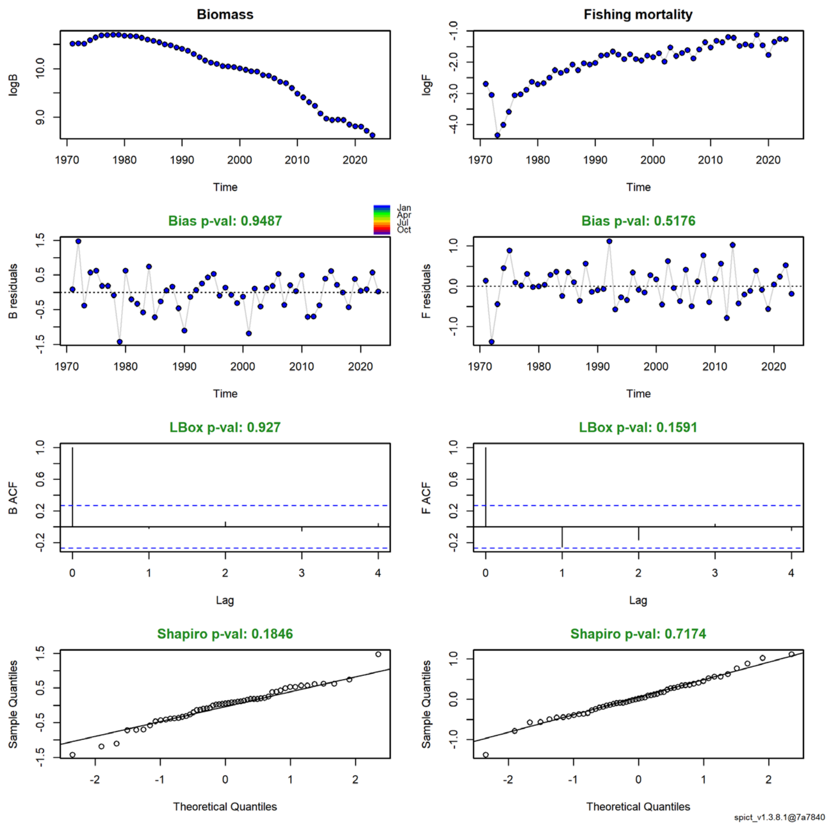
Annex 19. Hindcasting for the model for hake in GSA6 for scenario 1.



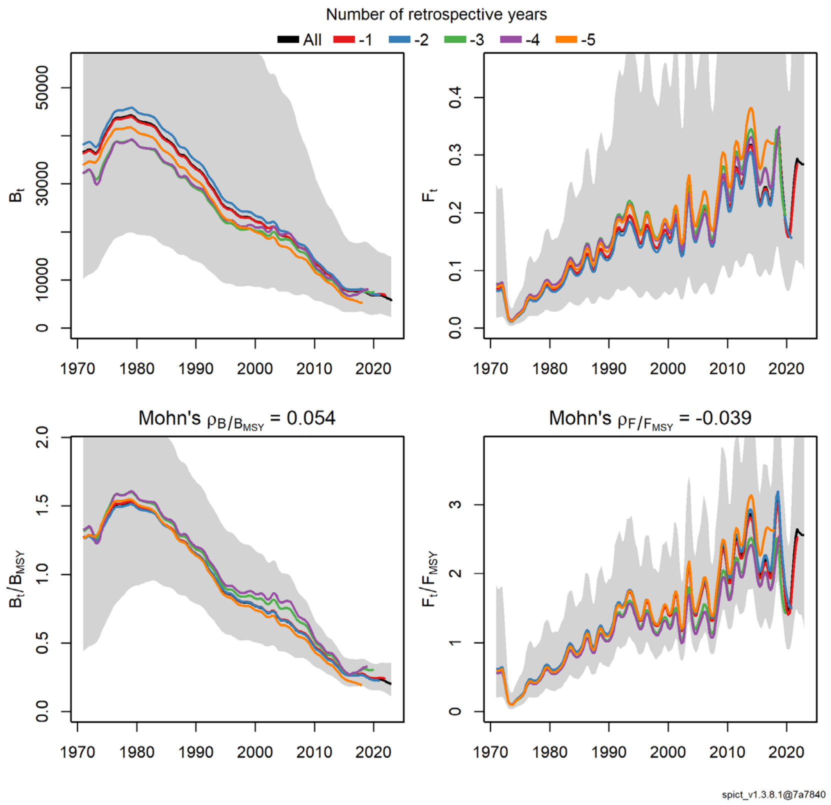
Annex 20. Estimated priors and posteriors for the updated assessment for hake in GSA6 for scenario 12.



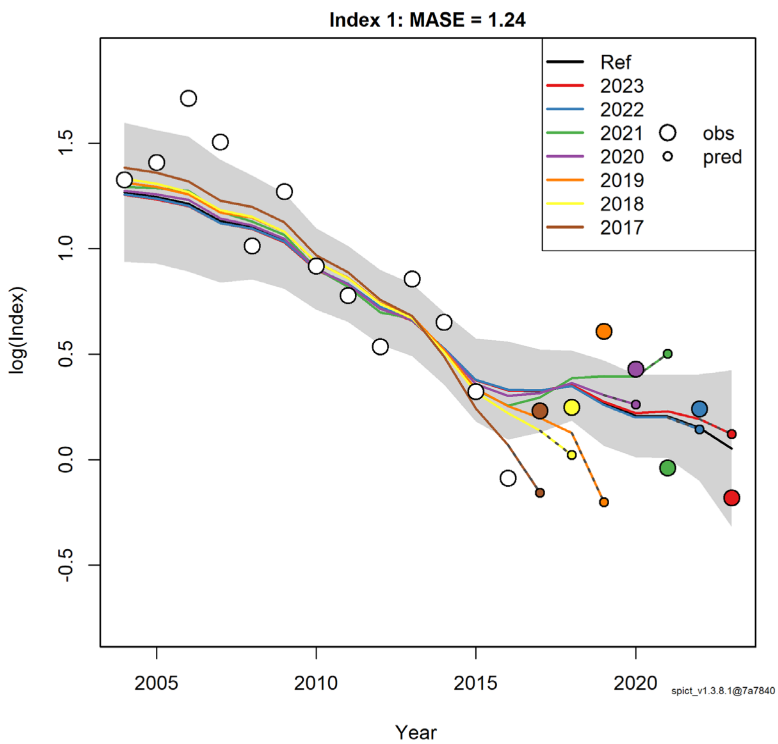
Annex 21. One-step-ahead residuals for the model for hake in GSA6 for scenario 12.



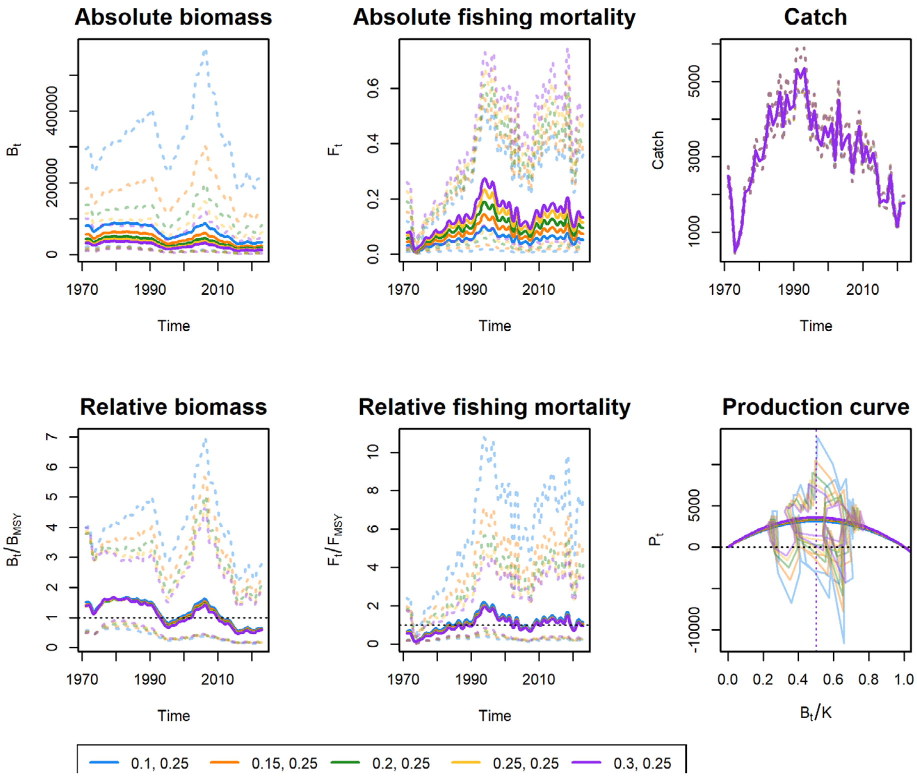
Annex 22. Process error deviations for the model for hake in GSA6 for scenario 12.



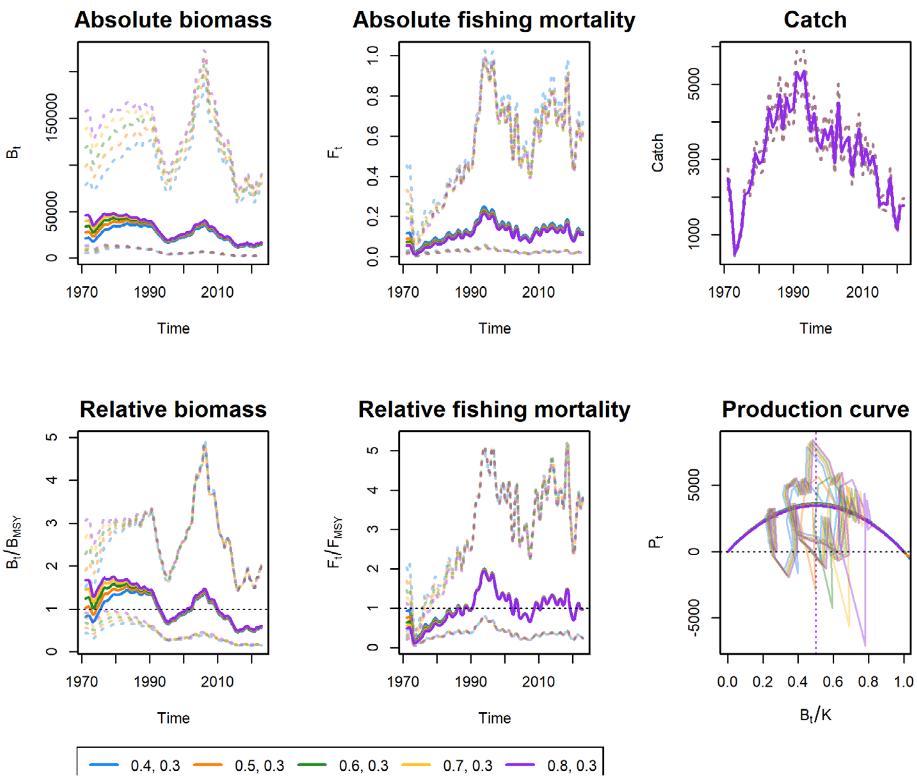
Annex 23. Retrospective analysis for hake in GSA6 for scenario 12.



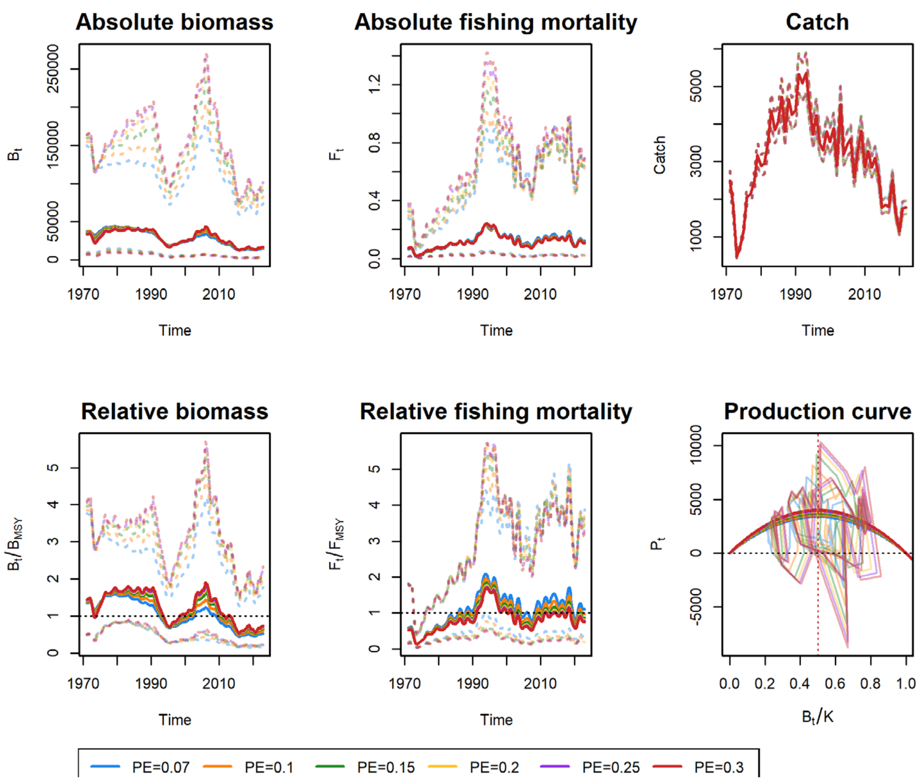
Annex 24. Hindcasting for the model for hake in GSA6 for scenario 12.



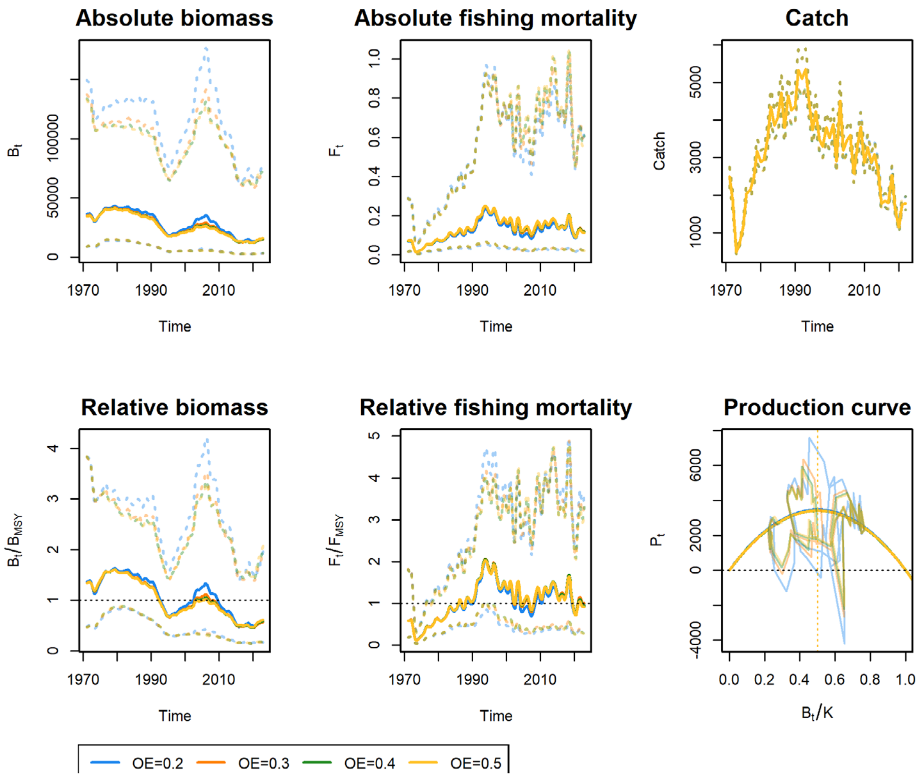
Annex 25. Scenario 11 r prior sensitivity for hake in GSA6.



Annex 26. Scenario 11 BKfrac sensitivity for hake in GSA6.

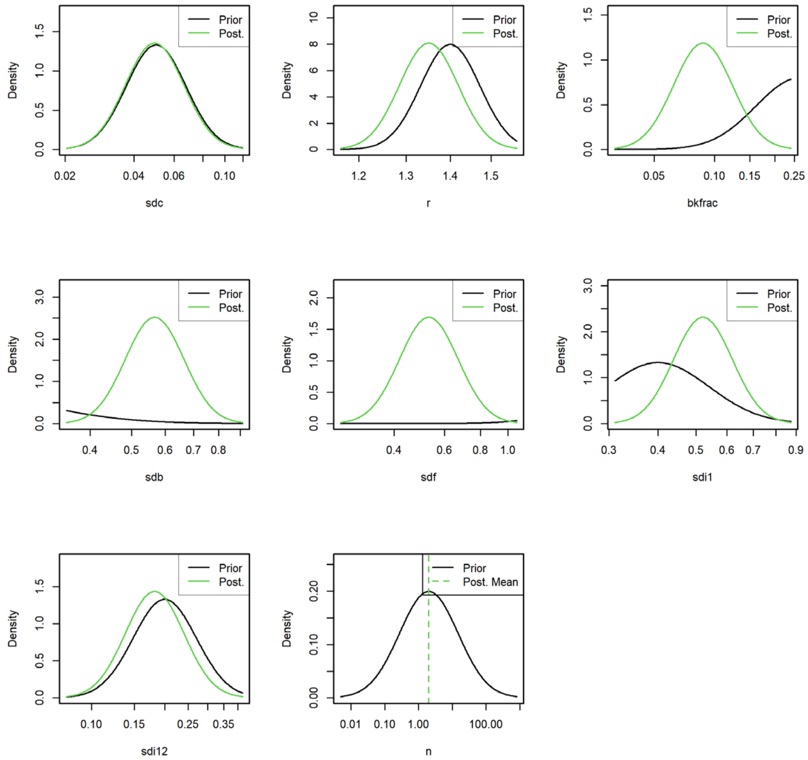


Annex 27. Scenario 11 Process error prior sensitivity for hake in GSA6.

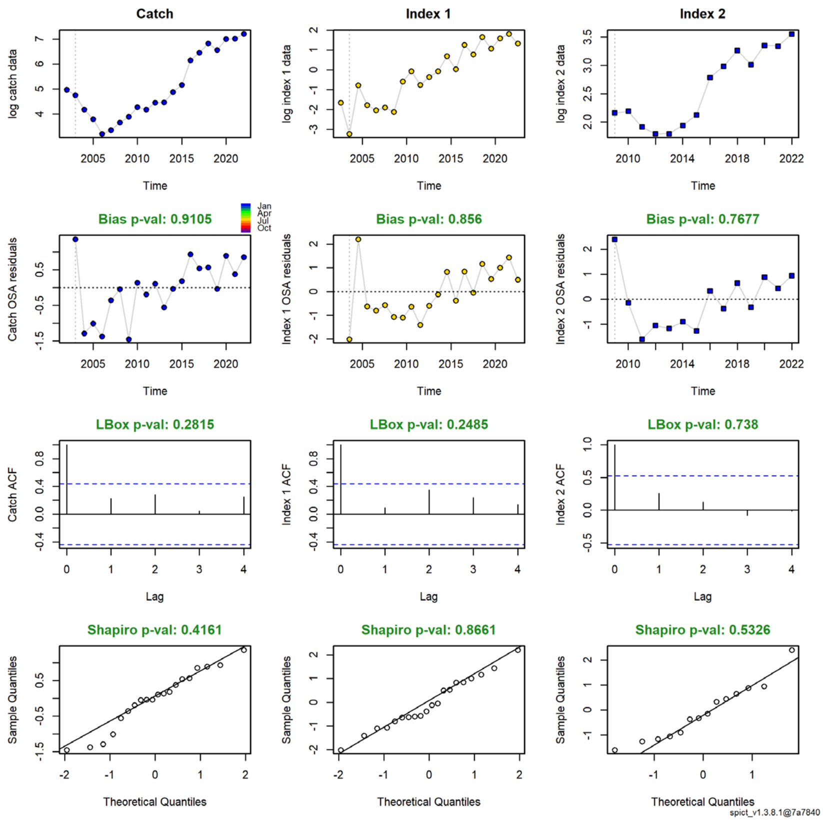


Annex 28. Scenario 11 Observation error sensitivity for hake in GSA6.

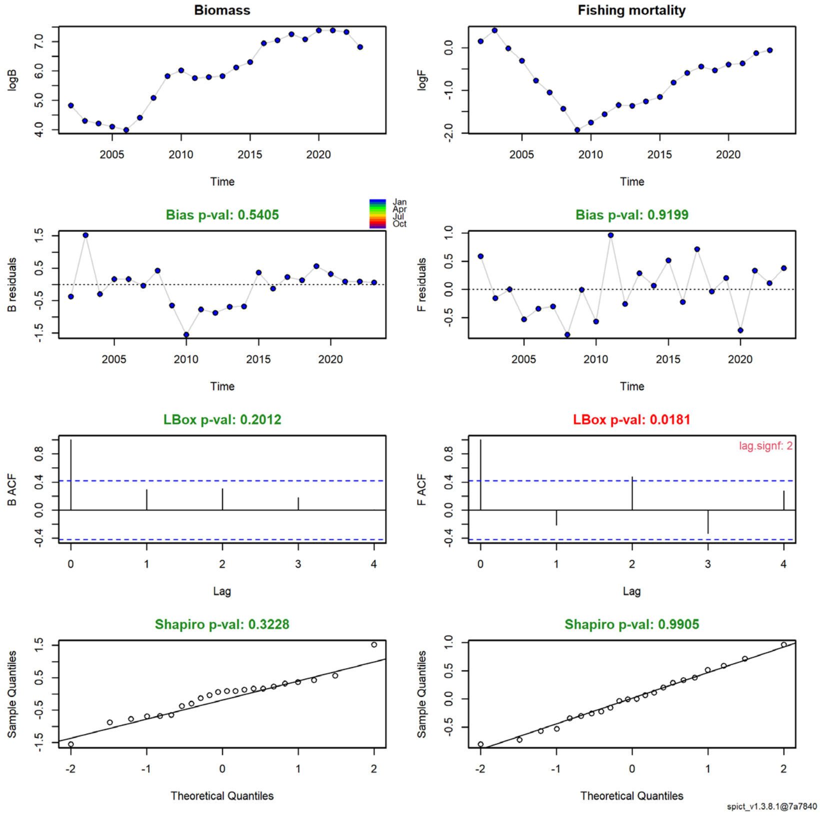
Deep-water rose shrimp (*Parapenaeus longirostris*) DPS



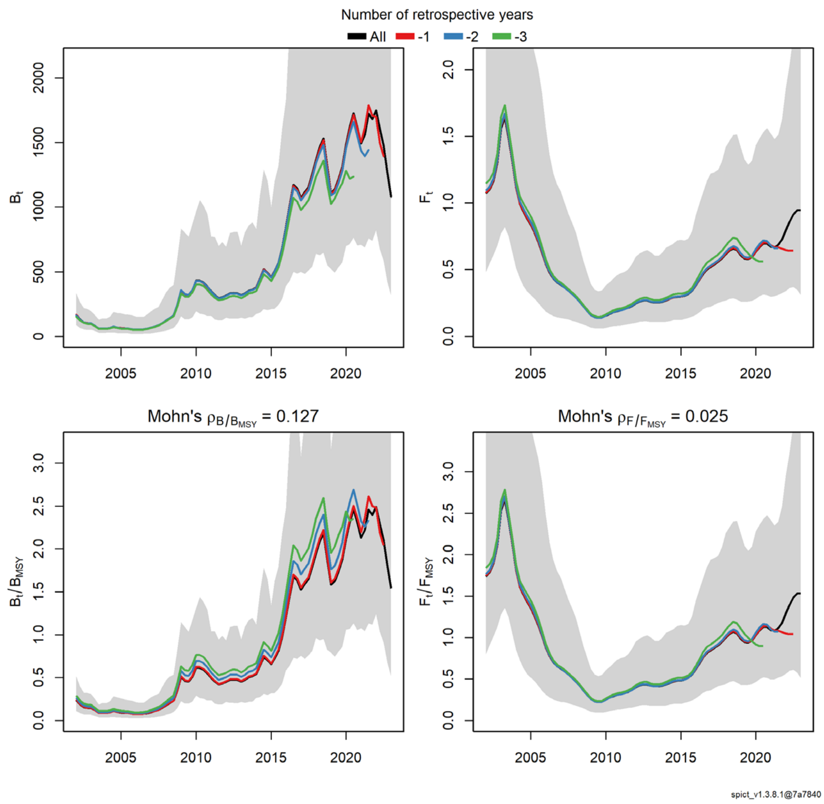
Annex 29. Estimated priors and posteriors for the updated assessment for deep-water rose shrimp in GSA6 for scenario 1.



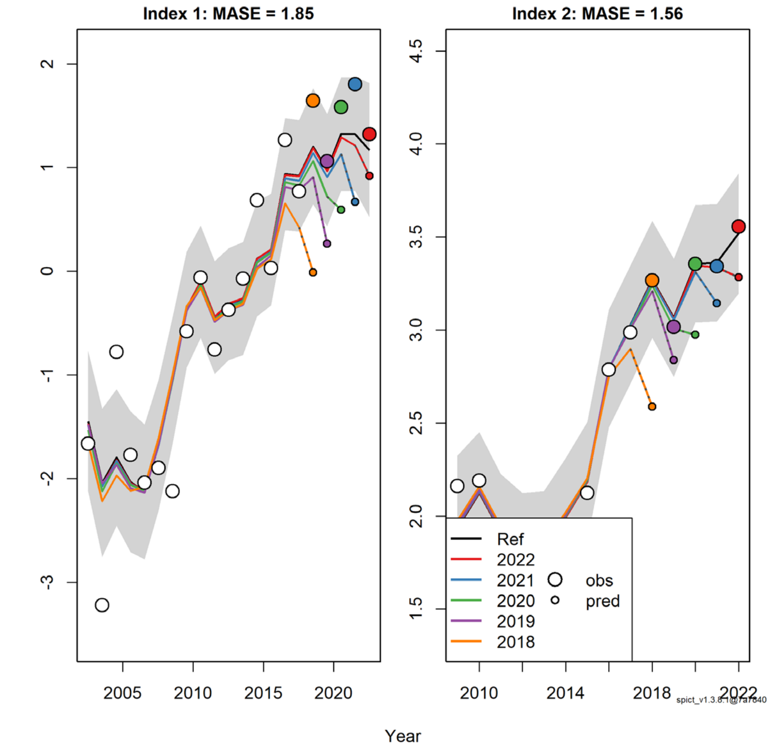
Annex 30. One-step-ahead residuals for the model for deep-water rose shrimp in GSA6 for scenario 1.



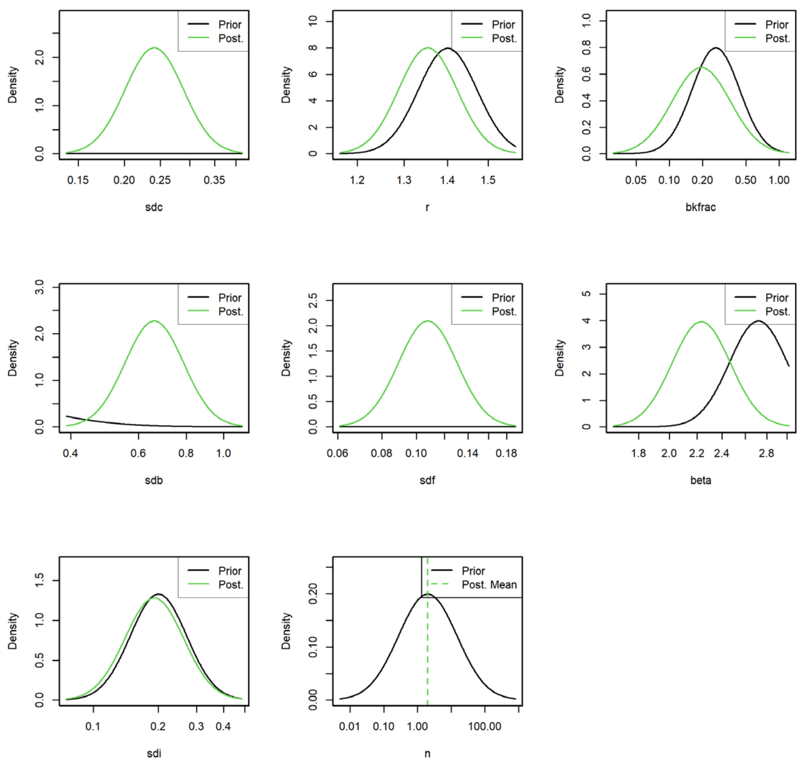
Annex 31. Process error deviations for the model for deep-water rose shrimp in GSA6 for scenario 1.



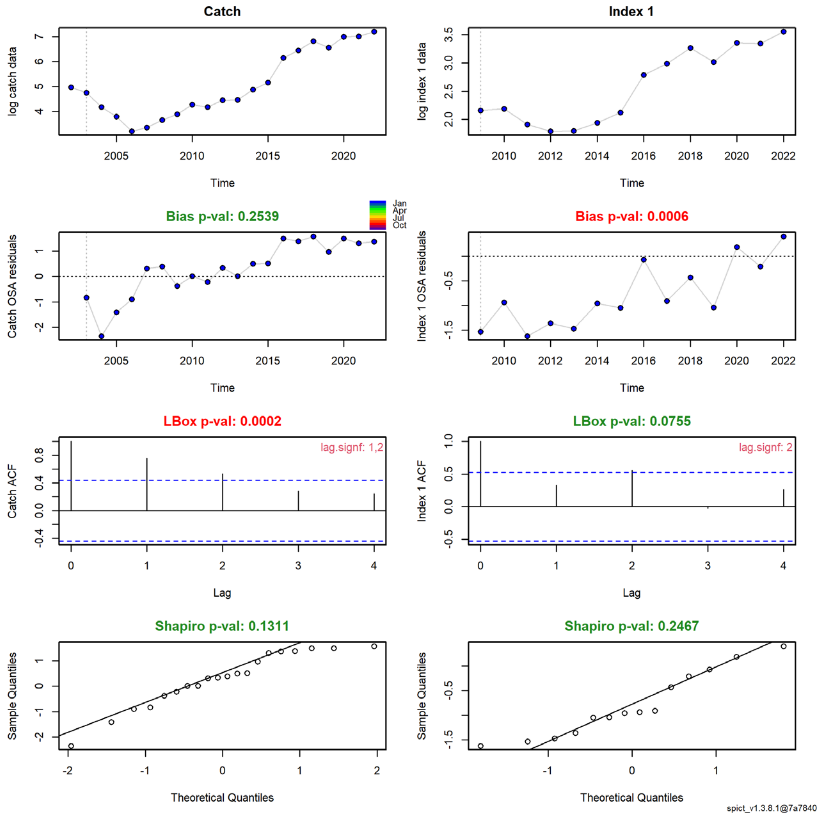
Annex 32. Retrospective analysis for deep-water rose shrimp in GSA6 for scenario 1.



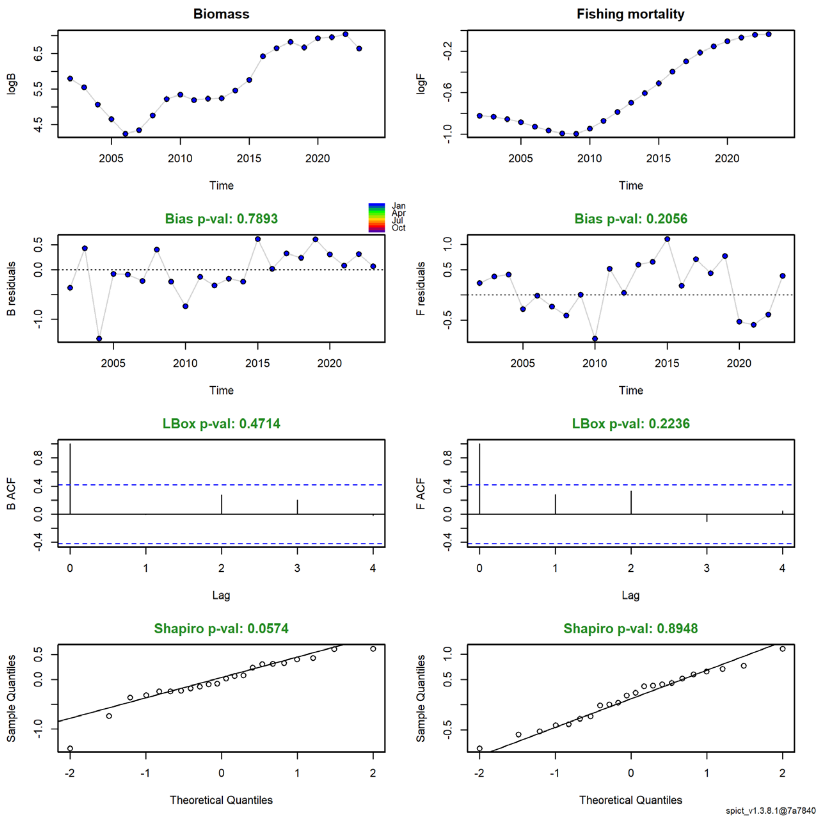
Annex 33. Hindcasting for the model for deep-water rose shrimp in GSA6 for scenario 1.



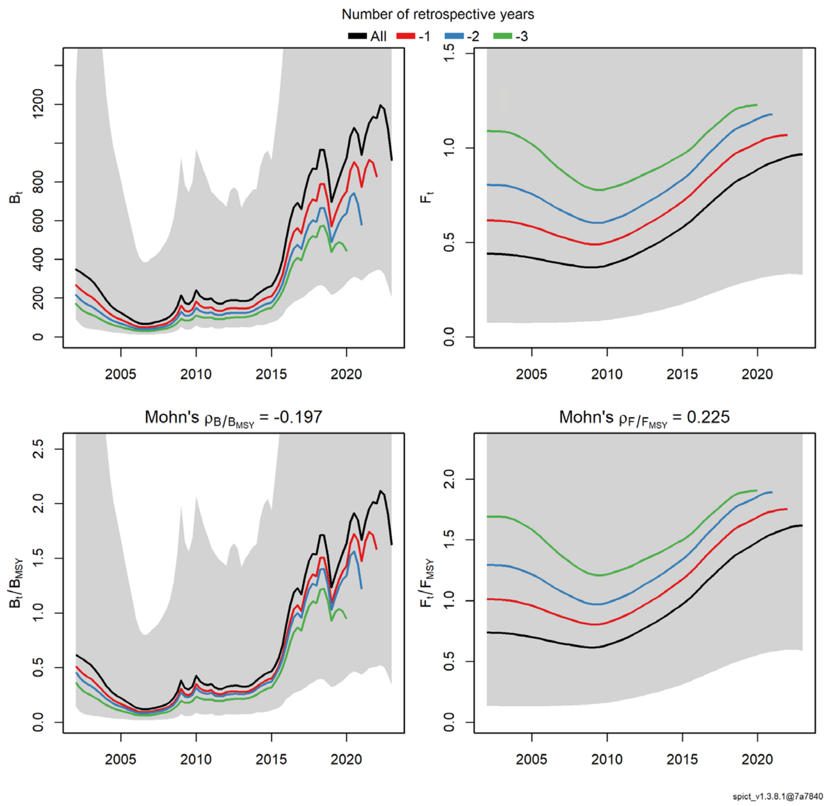
Annex 34. Estimated priors and posteriors for the updated assessment for deep-water rose shrimp in GSA6 for scenario 3.



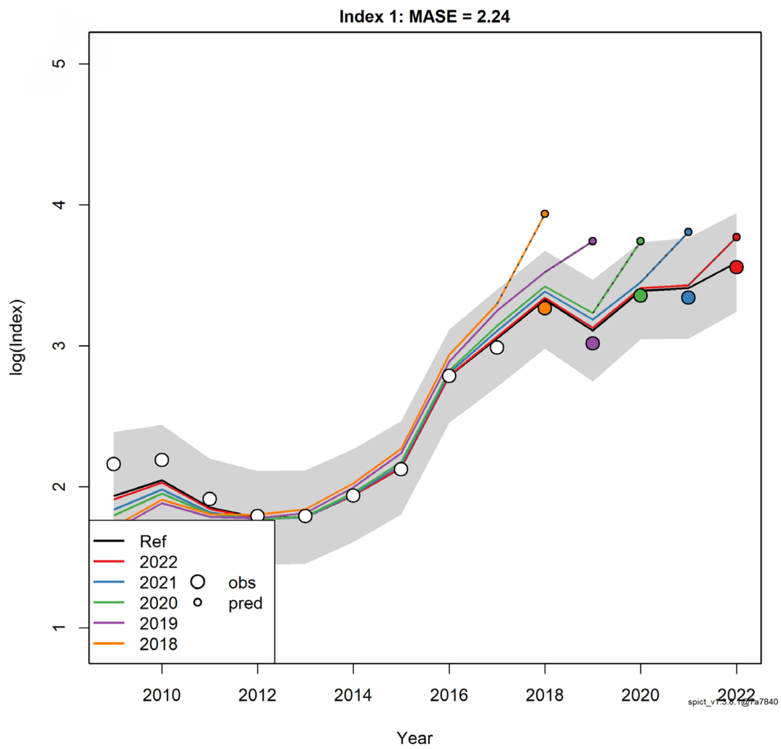
Annex 35. One-step-ahead residuals for the model for deep-water rose shrimp in GSA6 for scenario 3.



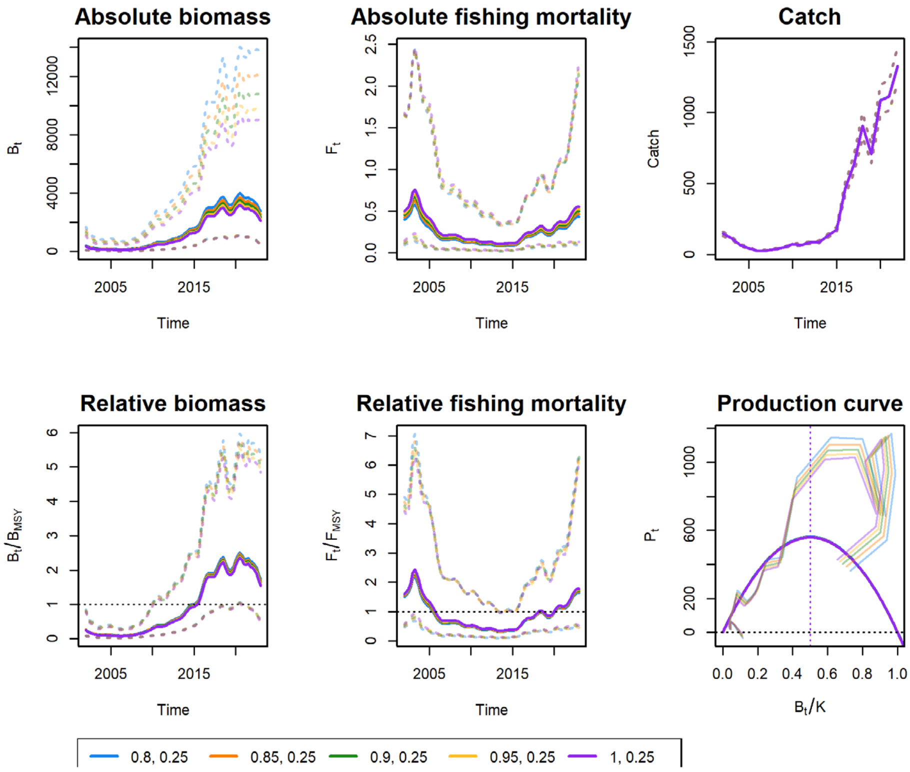
Annex 36. Process error deviations for the model for deep-water rose shrimp in GSA6 for scenario 3.



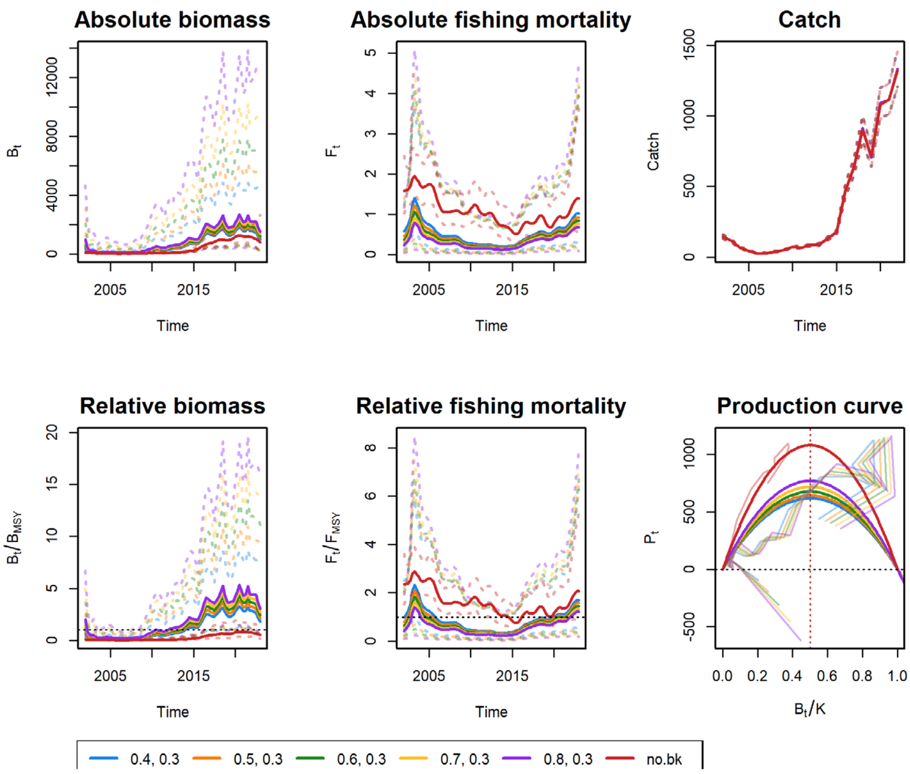
Annex 37. Retrospective analysis for deep-water rose shrimp in GSA6 for scenario 3.



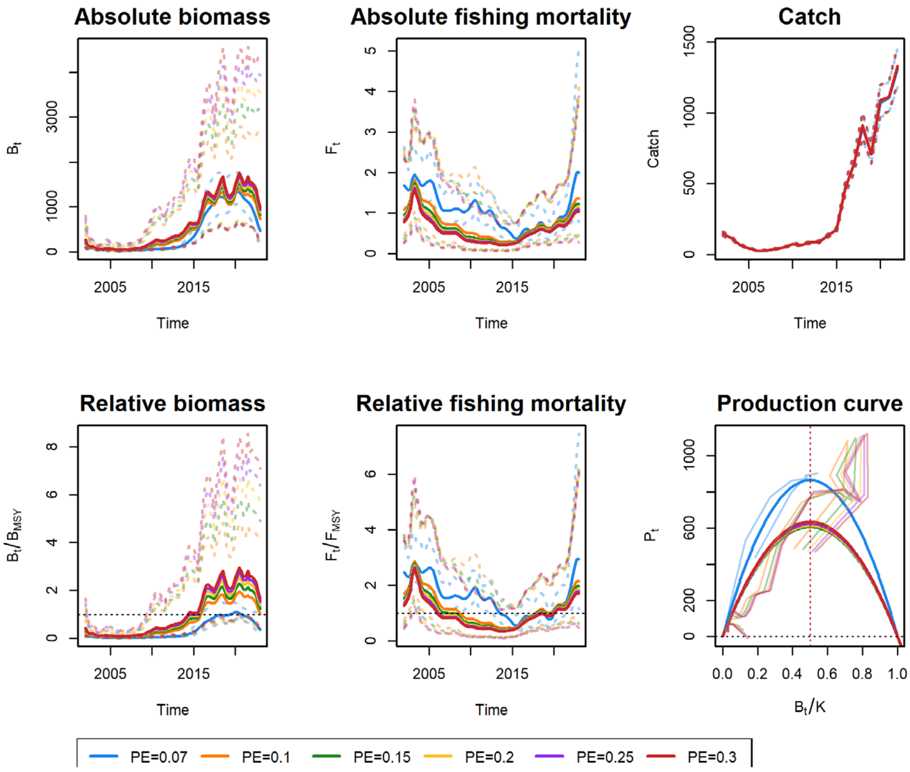
Annex 38. Hindcasting for the model for deep-water rose shrimp in GSA6 for scenario 3.



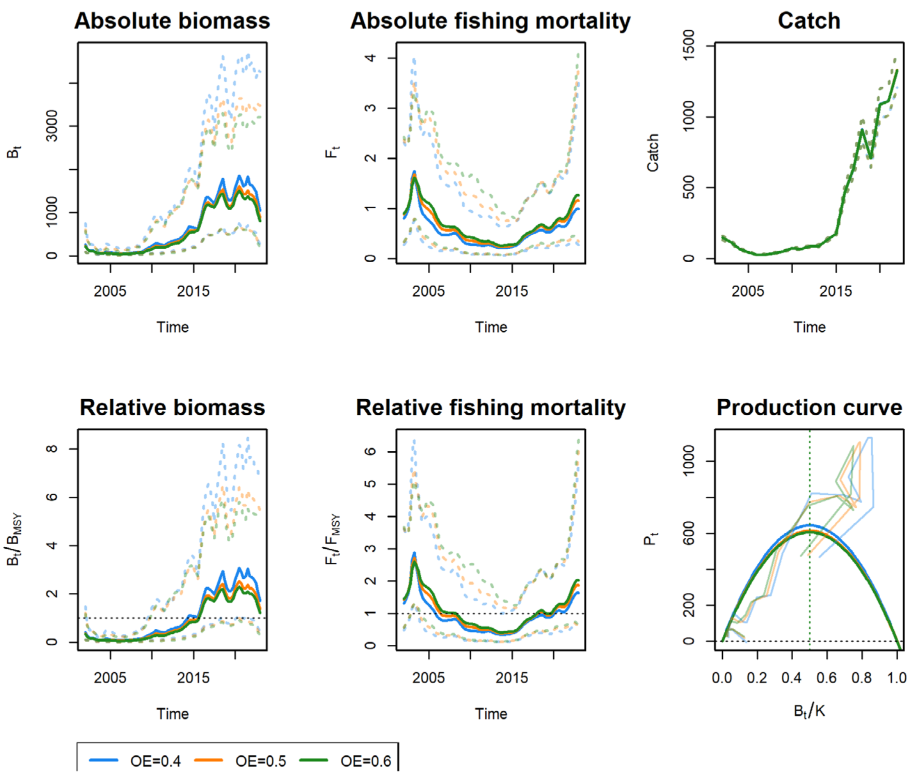
Annex 39. Scenario 2 r prior sensitivity for deep-water rose shrimp in GSA6.



Annex 40. Scenario 2 BKfrac sentitivity for deep-water rose shrimp in GSA6.

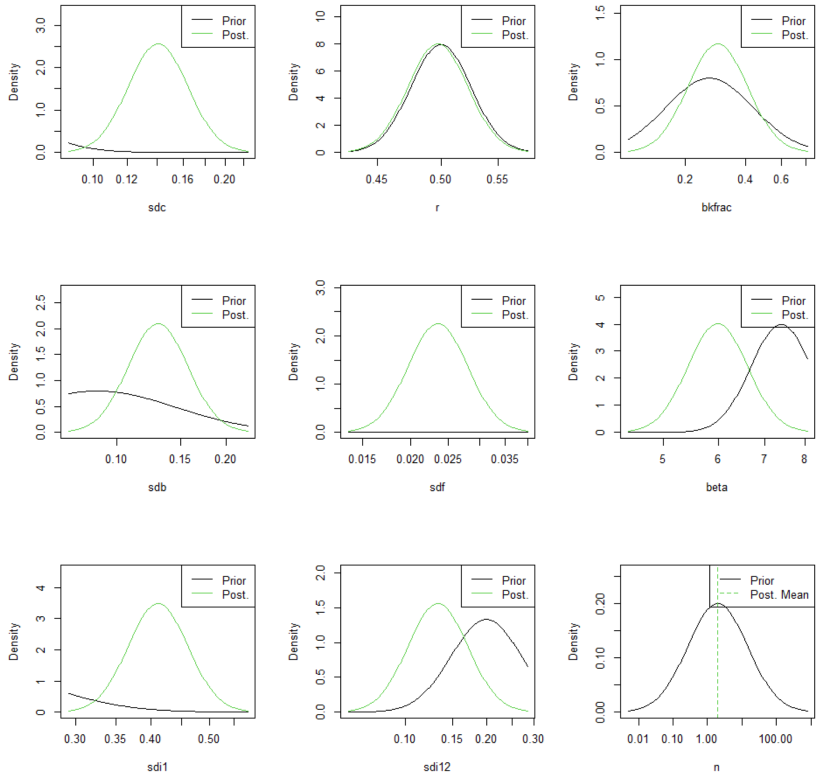


Annex 41. Scenario 2 Process error prior sensitivity for deep-water rose shrimp in GSA6.

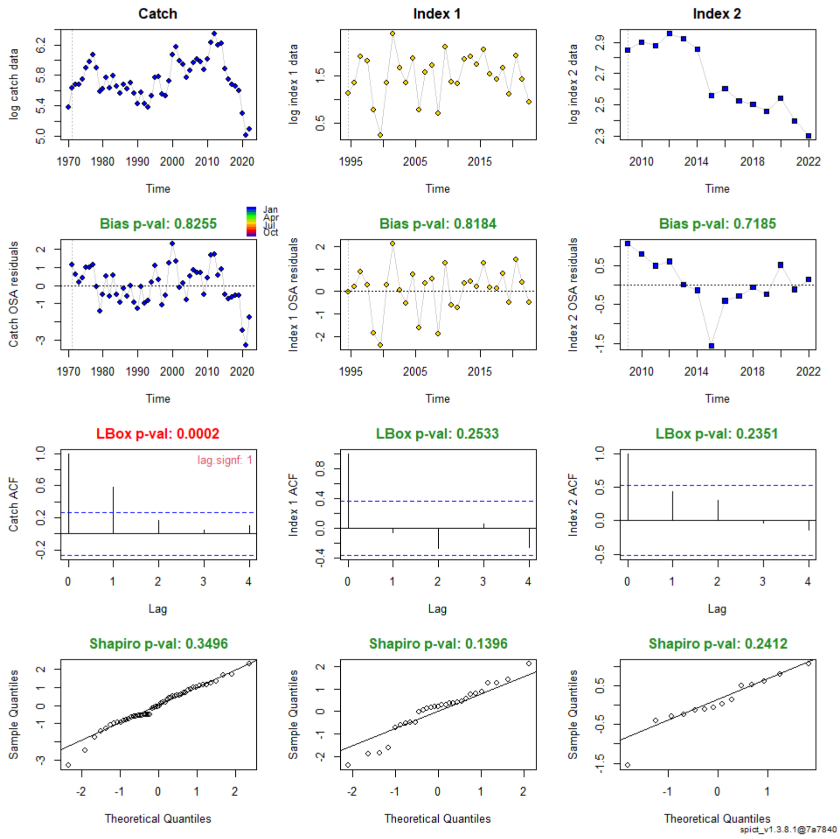


Annex 42. Scenario 2 Observation error sensitivity for deep-water rose shrimp in GSA6.

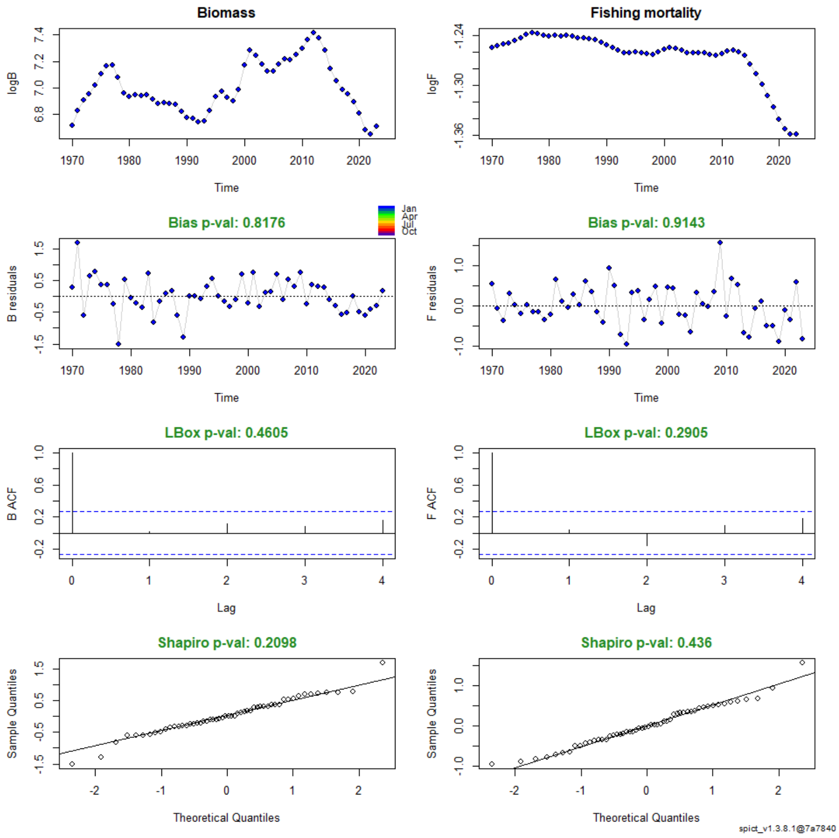
Norway lobster (Nephrops norvegicus) NEP



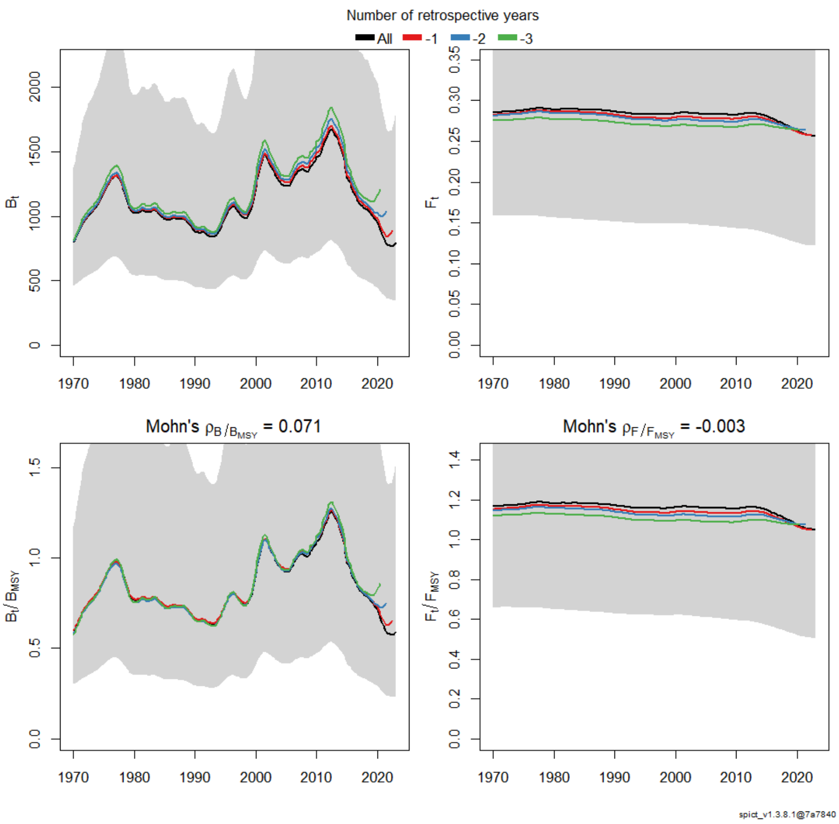
Annex 43. Estimated priors and posteriors for the updated assessment for Norway lobster in GSA6 for scenario 1.



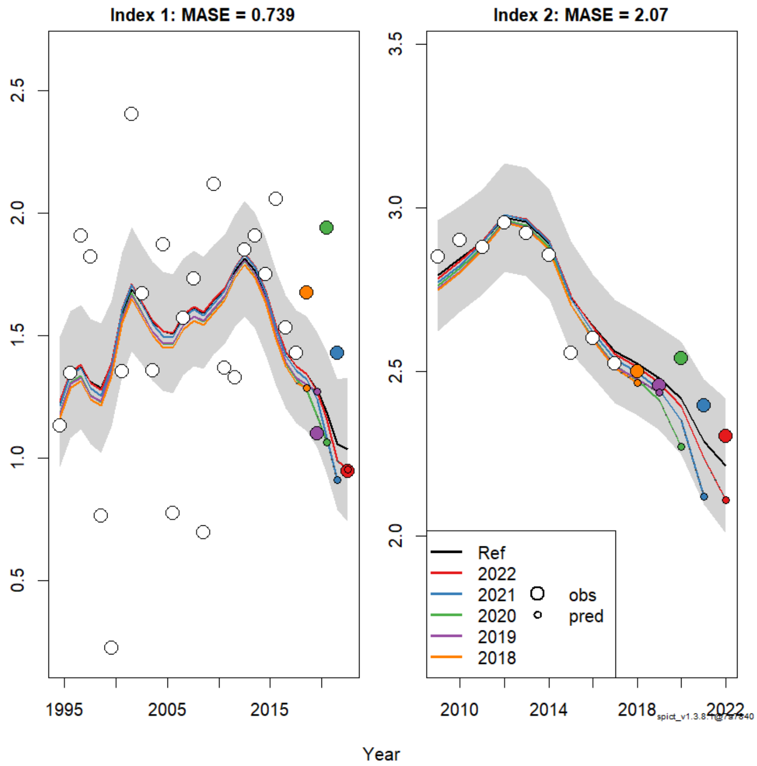
Annex 44. One-step-ahead residuals for the model for Norway lobster in GSA6 for scenario 1.



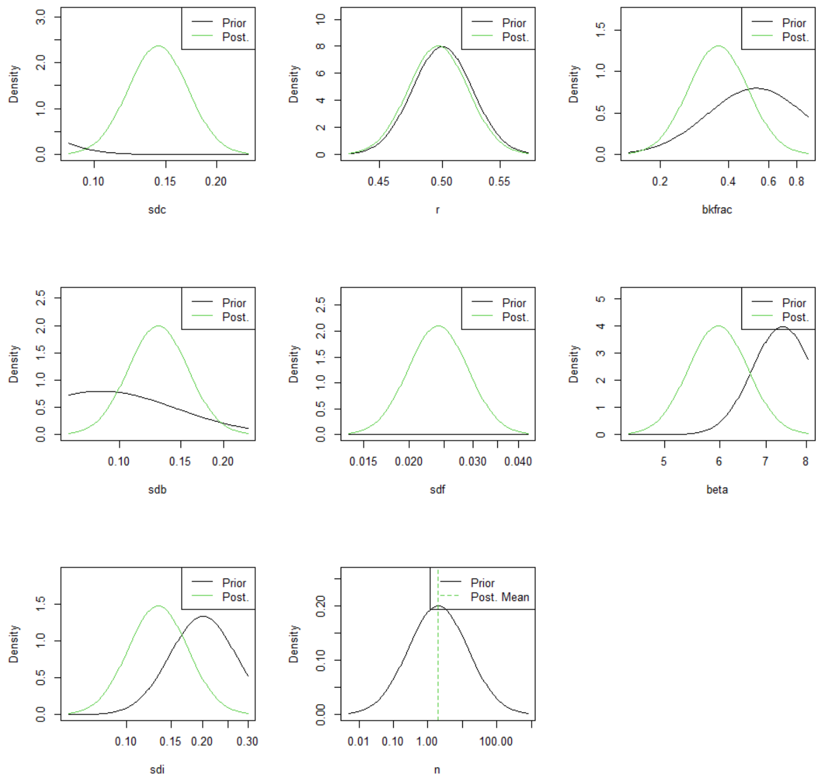
Annex 45. Process error deviations for the model for Norway lobster in GSA6 for scenario 1.



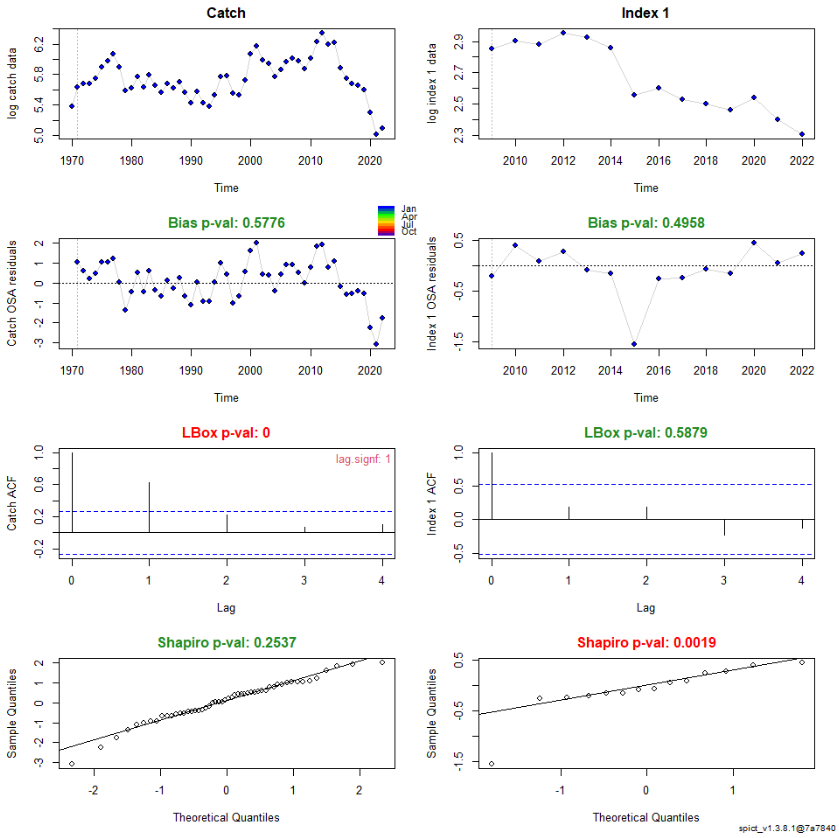
Annex 46. Retrospective analysis for Norway lobster in GSA6 for scenario 1.



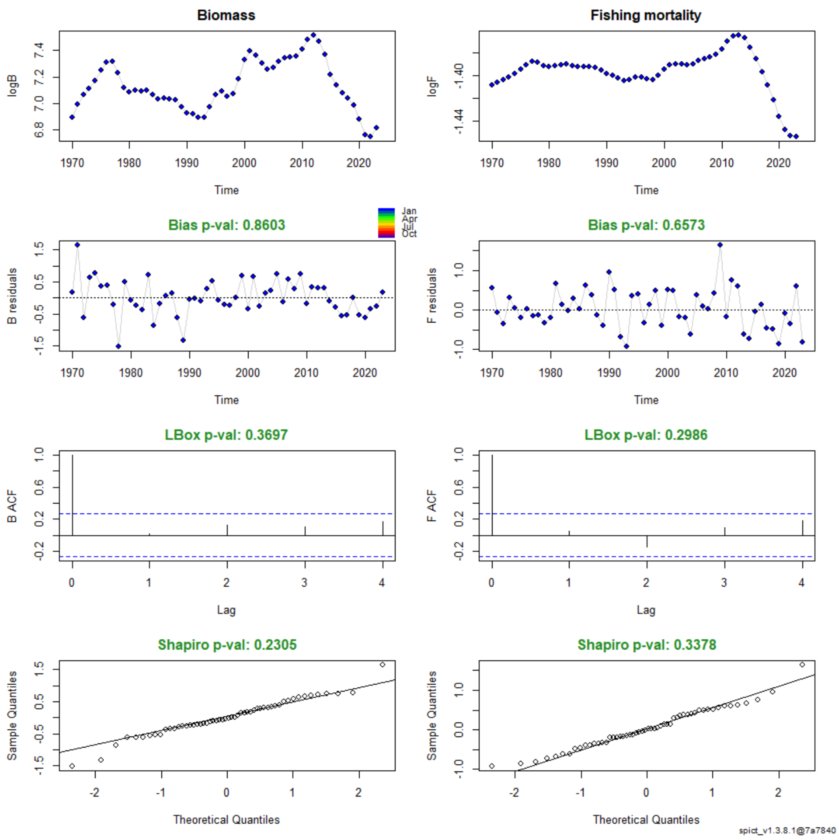
Annex 47. Hindcasting for the model for Norway lobster in GSA6 for scenario 1.



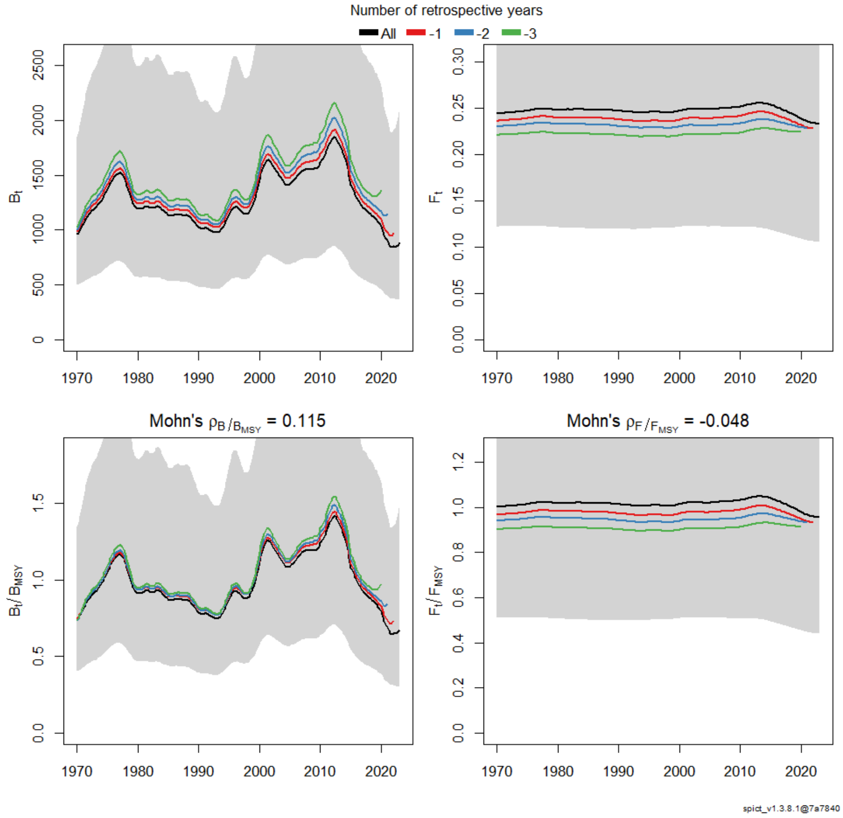
Annex 48. Estimated priors and posteriors for the updated assessment for Norway lobster in GSA6 for scenario 3.



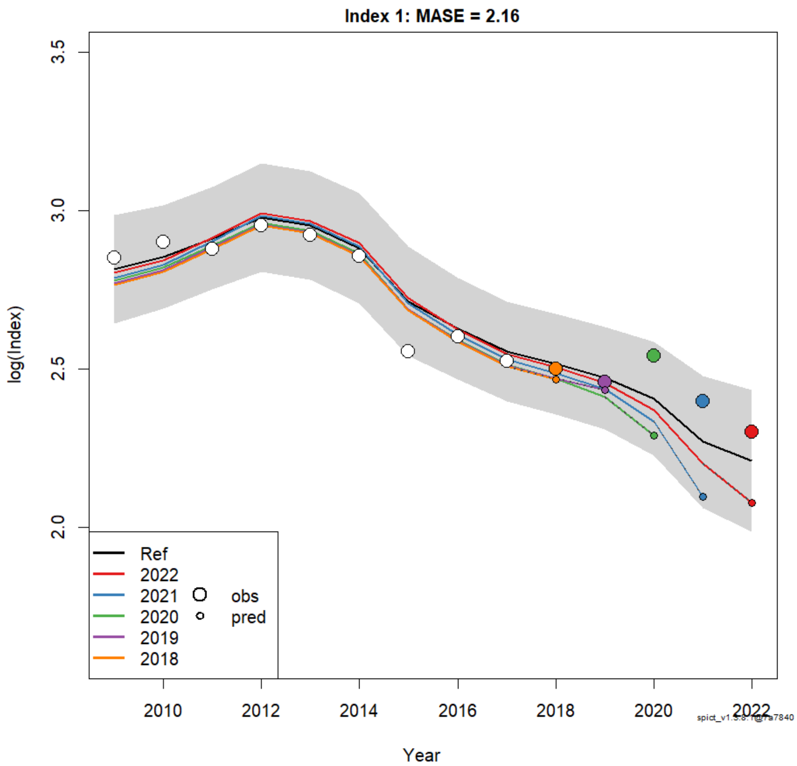
Annex 49. One-step-ahead residuals for the model for Norway lobster in GSA6 for scenario 3.



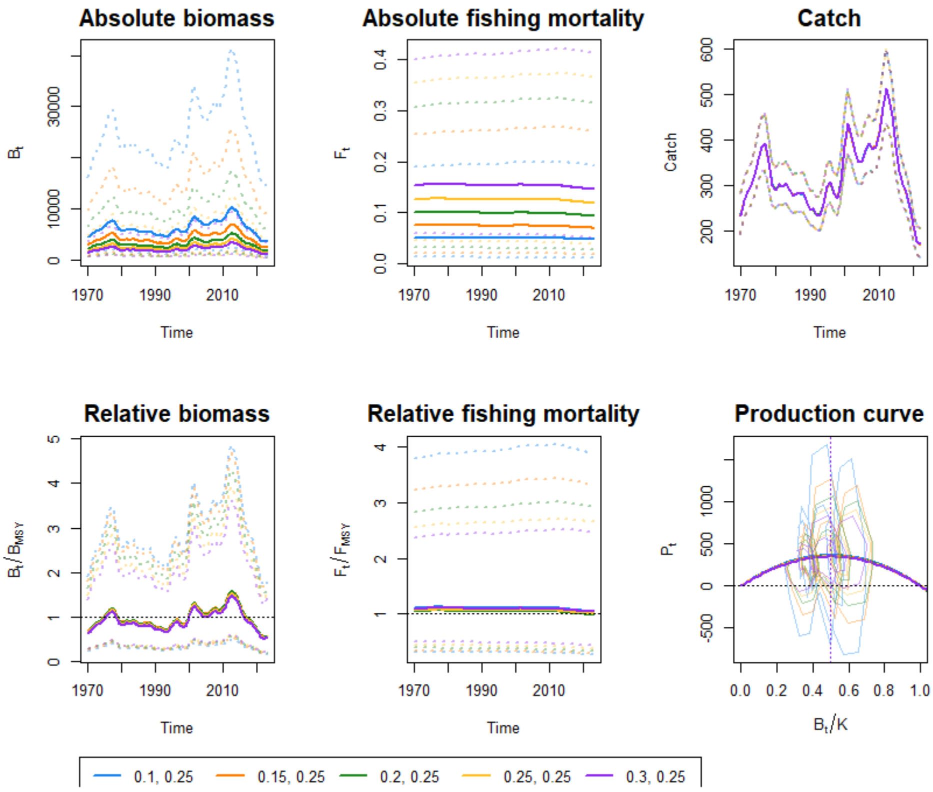
Annex 50. Process error deviations for the model for Norway lobster in GSA6 for scenario 3.



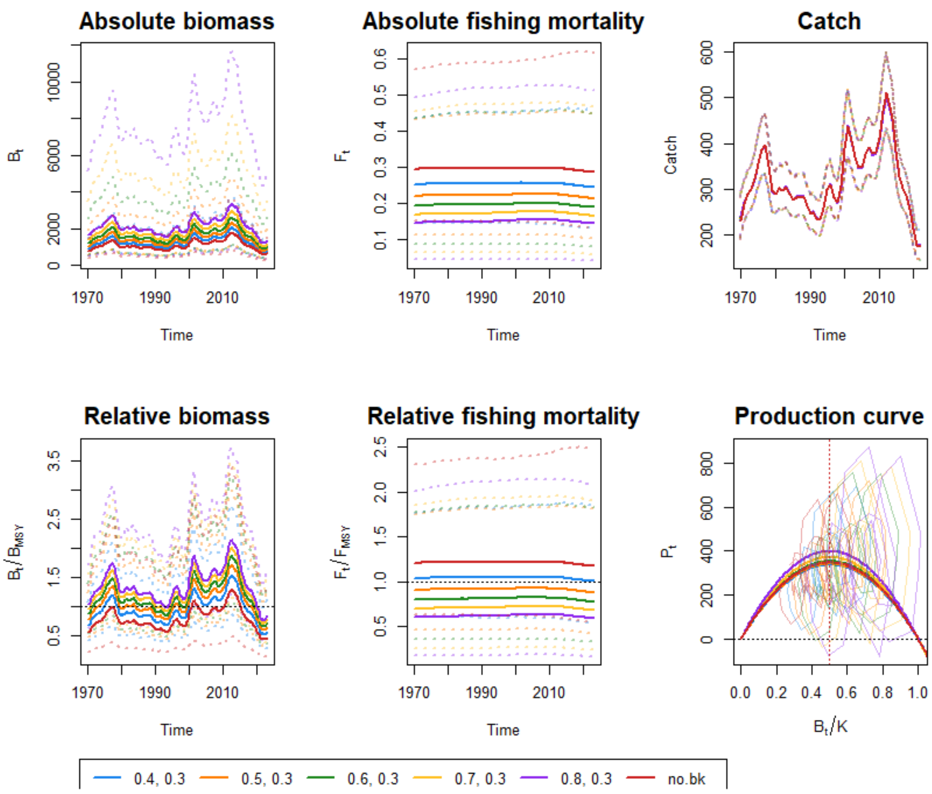
Annex 51. Retrospective analysis for Norway lobster in GSA6 for scenario 3.



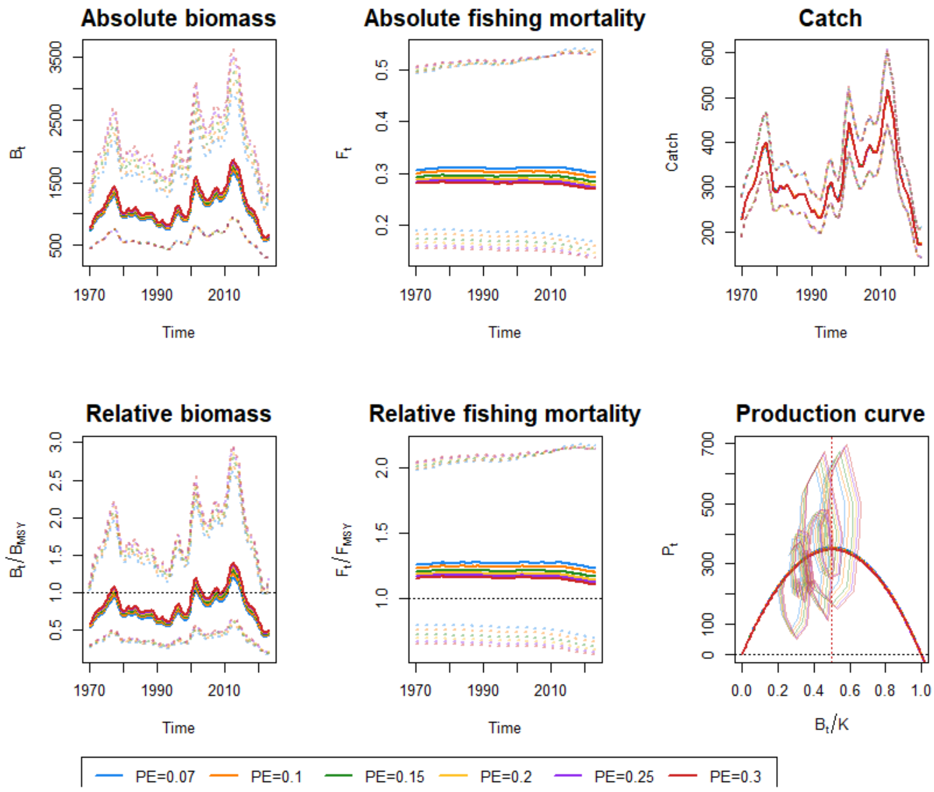
Annex 52. Hindcasting for the model for Norway lobster in GSA6 for scenario 3.



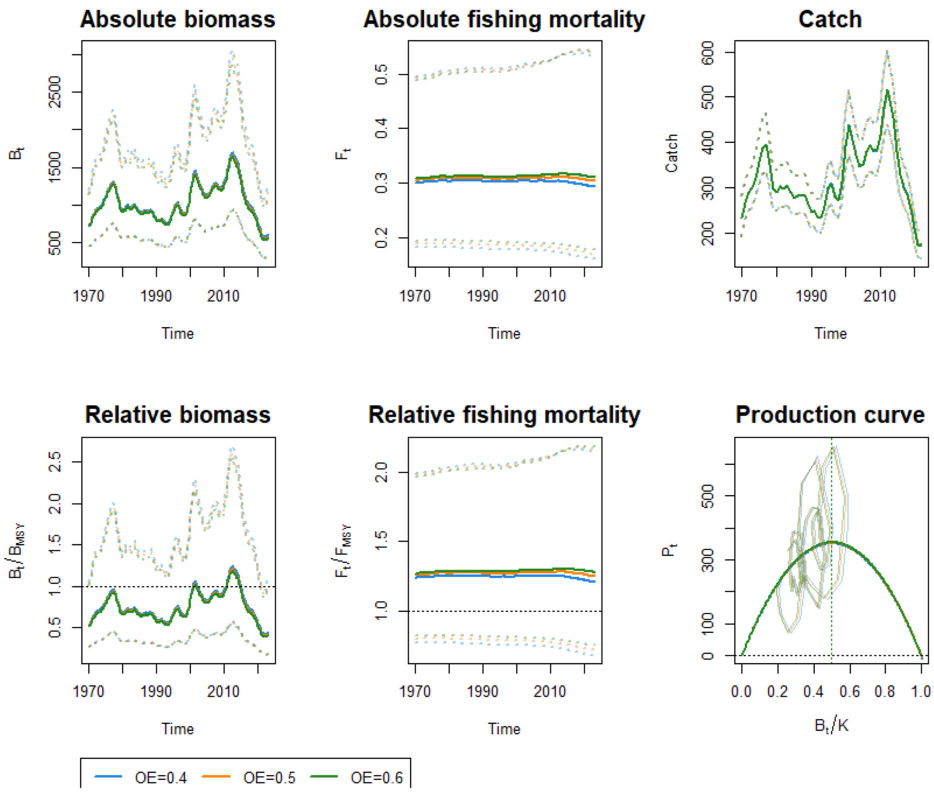
Annex 53. Scenario 2 r prior sensitivity for Norway lobster in GSA6.



Annex 54. Scenario 2 BKfrac sensitivity for Norway lobster in GSA6.

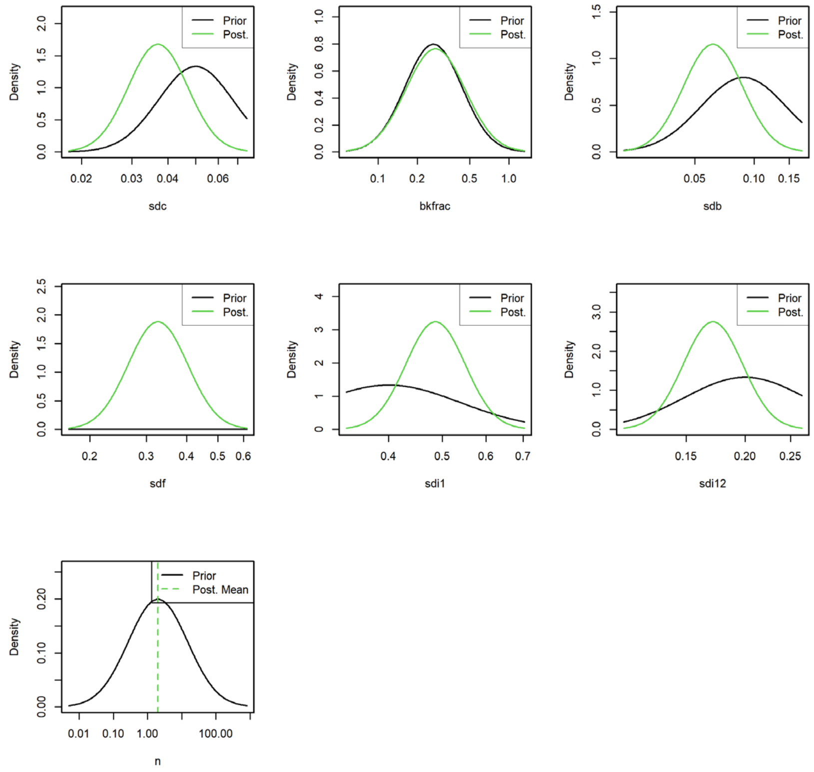


Annex 55. Scenario 2 Process error prior sensitivity for Norway lobster in GSA6.

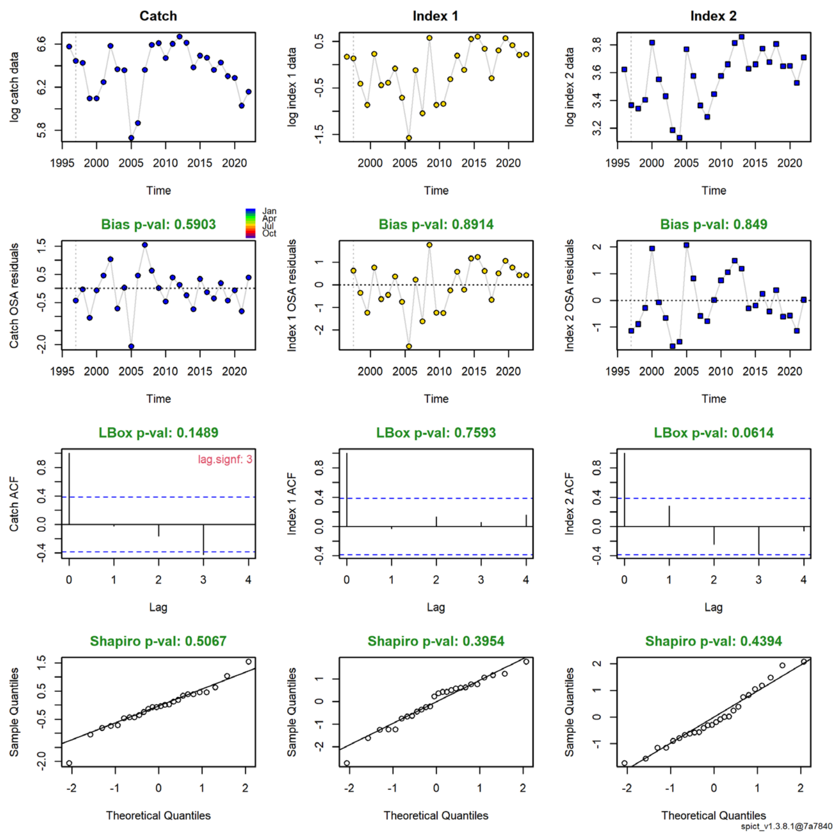


Annex 56. Scenario 2 Observation error sensitivity for Norway lobster in GSA6.

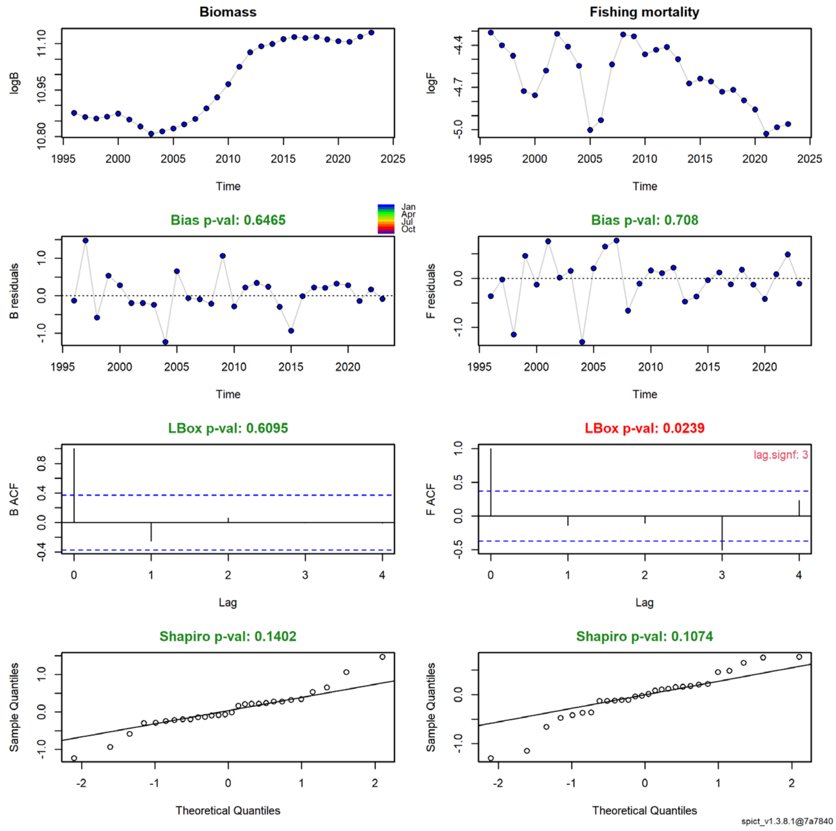
Blue and red shrimp (*Aristeus antennatus*) ARA



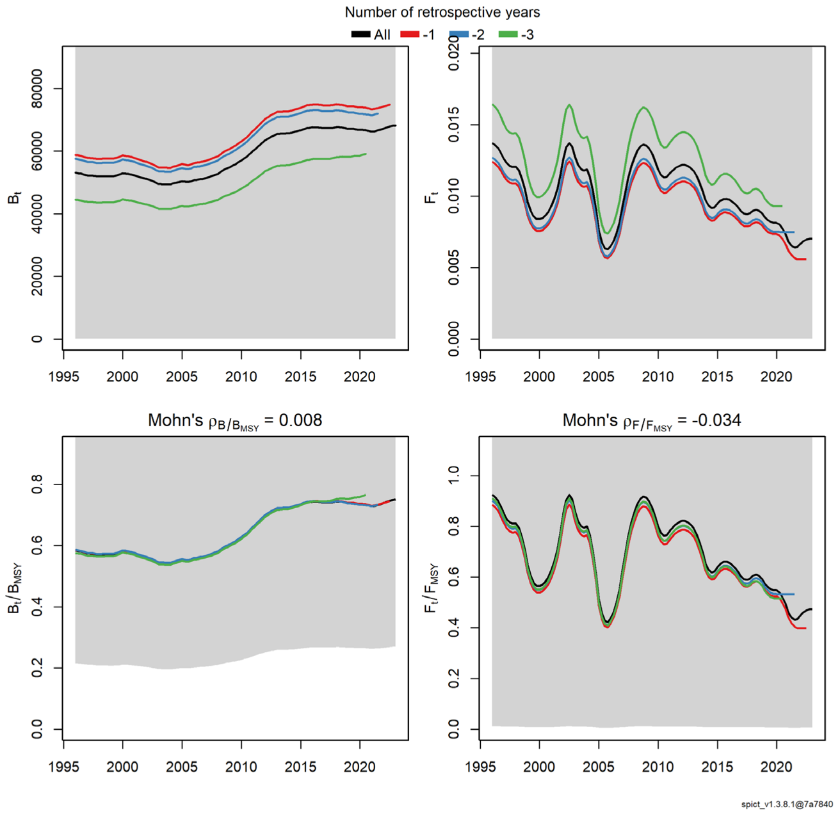
Annex 57. Estimated priors and posteriors for the updated assessment for blue and red shrimp in GSA6 for scenario 1.



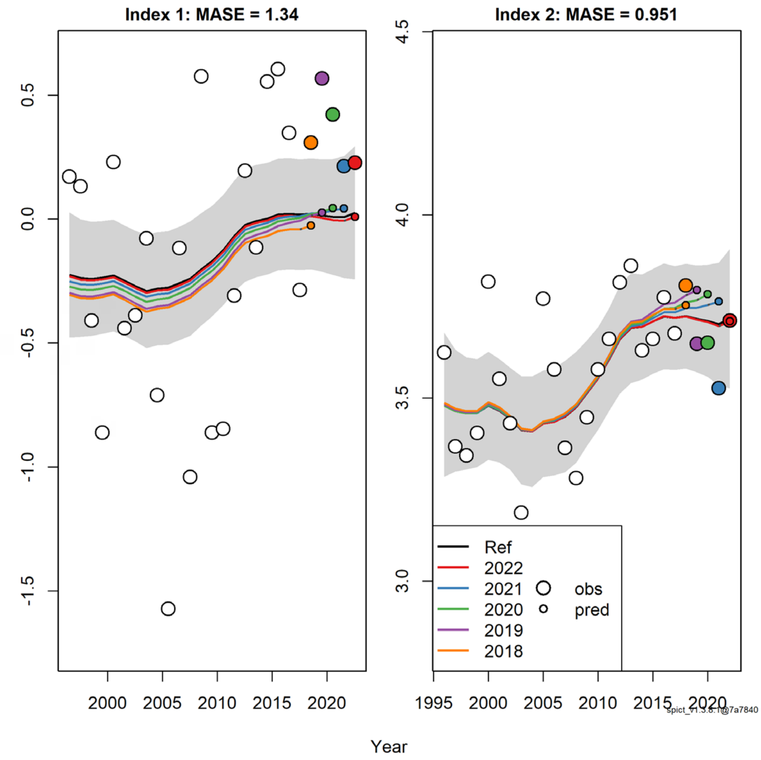
Annex 58. One-step-ahead residuals for the model for blue and red shrimp in GSA6 for scenario 1.



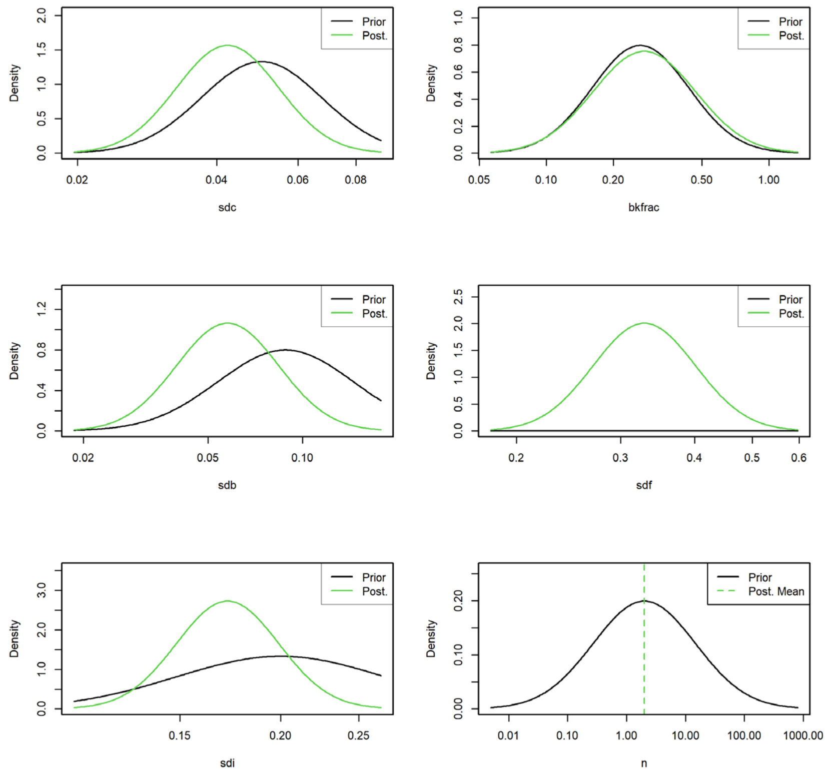
Annex 59. Process error deviations for the model for blue and red shrimp in GSA6 for scenario 1.



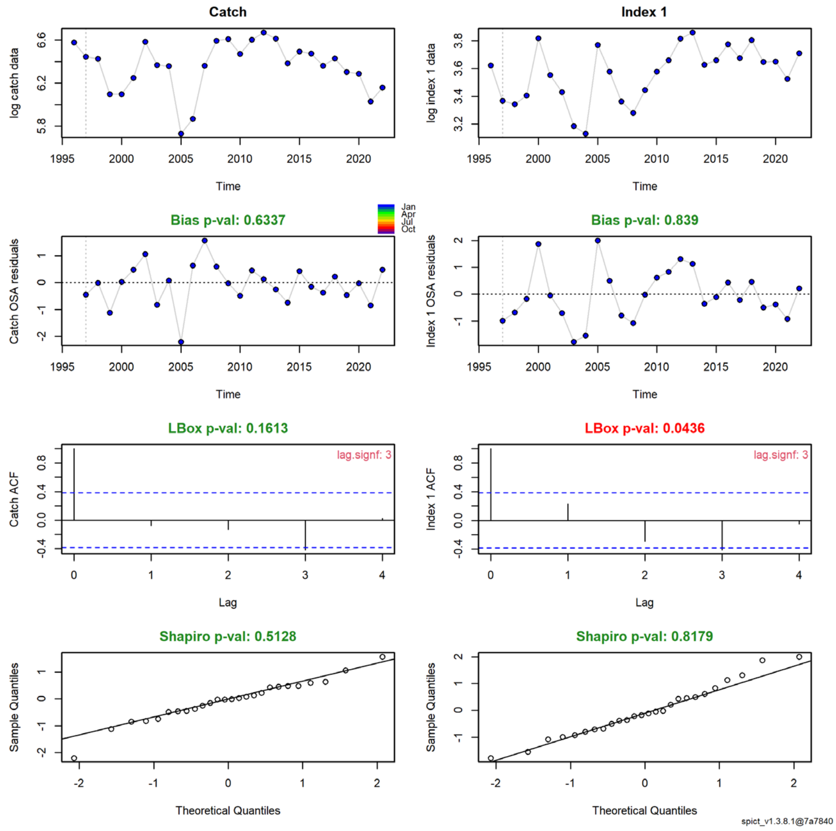
Annex 60. Retrospective analysis for blue and red shrimp in GSA6 for scenario 1.



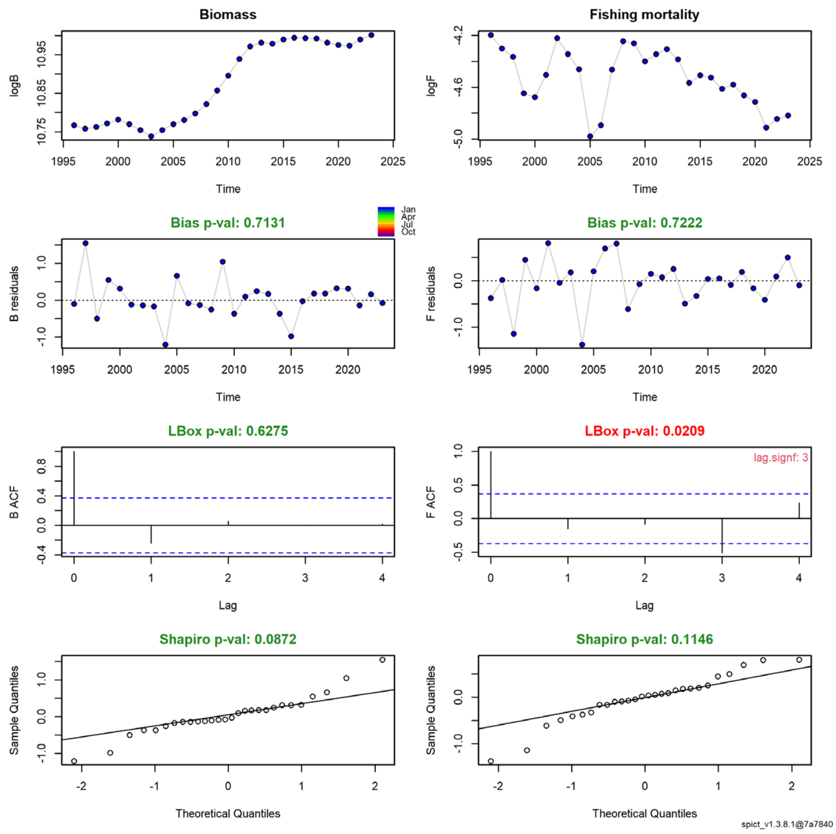
Annex 61. Hindcasting for the model for blue and red shrimp in GSA6 for scenario 1.



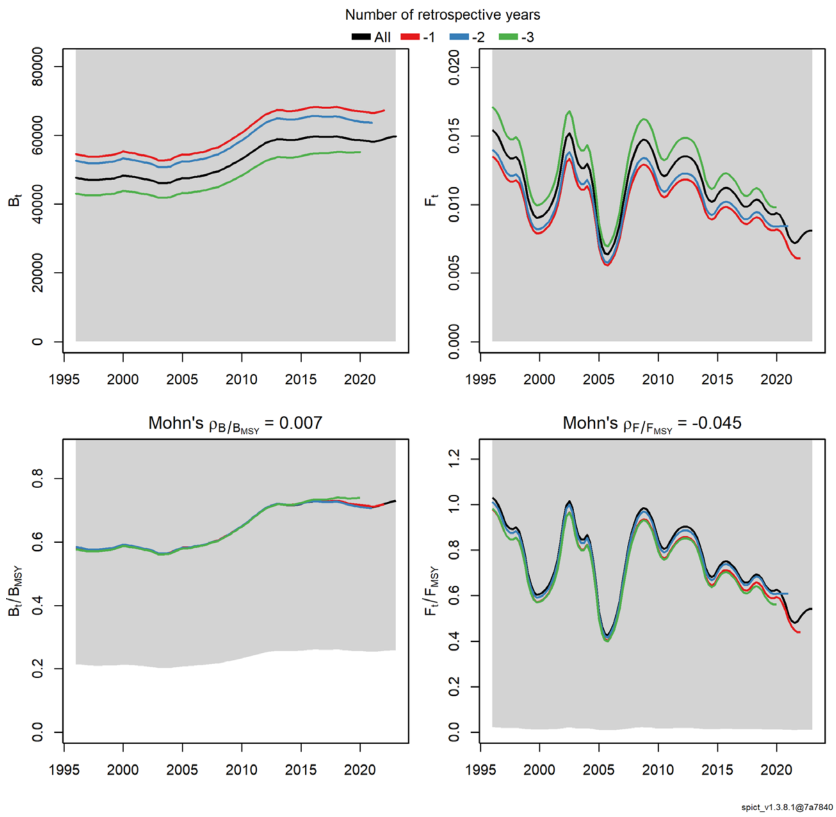
Annex 62. Estimated priors and posteriors for the updated assessment for blue and red shrimp in GSA6 for scenario 3.



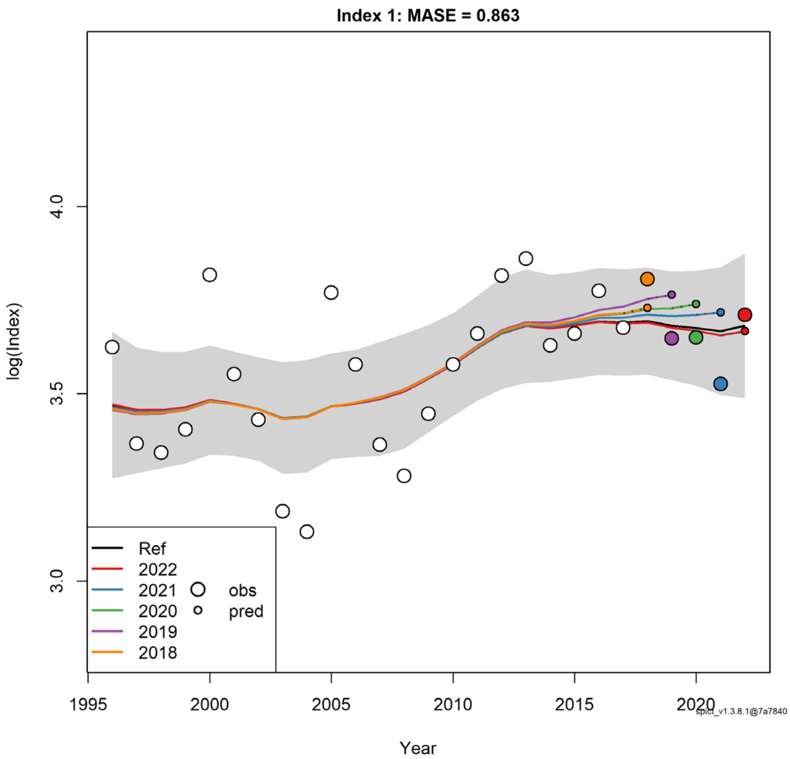
Annex 63. One-step-ahead residuals for the model for blue and red shrimp in GSA6 for scenario 3.



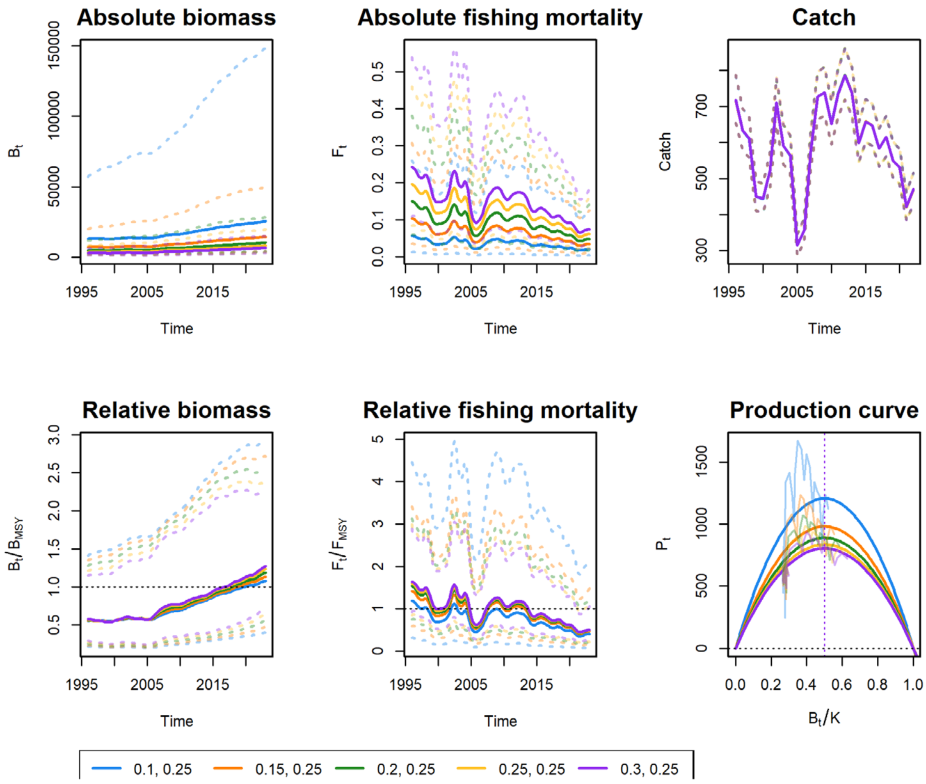
Annex 64. Process error deviations for the model for blue and red shrimp in GSA6 for scenario 3.



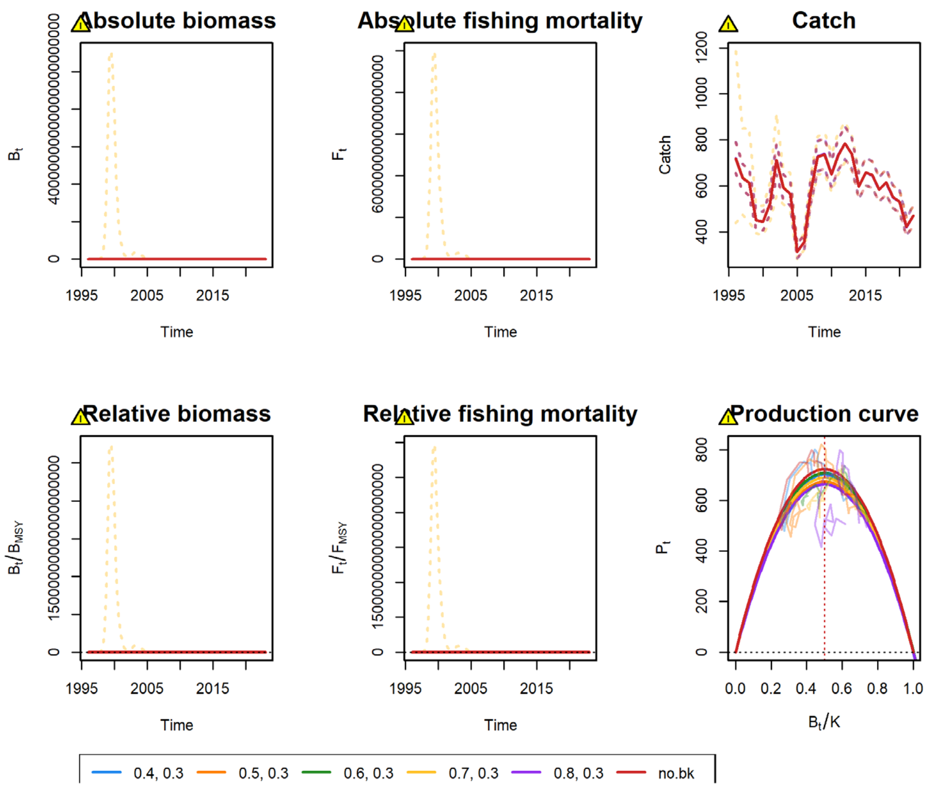
Annex 65. Retrospective analysis for blue and red shrimp in GSA6 for scenario 3.



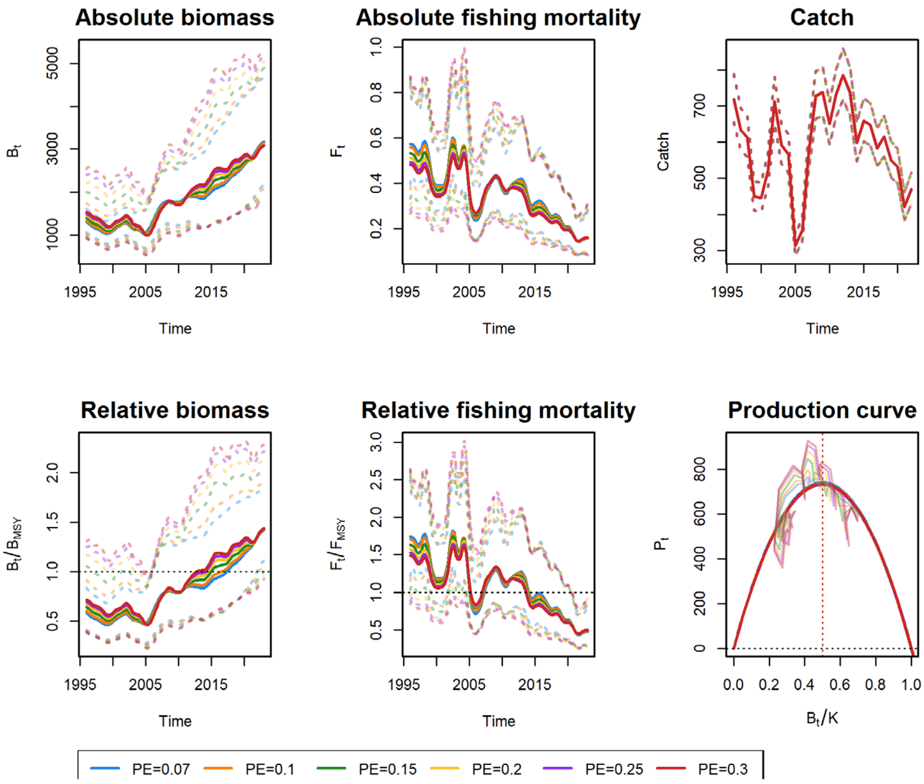
Annex 66. Hindcasting for the model for blue and red shrimp in GSA6 for scenario 3.



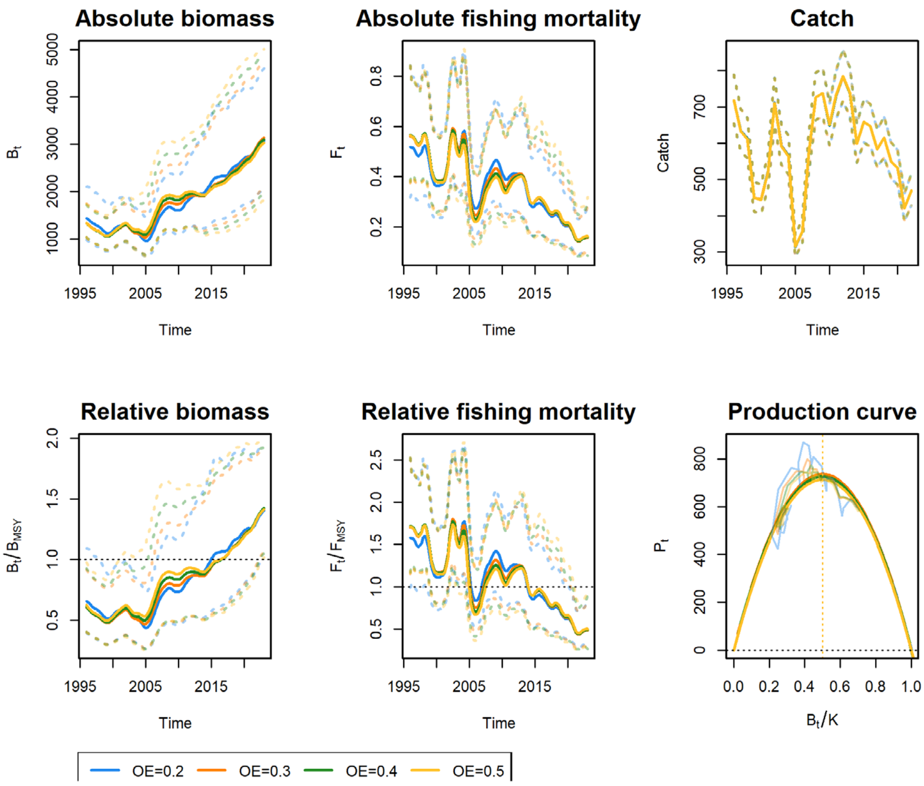
Annex 67. Scenario 2 r prior sensitivity for blue and red shrimp in GSA6.



Annex 68. Scenario 2 BKfrac sensitivity for blue and red shrimp in GSA6.

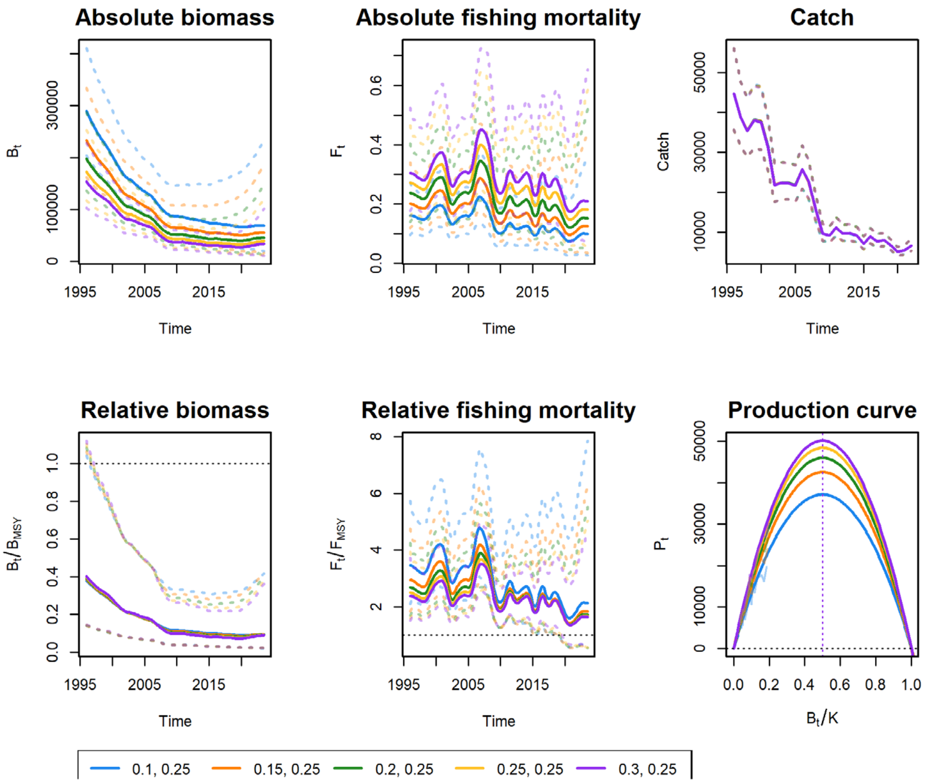


Annex 69. Scenario 2 Process error prior sensitivity for blue and red shrimp in GSA6.

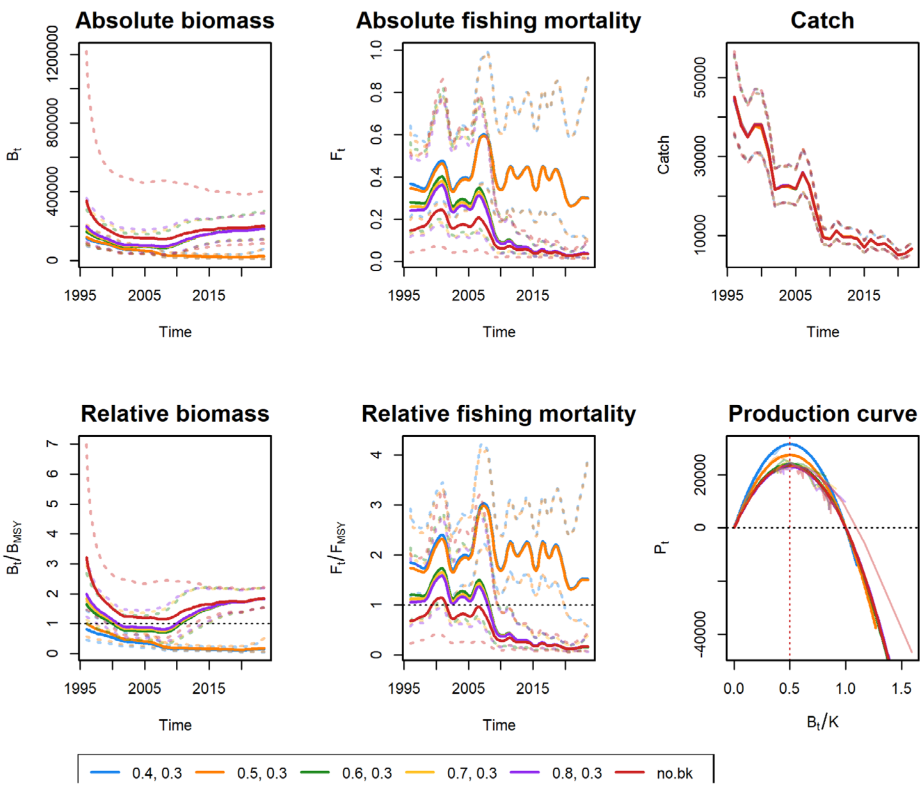


Annex 70. Scenario 2 Observation error sensitivity for blue and red shrimp in GSA6.

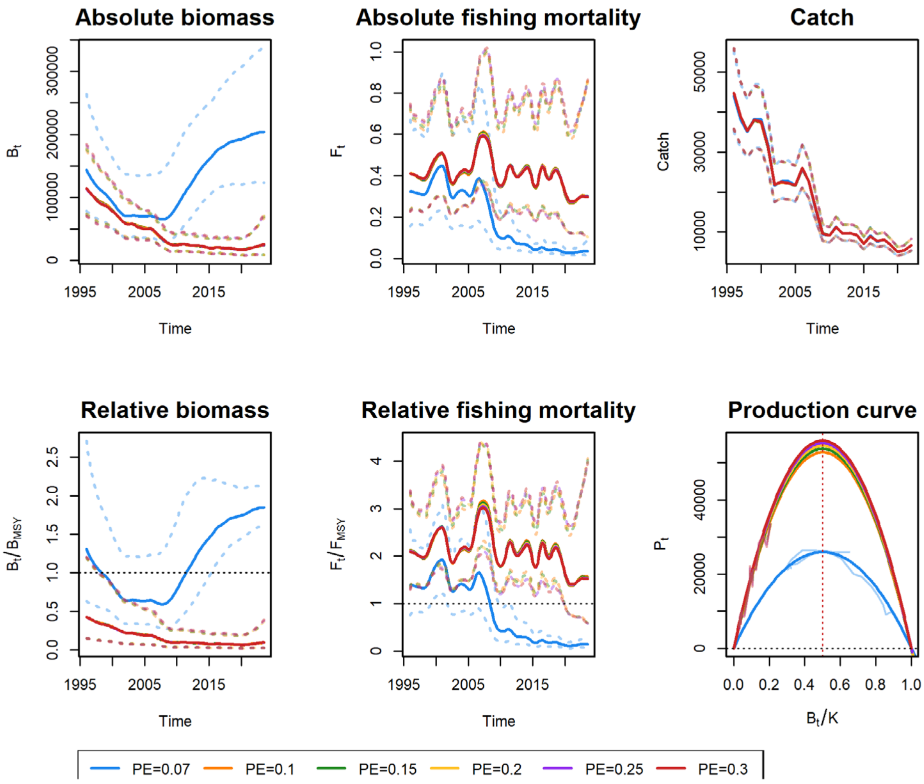
European sardine (*Sardina pilchardus*) PIL



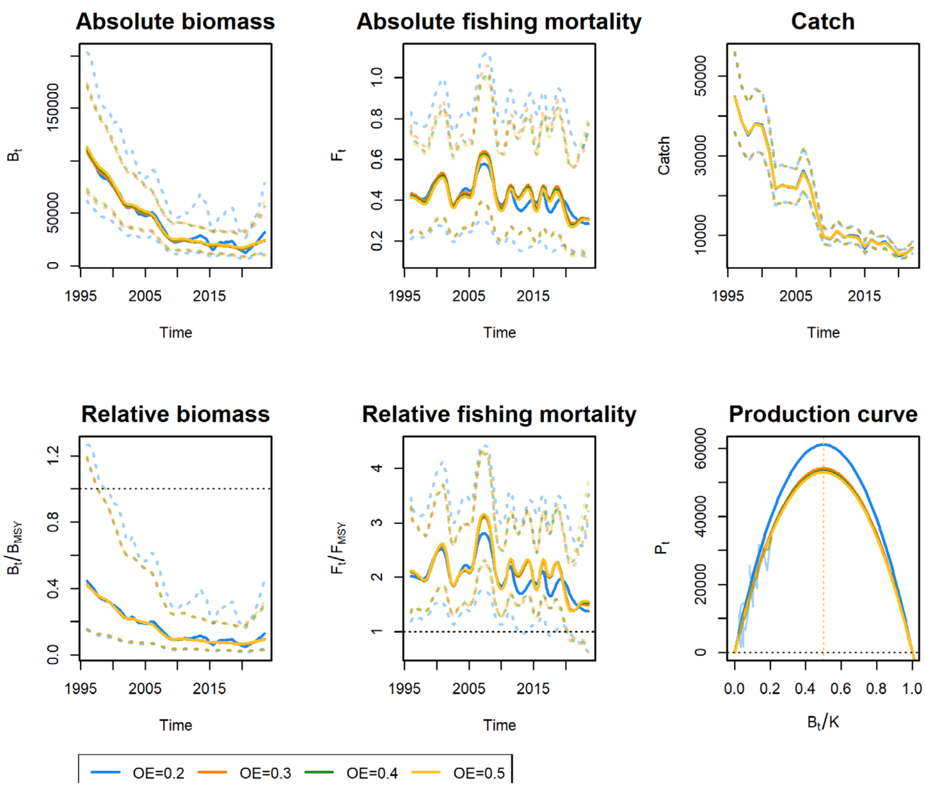
Annex 71. Model r prior sensitivity for European sardine in GSA6.



Annex 72. Model BKfrac sensitivity for European sardine in GSA6.

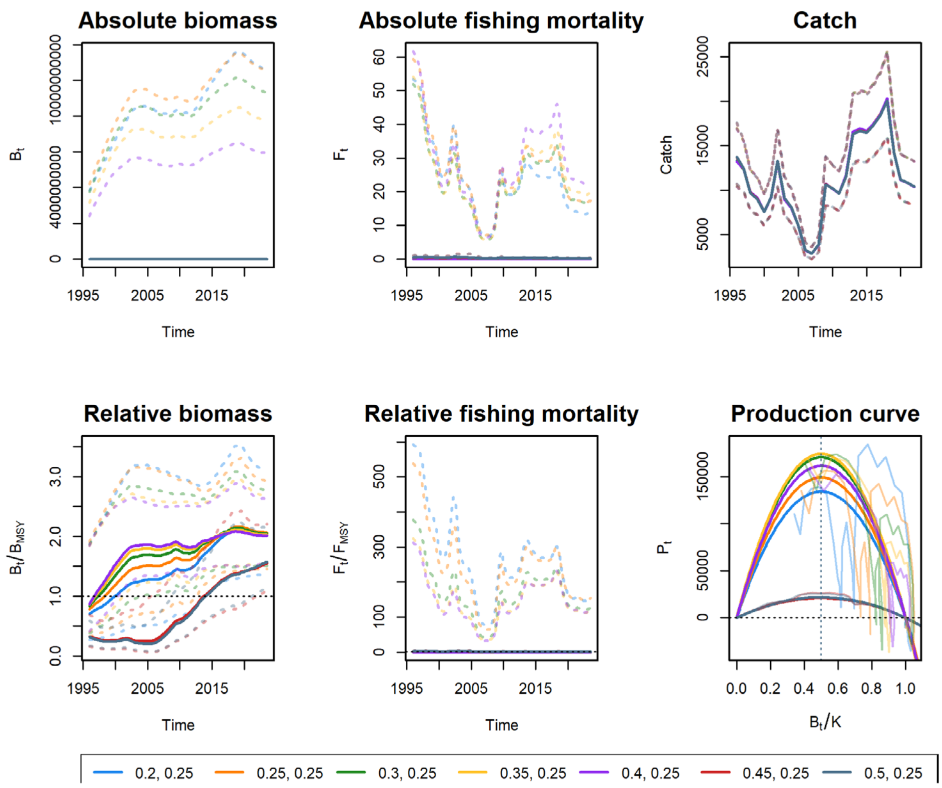


Annex 73. Model Process error prior sensitivity for European sardine in GSA6.

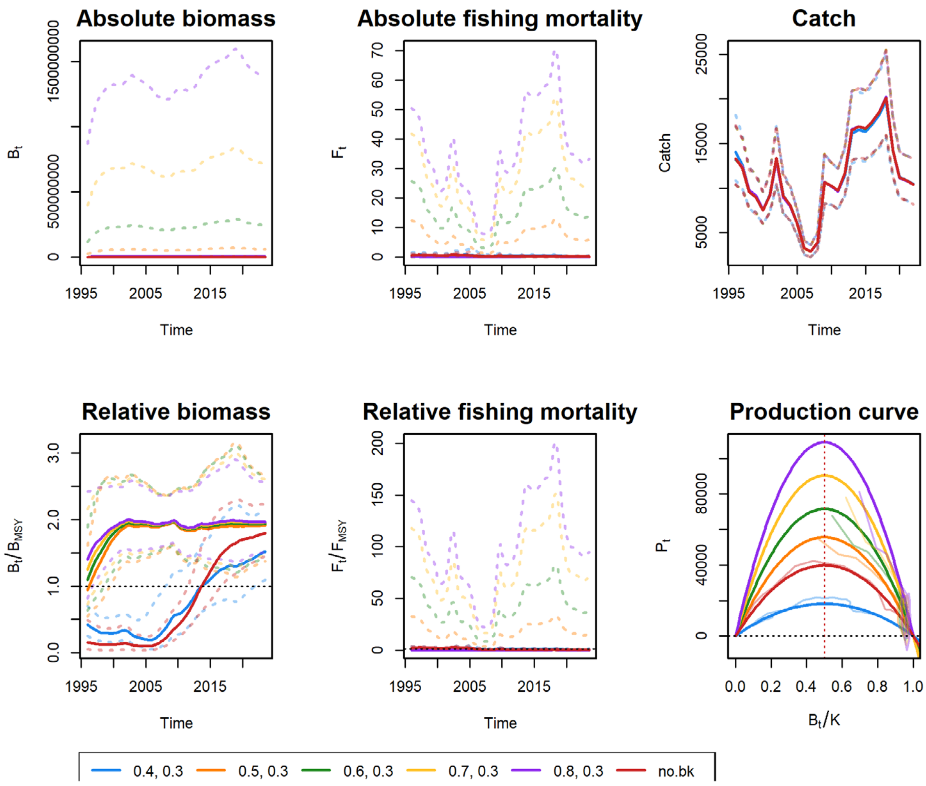


Annex 74. Model Observation error sensitivity for European sardine in GSA6.

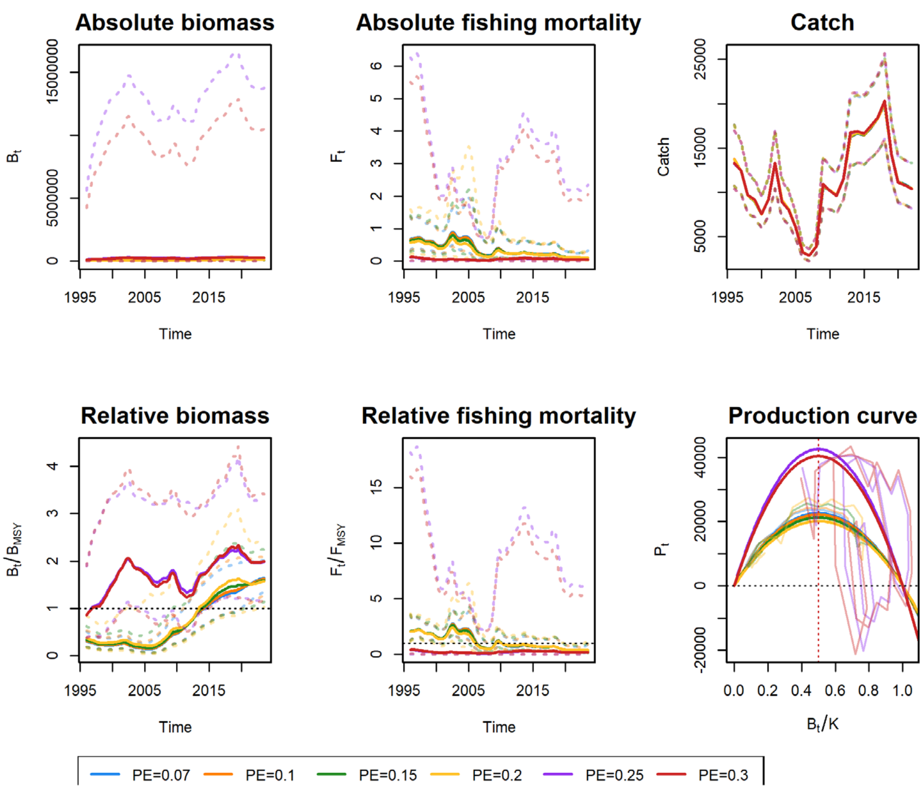
Anchovy (*Engraulis encrasicolus*) ANE



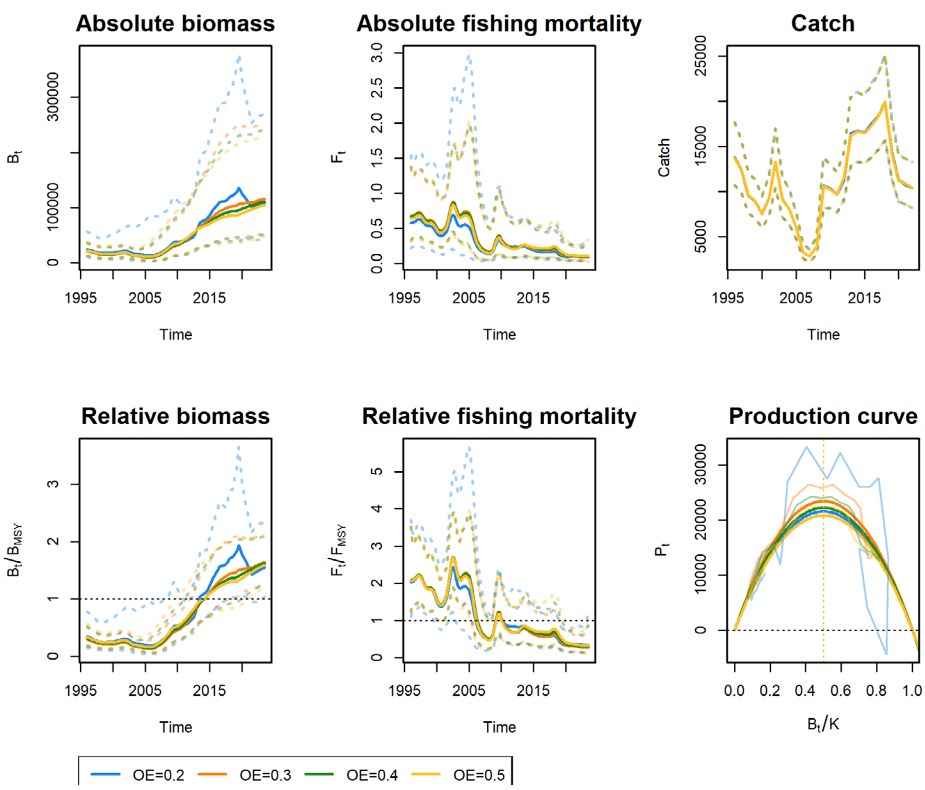
Annex 75. Model r prior sensitivity for anchovy in GSA6.



Annex 76. Model BKfrac sensitivity for anchovy in GSA6.



Annex 77. Model Process error prior sensitivity for anchovy in GSA6.



Annex 78. Model Observation error sensitivity for anchovy in GSA6.

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