Institut Català de Recerca per a la Governança del Mar

State of fisheries in Catalonia 2022, Part 2:

Stock assessment

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Co-funded by the European Union

Generalitat de Catalunya
Departament d'Acció Climàtica, Alimentació i Agenda Rural

CSIC Consejo Superior de Investigaciones Científicas

Institut de Ciències del Mar

This report presents the state of fisheries in Catalonia in 2022 and is the second volume to State of fisheries in Catalonia 2022, Part II: stock assessment.

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How to cite this document
Institut Català de Recerca per a la Governança del Mar (ICATMAR). State of fisheries in Catalonia 2022, Part 2: stock assessment (ICATMAR, 23-08) 96 pp, Barcelona. DOI: 10.57645/10.8080.05.8

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Glossary

a: scaling coefficient for the weight at length of the fish species from length-weight relationship W = aLb

b: a shape parameter for the body form of the fish species from length-weight relationship W = aLb

B_{lim}: Biomass límit

B_{th}: Biomass threshold

B_{tgt}: Biomass target

DCF: Data Collection Framework

F: Fishing mortality

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

F/M: relative fishing mortality.

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)

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

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

M: Natural mortality

SL50: 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.

SPR_{th}: threshold spawning potential ratio.

SPR_{pa}: precautory aproach spawning potential ratio.

SPR_{tgt}: target spawning potential ratio.

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 using its own data set and a data-resource limited (length-based) model (i.e. LBSPR) in the N GSA06. The results estimate that the Spawning Potential Ratio (SPR) for hake (HKE), red mullet (MUT) and blue and red shrimp (ARA) is under SPR_{lim}. On the contrary, for deep-water rose shrimp (DPS), Norway lobster (NEP), European sardine (PIL) and anchovy (ANE), the estimated SPR is above SPR_{lim} (Figure 1).

In detail, for each species, the results are:

Hake, red mullet and blue and red shrimp are under SPR_{lim} for the four years evaluated and with the three scenarios tested. For the blue and red shrimp there is a negative trend in the SPR estimates.

The deep-water rose shrimp stock is between SPR_{pa} and SPR_{lim} for all years and the four scenarios, with no clear trend.

Norway lobster and European sardine are between SPR_{pa} and SPR_{lim}, or above SPR_{pa} in some years, depending on the scenario. The Norway lobster has a negative trend, as opposed to the European sardine, which has a positive trend.

Anchovy is above SPR_{pa} and, in 2022, it is near the SPR_{tgt} for all scenarios tested.

The advice drawn from these models should be considered as qualitative, and the stocks are considered overexploited in all cases.

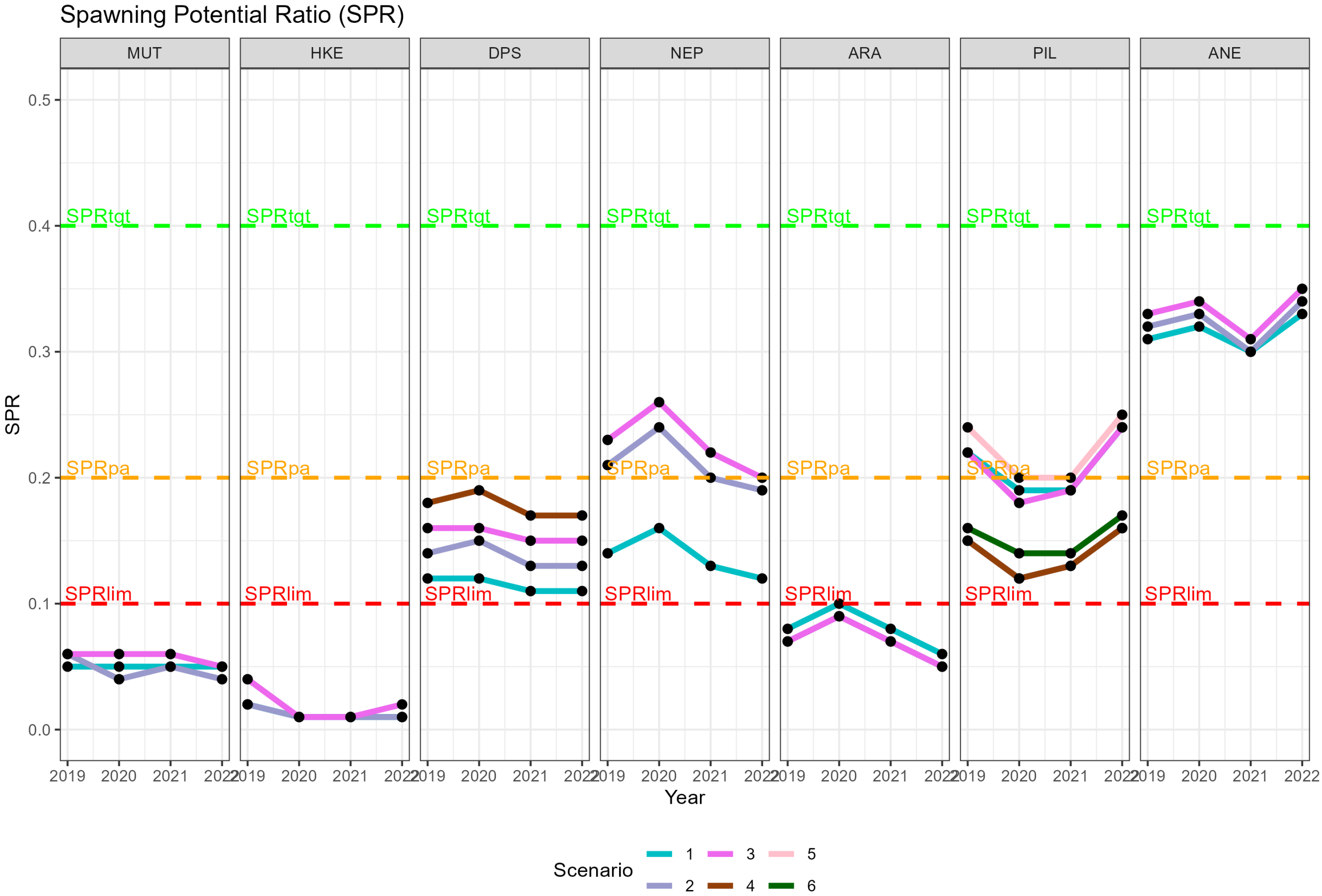

Figure 1. Spawning potential ratio (SPR) per year (2019, 2020, 2021 and 2022) and scenario (1 to 6) for the seven stocks evaluated with LBSPR model. MUT: red mullet, HKE: hake, DPS: deep-water rose shrimp, NEP: Norway lobster, ARA: blue and red shrimp, PIL: European sardine, ANE: anchovy. LBSPR: Length-Based Spawing Potential Ratio. SPR_{lim}: limit spawning potential ratio, SPR_{th}: threshold spawning potential ratio, SPR_{tgt}: target spawning potential ratio. Each scenario is explained in the corresponding section for each species.

Summary table by stock

A summary Table 1 is provided to understand, in a glance, the results obtained from the stock assessment models. The species analyzed are red mullet (MUT), hake (HKE), deep-water rose shrimp (DPS), Norway lobster (NEP), blue and red shrimp (ARA), European sardine (PIL) and anchovy (ANE).

Table 1. Stock assessment results for Catalonia in 2022. The species analyzed are 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. $SPR_{0.4}$: SPR at 40%. $SPR_{0.1}$: SPR at 10%. F: Fishing mortality.

Area	Species	Method	Ref. Year	$SPR/SPR_{0.4}$	$SPR/SPR_{0.1}$	F/F_{target}
CAT	HKE	Data-Resource-limited (LBSPR)	2022	Below	Below	Above
CAT	MUT	Data-Resource-limited (LBSPR)	2022	Below	Below	Above
CAT	DPS	Data-Resource-limited (LBSPR)	2022	Below	Above	Above
CAT	NEP	Data-Resource-limited (LBSPR)	2022	Below	Above	Above
CAT	ARA	Data-Resource-limited (LBSPR)	2022	Below	Below	Above
CAT	PIL	Data-Resource-limited (LBSPR)	2022	Below	Above	Above
CAT	ANE	Data-Resource-limited (LBSPR)	2022	Below	Above	Above

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 GSA06 (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 of 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 1000 m depth or 3 miles far from shore when the seabed is shallow and five days per week with a maximum of 12 labor 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 a very recent 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.

The establishment of scientific-based management strategies is only possible when scientific data is provided to understand the state of the fisheries. For that, the EU Member States have been collecting fisheries data to support CFP since 2000. These data are collected through fisheries-dependent (fishing on board) and –independent methods (annual surveys), with variable periodicity throughout the year. The fisheries-dependent data 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 get a more exhaustive data set to better manage marine resources, the monitoring program established by the DCF is completed 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 GSA06 (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 55.37 M€ in 2022 (ICATMAR,23-03). 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 caught most biomass, with a total value of 11.485 t in 2022 (ICATMAR,23-03) and catches sardine and anchovy, species of special interest to manage for the CFP.

To provide scientific advice for management purposes in the northern GSA 6, the data gathered by ICATMAR during 2019, 2020, 2021 and 2022 has been used for stock assessment evaluations. This report will analyze the different species from the WMMAP and, for the first time, small pelagic species, using data-resource limited (length-based) model (i.e. LBSPR). For hake, and taking advantage of the availability of the long-term data series for the commercial landings and the biomass index obtained from MEDITS, a surplus production model (i.e. SPICT) was also applied obtaining results from two different data sets. ICATMAR will continue the intense monitoring program in the area, the long-term data collection will allow, in next years, the use of the models commonly used by the Scientific, Technical and Economic Committee for Fisheries (STECF).

SECTION 2
Material and Methods

Machine learning for *métiers* assignation

As explained in the 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*.

As in the previous report, 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 2022 data, 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 and 2022 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.

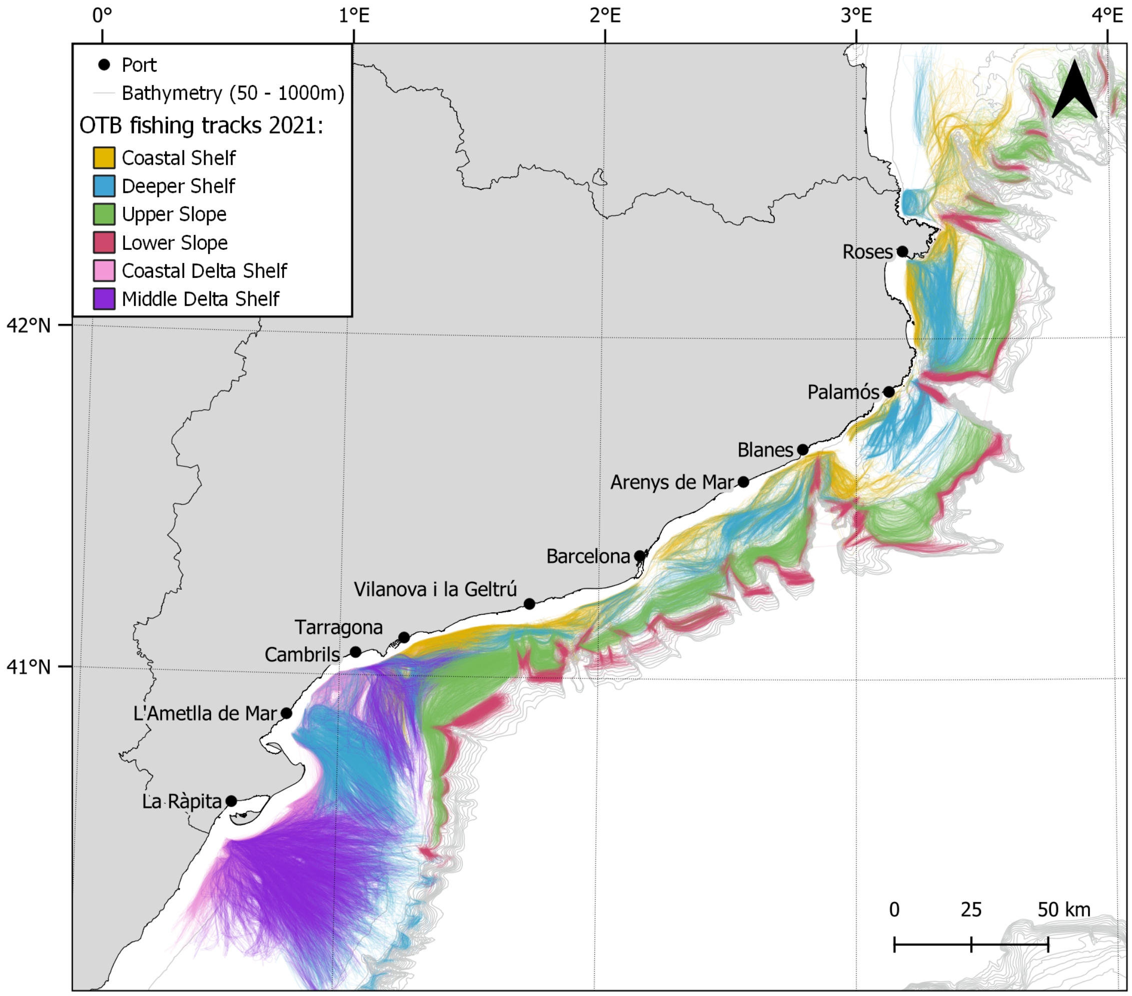

Figure 2. Spatial distribution of the bottom trawl fishery (OTB) tracks. Colors represent the different OTB *métiers* identified for the Catalan fishery in 2021.

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 from 2022. 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 2 and Figure 3). Finally, the predicted *métiers* for 2022 are imported to the database for the extrapolation of the data.

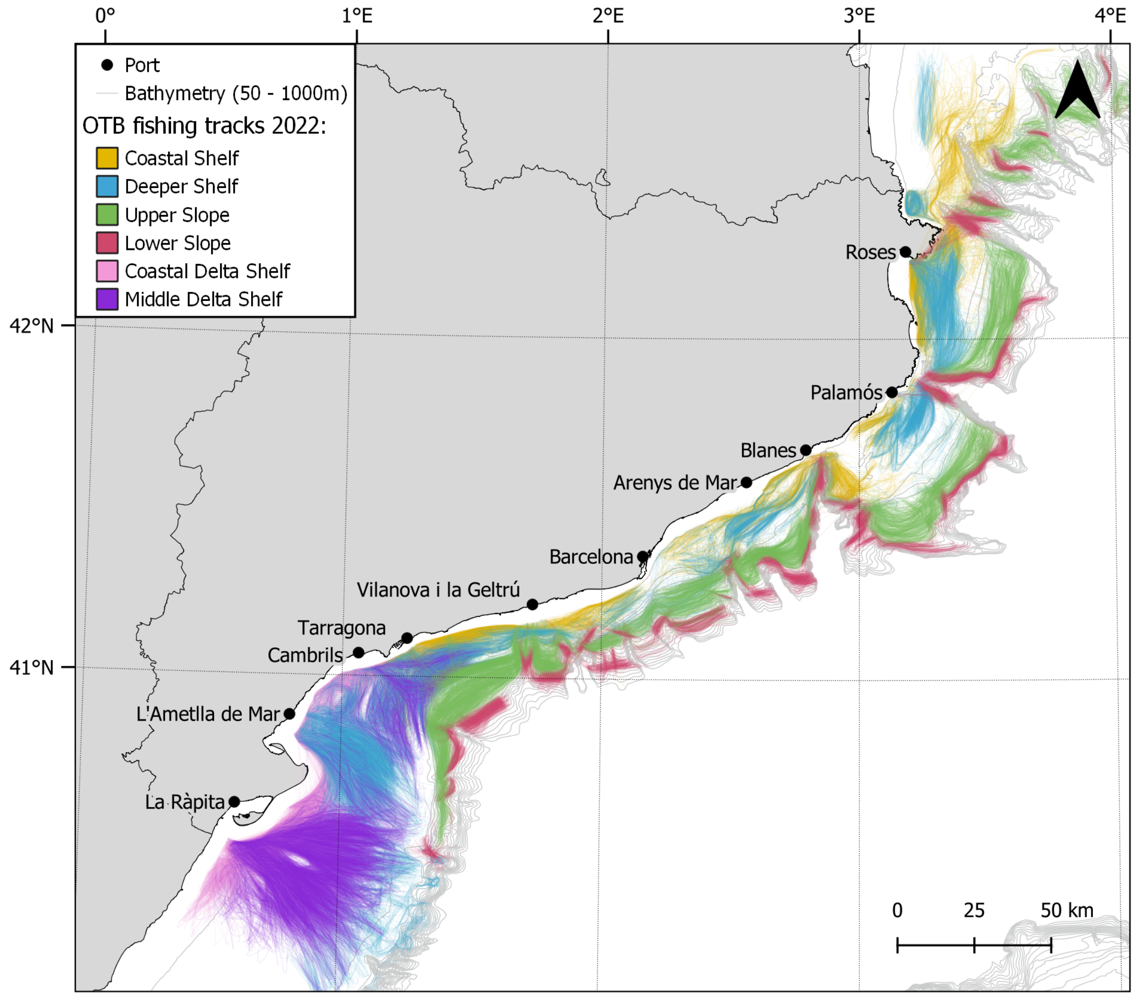

Figure 3. Spatial distribution of the bottom trawl fishery (OTB) tracks. Colors represent the different OTB *métiers* identified for the Catalan fishery in 2022.

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.

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}

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.

Stochastic Production model in Continuous Time (SPiCT)

In this report, we have explored the surplus production model in continuous time (SPiCT) for the hake assessment. The preliminary results can be found in the Annex section. These results are considered work in progress, which is why no advice can be given based on them. Subsequent work will explore working with longer index time series as well as the potential use of other indices.

SECTION 3
Results by stock

Stock assessment results for species in the northern GSA6

Hake (*Merluccius marluccius*) HKE

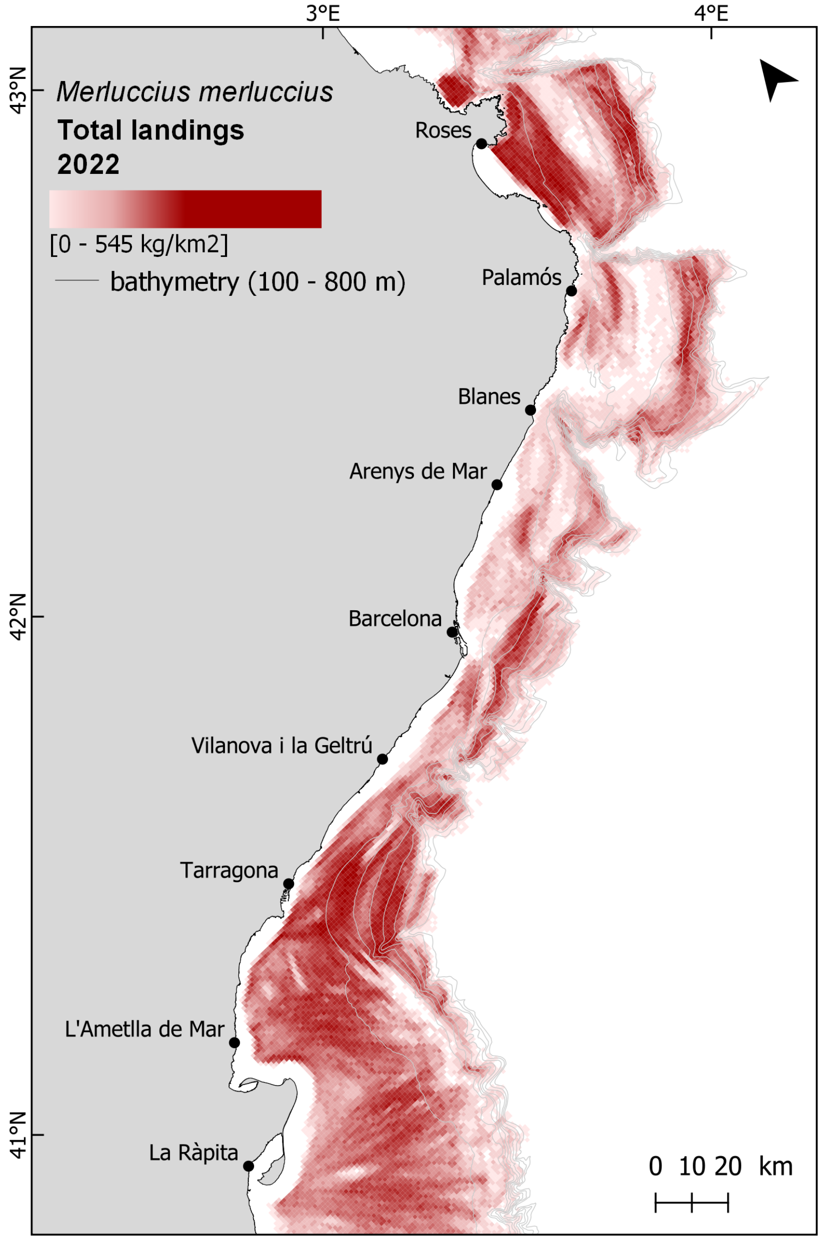

Figure 4. Spatial distribution of total landings for hake in the Catalan fishing grounds (N GSA6) in 2022.

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

Historical hake landings in Catalonia, from 1988 to 2022, are shown in Figure 5. 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.

Figure 6 shows hake landing distribution by *métier* from 2019 to 2022. Bottom trawlers have the highest landings, specifically for coastal *métiers* and upper slopes. Artisanal fisheries and set longliners have fewer landings.

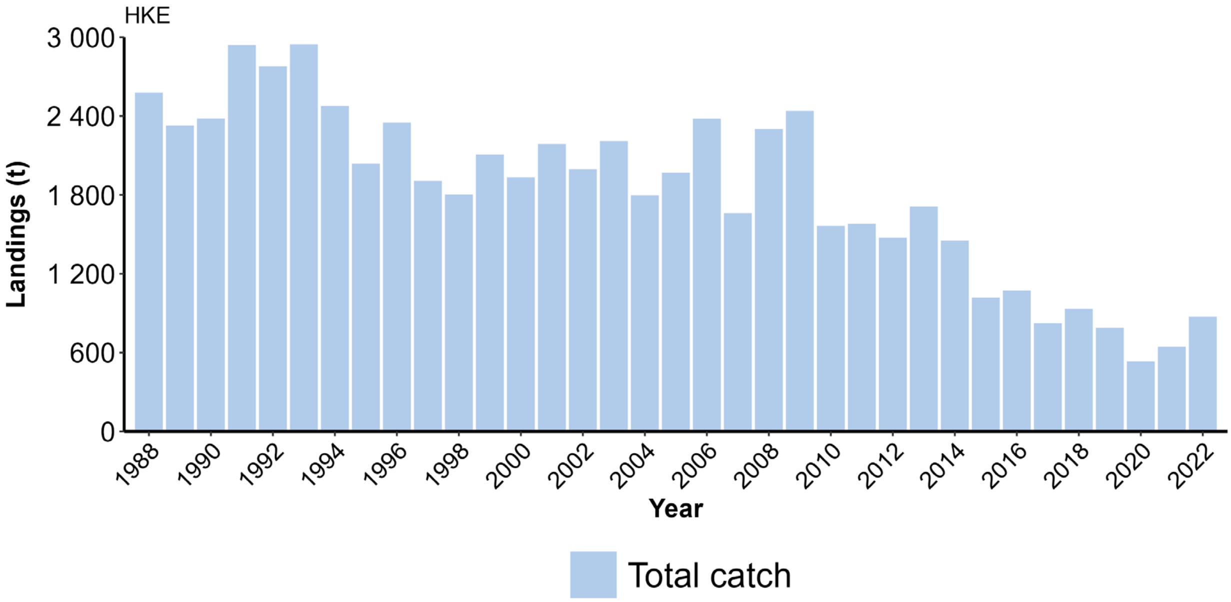

Figure 5. Landings (t) for hake in Catalonia from 1988 to 2022.

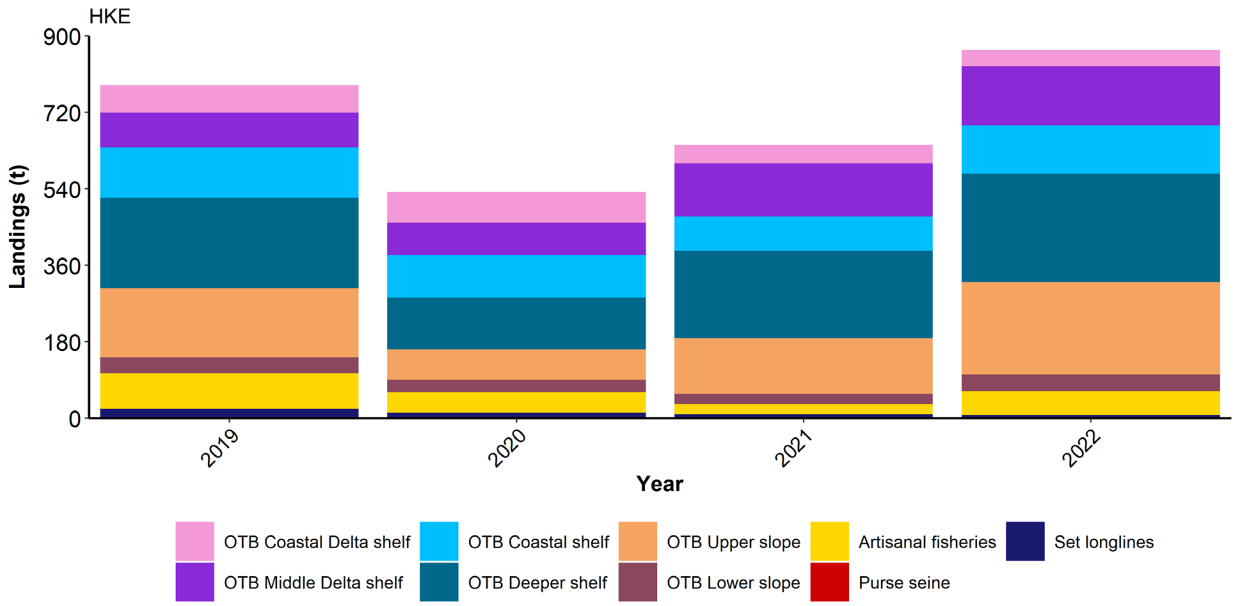

Figure 6. Landings (t) for hake in Catalonia from 2019 to 2022 by *métier* and fishing gear. OTB: bottom trawling.

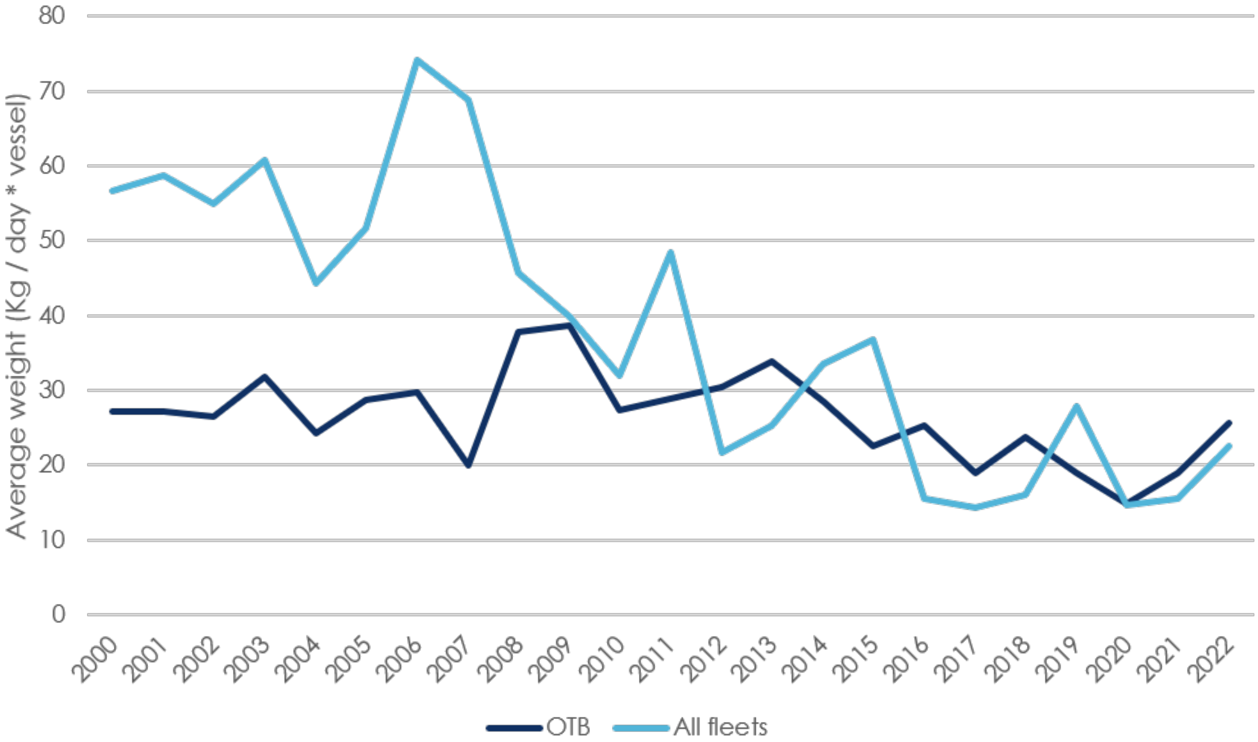

Figure 7. Landings per unit of effort (average weight in Kg/day*vessel) for hake in Catalonia for all fishing fleets (light blue line) including bottom trawling (OTB) and for OTB separately (dark blue line).

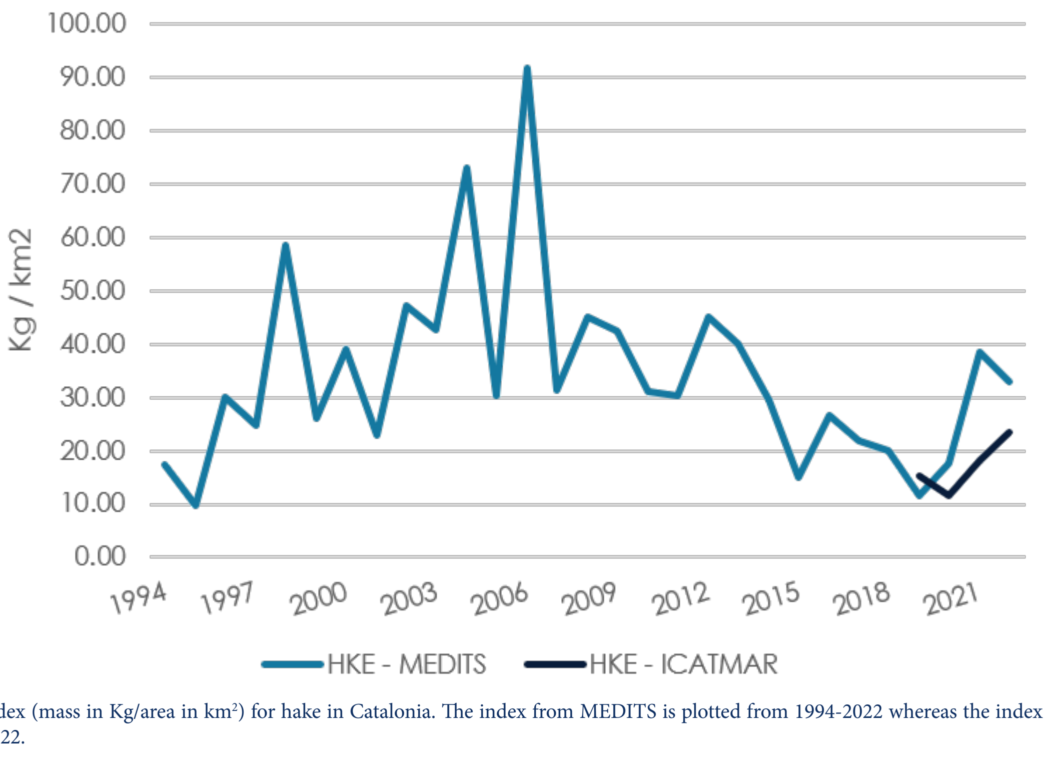

Figure 8. Biomass index (mass in Kg/area in km^2) for hake in Catalonia. The index from MEDITS is plotted from 1994-2022 whereas the index from ICATMAR is plotted from 2019-2022.

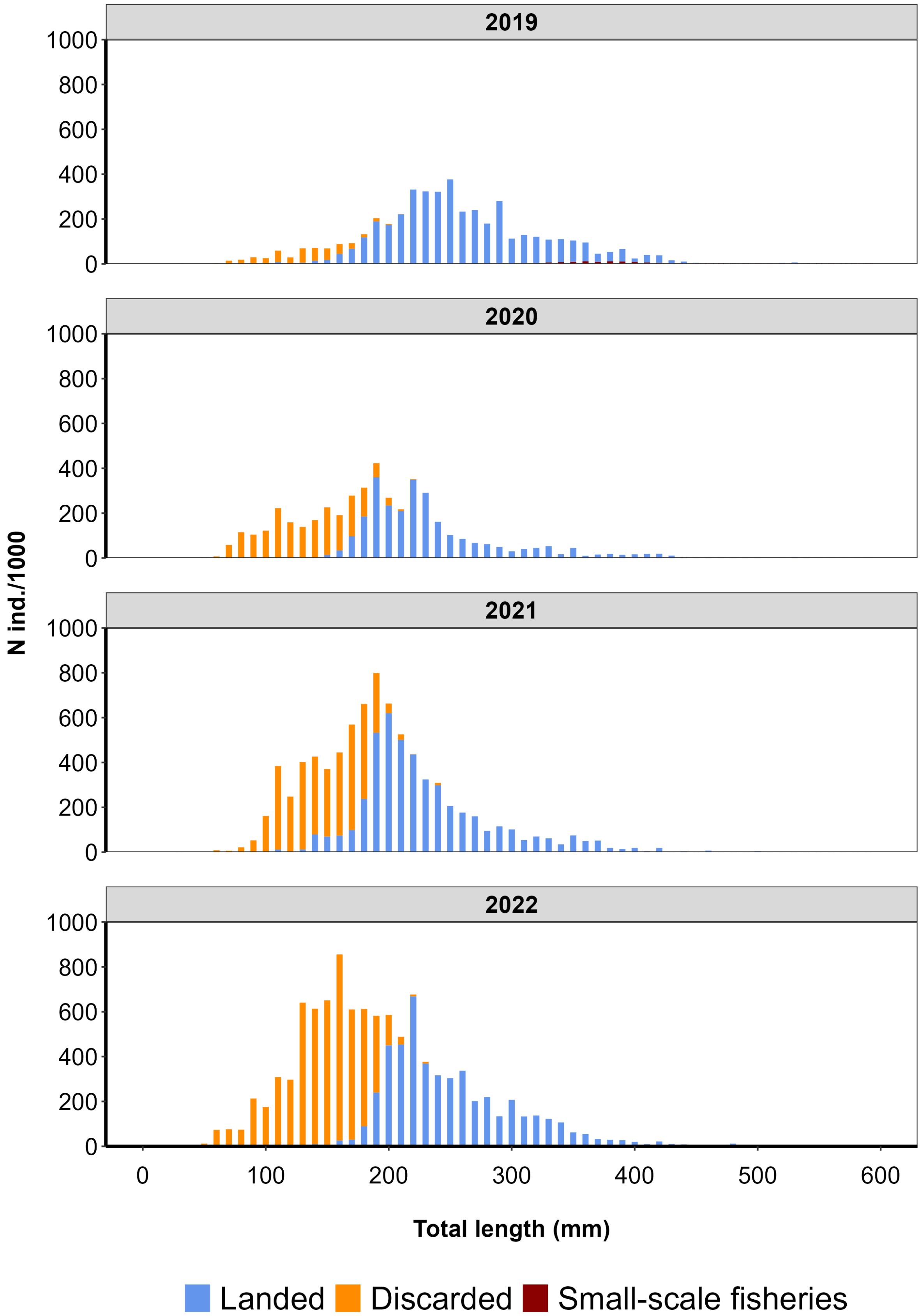

Figure 9. Annual length frequency distributions of hake from bottom trawling and small-scale fisheries (SSF). The data from bottom trawling is raised from ICATMAR data and details landed and discarded hake. The data from SSF is obtained from DCF (Data Collection Framework) dataset.

Table 3. Number of hake individuals sampled with bottom trawlers 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	19	636	216	201	42
Bottom trawl	2019	Center	474	417	211	446	32
Bottom trawl	2019	South	525	181	305	218	31
Bottom trawl	2020	North	104	87	253	227	30
Bottom trawl	2020	Center	208	130	466	310	29
Bottom trawl	2020	South	56	197	370	328	19
Bottom trawl	2021	North	320	390	487	293	43
Bottom trawl	2021	Center	190	528	751	325	27
Bottom trawl	2021	South	141	56	641	441	20
Bottom trawl	2022	North	181	449	755	643	41
Bottom trawl	2022	Center	464	216	507	394	31
Bottom trawl	2022	South	92	165	353	306	18

Even though the landings follow a historical negative trend, the landings per unit of effort (Figure 7) from bottom trawlers do not show this tendency. These remain more constant than the landings per unit of effort for the whole fleet, which has values between the threshold of 20 and 40 kg/day*vessel.

The MEDITS biomass index was available for Catalonia since 1994 and was compared to the ICATMAR biomass index, which is calculated since 2019 (Figure 8). The trend is similar for both indexes despite the short time series of the data from ICATMAR.

Annual LFD

After raising the length frequencies obtained with the monitoring program (Table 3), and considering discards and small-scale fisheries length frequencies, the annual length frequency of hake in Catalonia is plotted in Figure 9. An important increase in small-length classes is observed, with more individuals in the discard fraction than the commercial fraction in 2022. 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.

Model setting and results (LBSPR)

Scenarios

Three different scenarios were applied for the sensitivity analysis for hake. 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 4. 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)	k	M	L_{mat50} (mm)	L_{mat95} (mm)
HKE	1	1100	0.178	0.4	260.0	309.4
HKE	2	1100	0.178	0.4	263.5	313.4
HKE	3	802	0.113	0.2	263.5	313.4

Fitted data

The length frequency distribution fit per year is shown in Figure 10. The model generally follows the mode for all years, but tends to overestimate or underestimate the number of individuals in the middle-length classes.

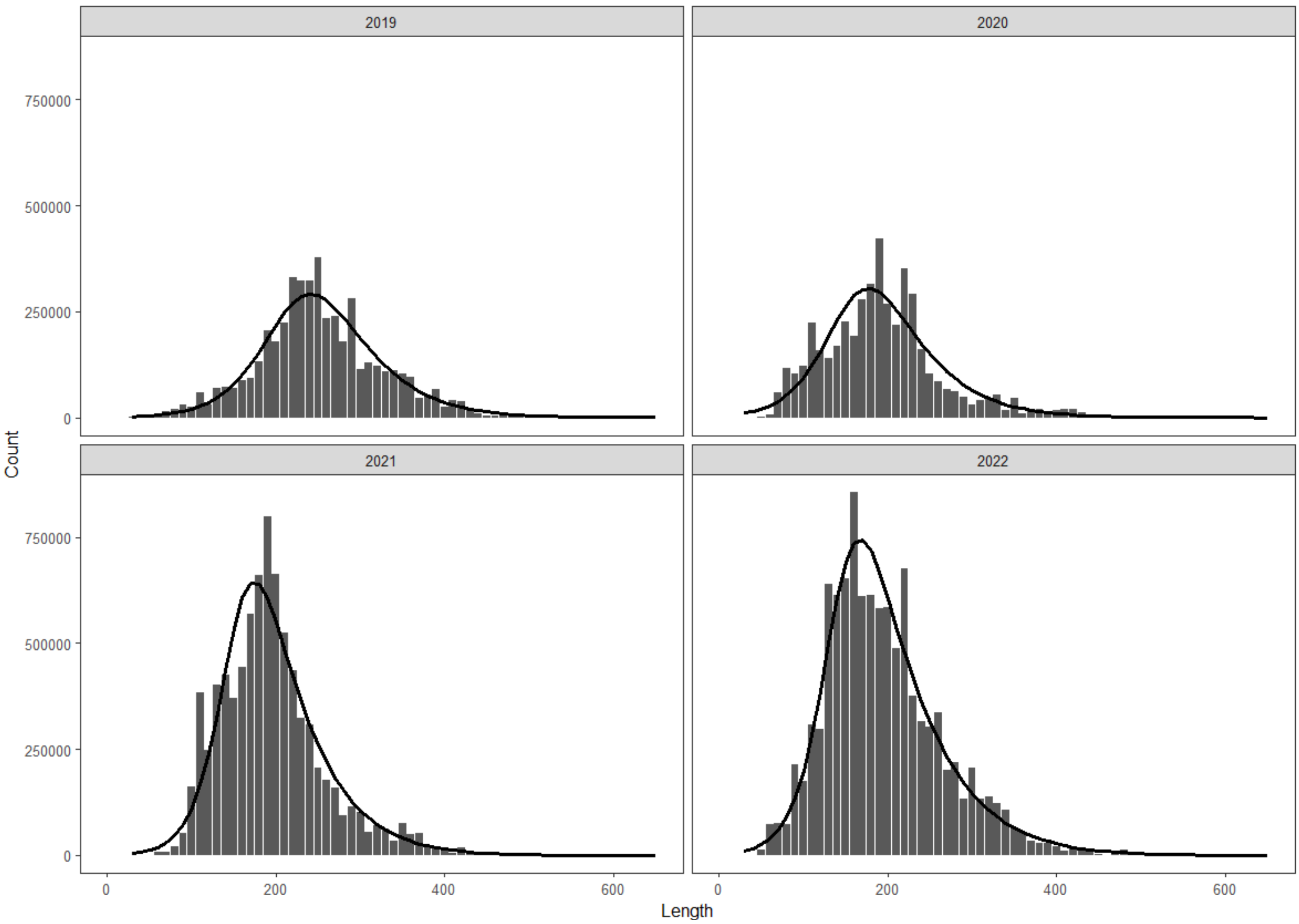

Figure 10. Fit of the data using the LBSPR model for hake for each studied year (2019-2022). Grey columns indicate length frequencies. Black lines indicate the fit of the model.

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 11. For the different scenarios, the model outputs reveal that the fishery is fishing below the SL_{50}.

Table 5. Hake (HKE) length (mm) in different studied scenarios (1-3). L_{mat50}: length at 50% maturity. SL_{50}: length at 50% of selectivity resulting from LBSPR outputs in each studied year (2019-2022).

Species	Scenario	L_{mat50}	SL_{50}			
			2019	2020	2021	2022
HKE	1	260.0	221.02	156.06	152.12	140.96
HKE	2	263.5	221.08	156.10	152.15	140.99
HKE	3	263.5	217.56	152.82	149.88	138.30

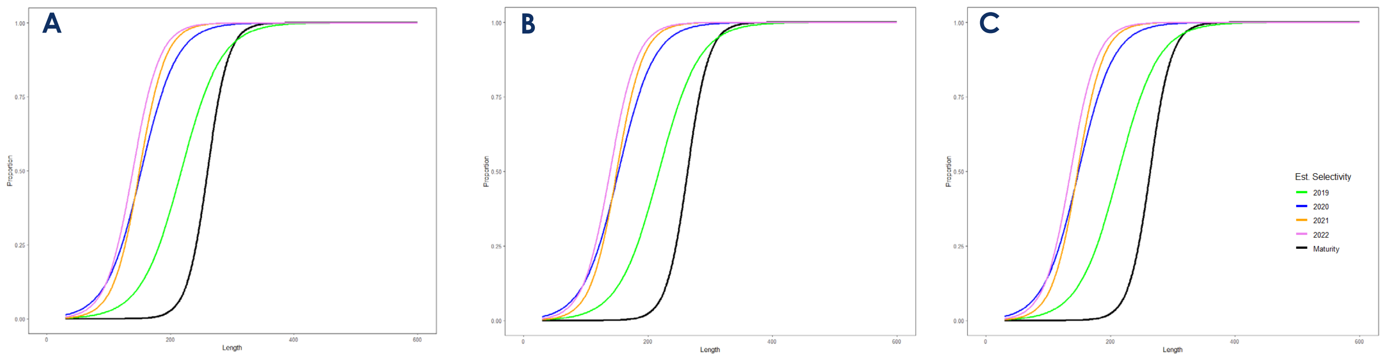

Figure 11. Length curves for hake. Black line shows the length curve at maturity. Color lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (A), scenario 2 (B) and scenario 3 (C).

Table 6. Hake (HKE) estimated values for Spawning Potential Ratio (SPR) and relative fishing mortality (F/M) in each studied year (2019-2022) for each scenario (1-3).

Scenario		SPR				F/M			
Species		2019	2020	2021	2022	2019	2020	2021	2022
HKE	1	0.02	0.01	0.01	0.01	5.80	6.41	6.57	5.39
HKE	2	0.02	0.01	0.01	0.01	5.75	6.35	6.52	5.35
HKE	3	0.04	0.01	0.01	0.02	4.36	5.06	5.26	4.28

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 6). The Kobe plot for hake (Figure 12) 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.

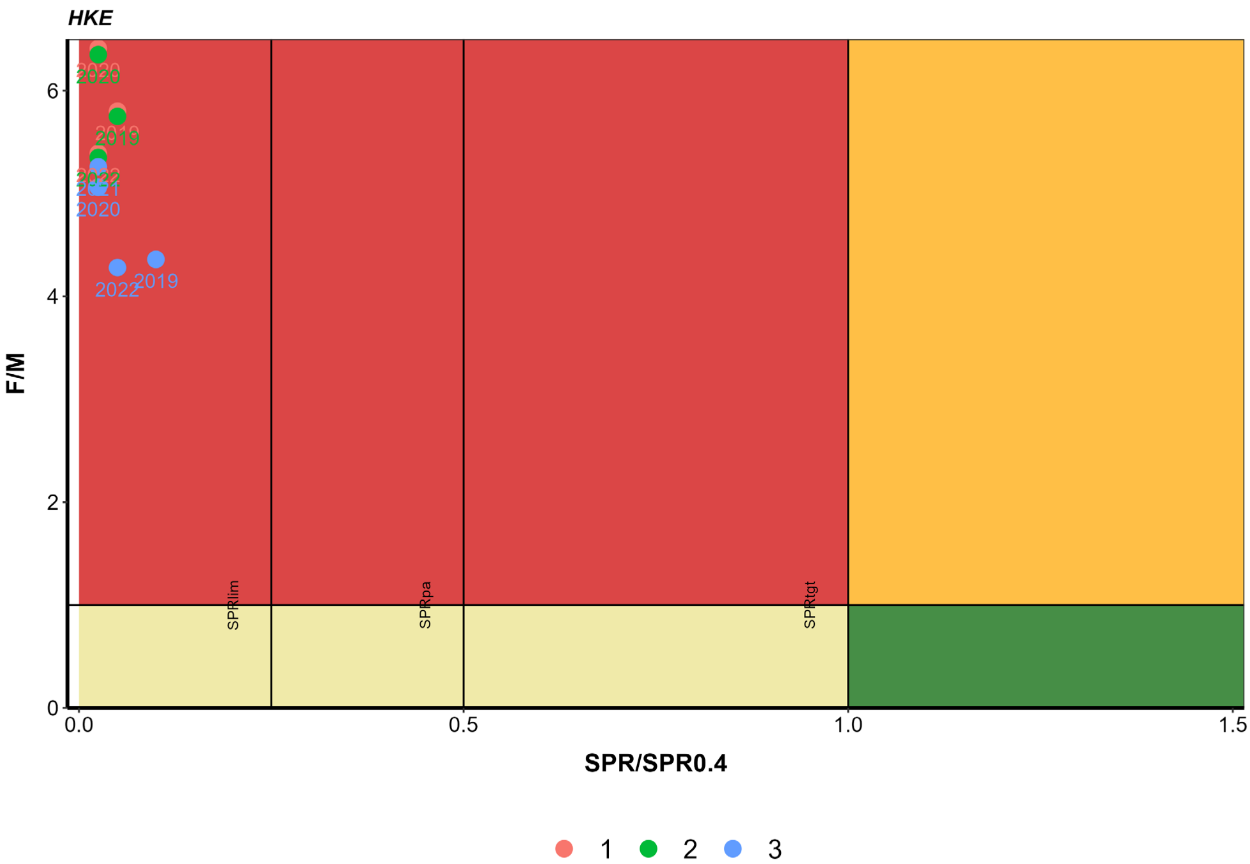

Figure 12. Kobe plot for hake by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{pa}: precautory aproach spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

Red mullet (*Mullus barbatus*) MUT

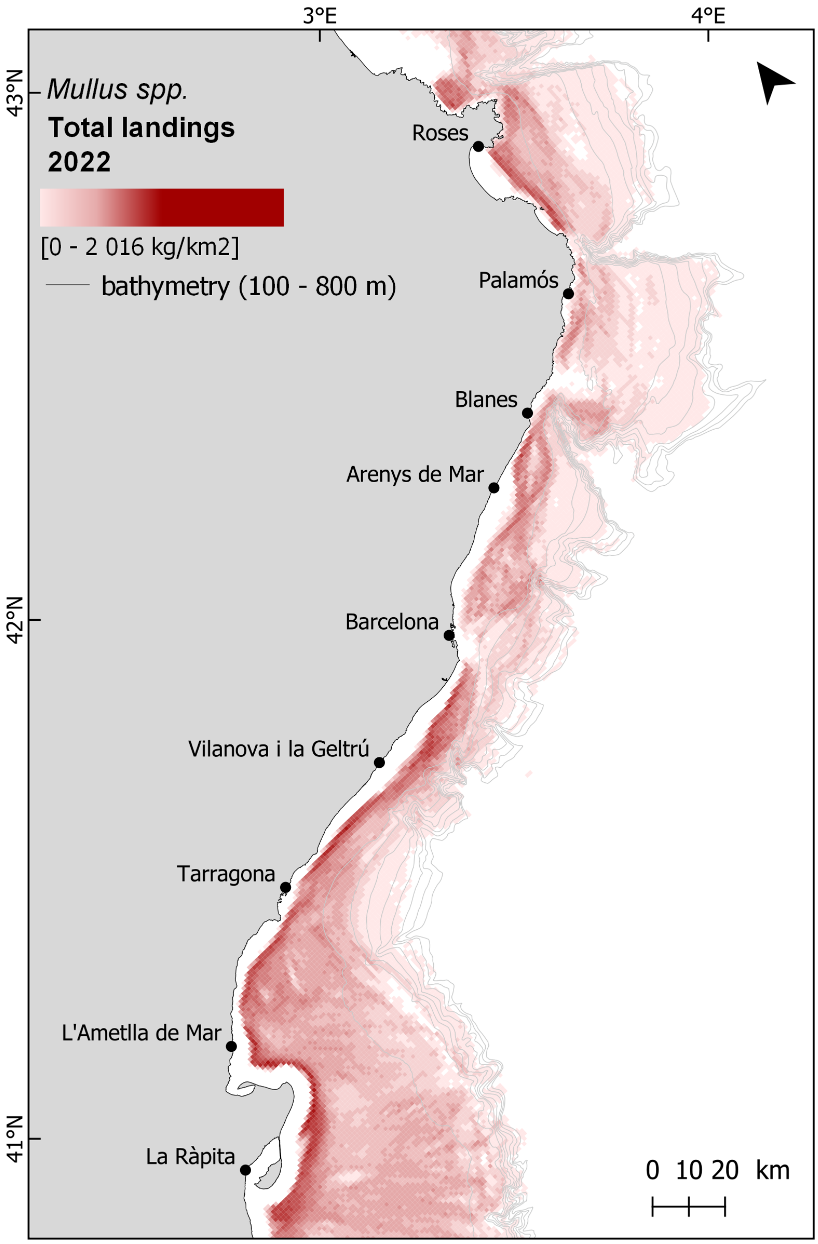

Figure 13. Spatial distribution of landings per unit of effort (LPUE) for red mullet (*Mullus spp.*) in the Catalan fishing grounds (North GSA6) in 2022.

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 13) 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 14. Landings increased throughout the time series until 2016, when the highest value was observed. Thereafter, landings were relatively stable.

Figure 15 shows red mullet landing distribution by *métier* from 2019 to 2022. Bottom trawlers have the highest landings for coastal *métiers* and the lowest in the deeper shelf *métier*. Artisanal fisheries only have residuals landings in all years.

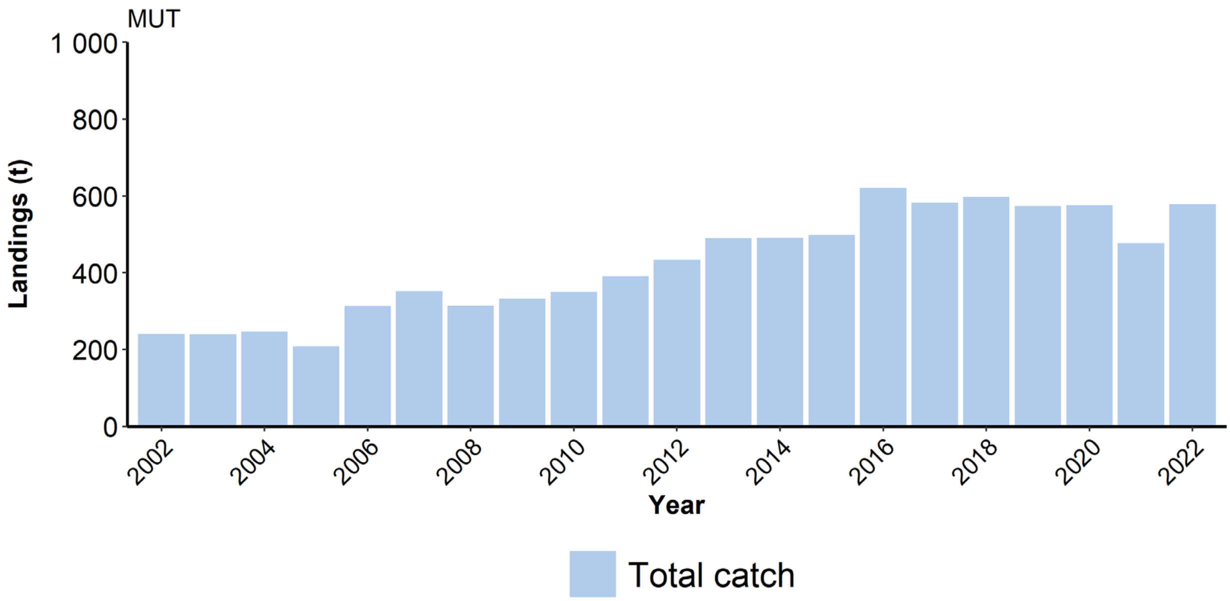

Figure 14. Landings (t) for red mullet in Catalonia from 2002 to 2022.

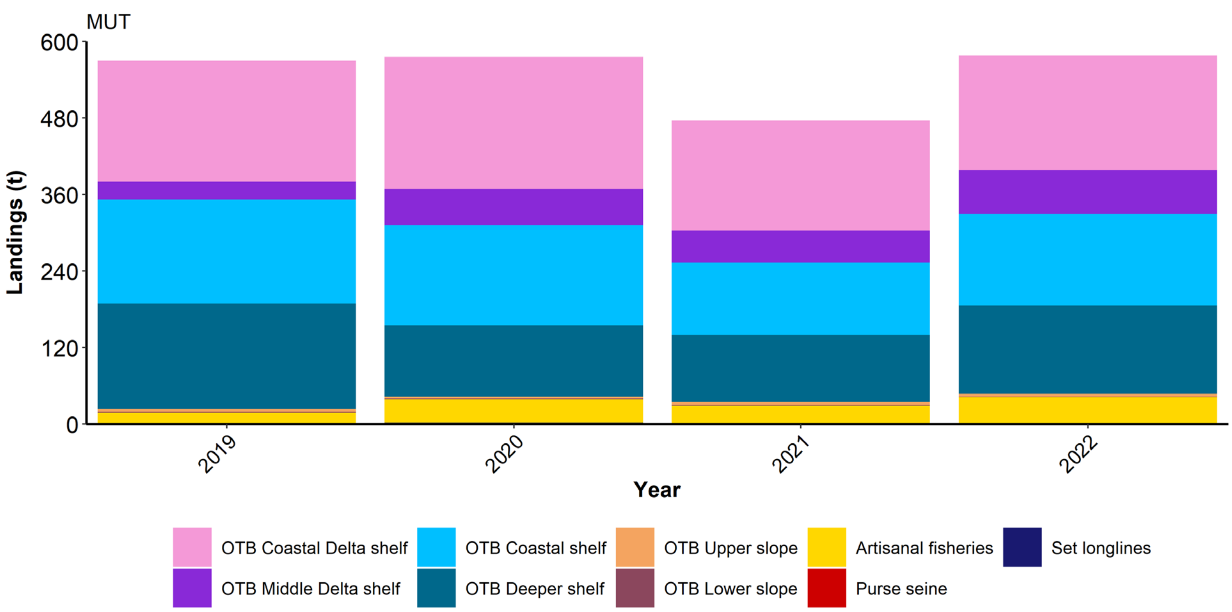

Figure 15. Landings (t) for red mullet from 2019 to 2022 by métier and fishing gear. OTB: bottom trawling.

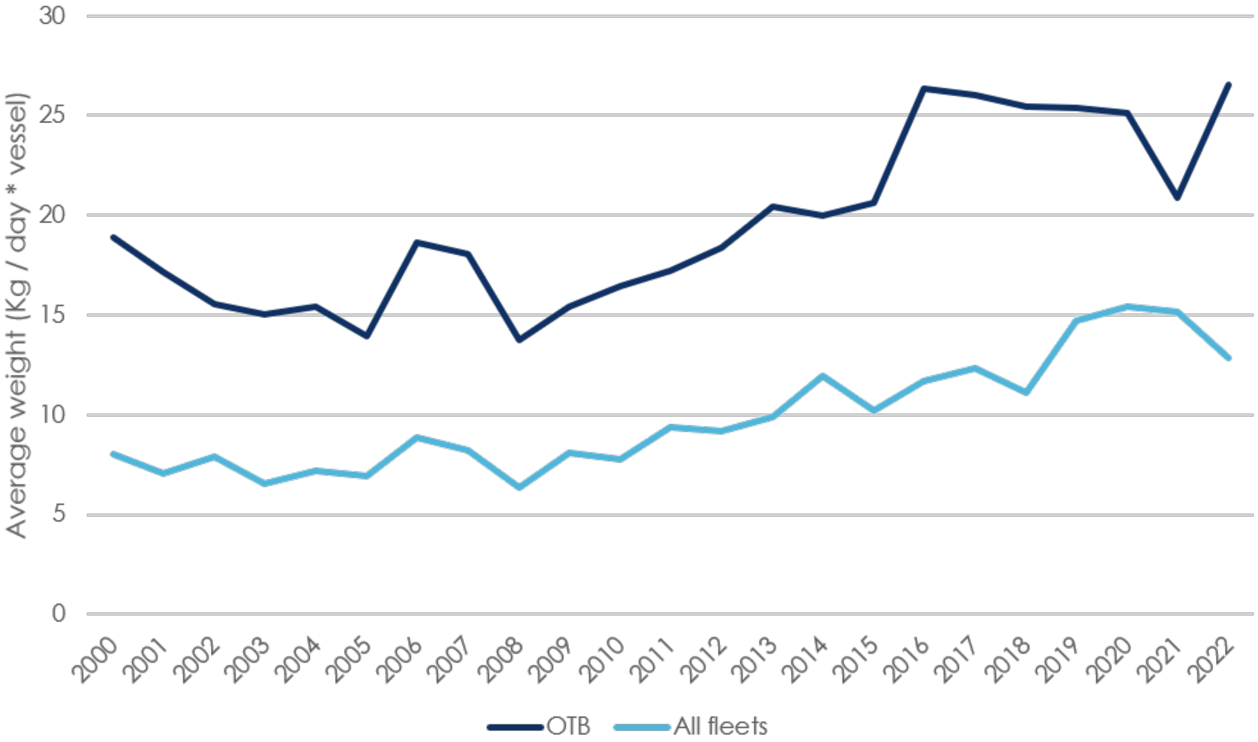

Figure 16. Landings per unit of effort (average weight in Kg/day*vessel) for red mullet in Catalonia for all fishing fleets (light blue line) including bottom trawling (OTB) and for OTB separately (dark blue line).

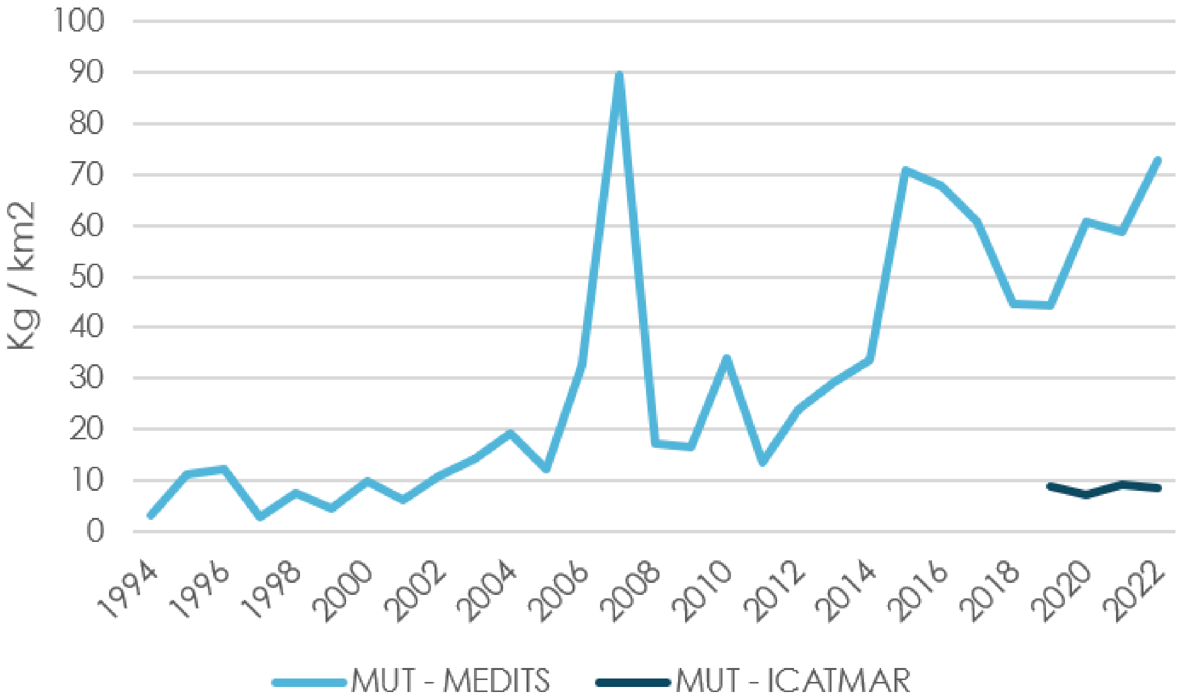

Figure 17 Biomass index (mass in Kg/area in km^2) for red mullet in Catalonia. The index from MEDITS is plotted from 1994-2022 whereas the index from ICATMAR is plotted from 2019-2022.

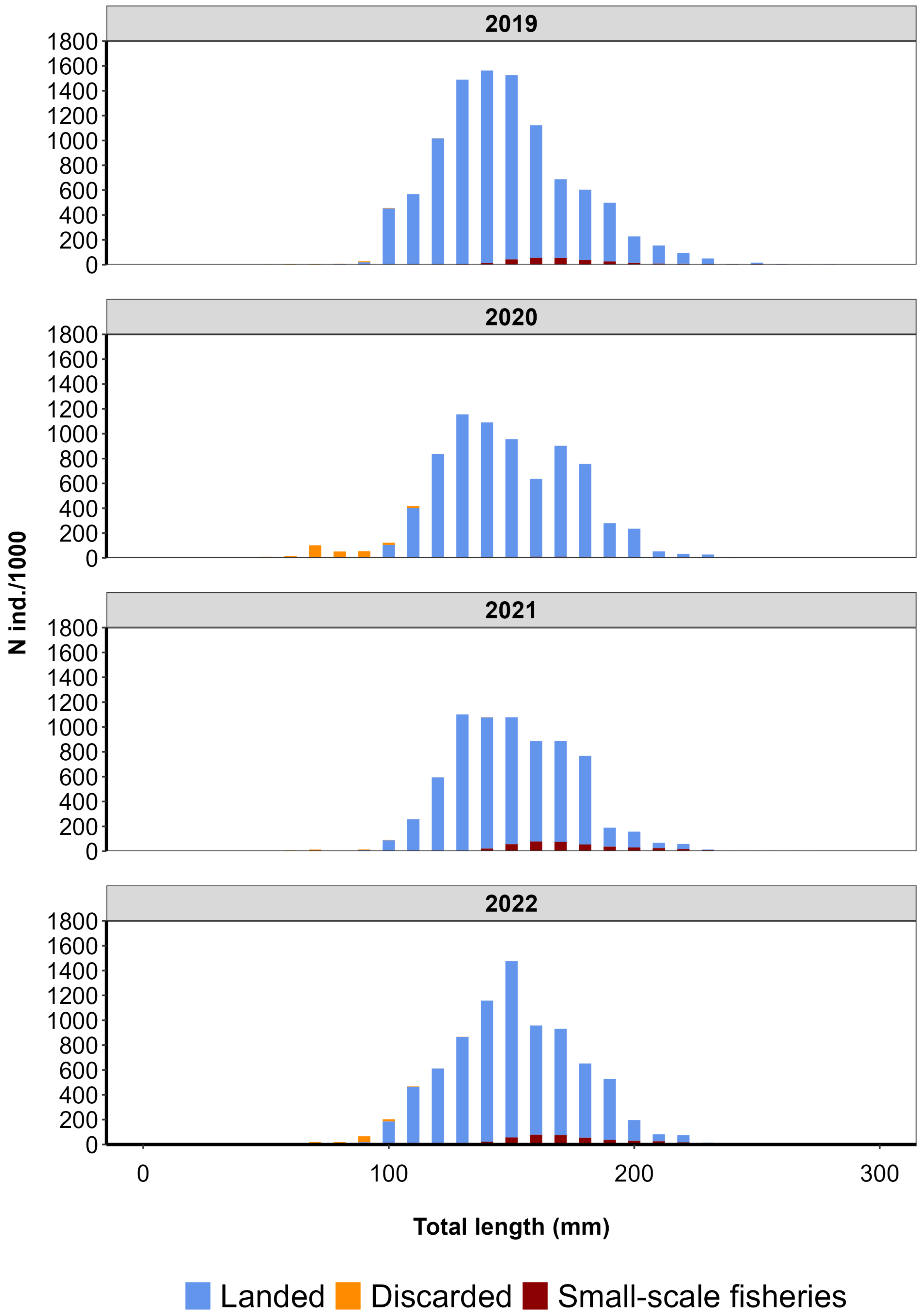

Figure 18. Annual length frequency distributions of red mullet from bottom trawling and small-scale fisheries (SSF). The data from bottom trawling is raised from ICATMAR data and details landed and discarded red mullet. The data from SSF is obtained from DCF (Data Collection Framework) dataset.

Table 7. Number of red mullet individuals sampled with bottom trawlers 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

The historical landings per unit of effort (Figure 16) show a positive trend since 2015, with the highest value recorded in 2022 and OTB; all fleets have a similar trend.

The MEDITS biomass index was available for Catalonia since 1994 and was compared to the ICATMAR biomass index, which is calculated since 2019 (Figure 17). The trend for both datasets is different and whereas the MEDITS index seems to be increasing, that for ICATMAR seems constant.

Annual LFD

After raising the length frequencies obtained with the monitoring program (Table 7), and considering discards and small-scale fisheries length frequency, the annual length frequency of red mullet in Catalonia is plotted in Figure 18. The shape of the plots vary among them, indicating different length-frequency distributions in time. There was an increase in small-length classes in 2022. Finally, the largest individuals are mainly caught with small-scale fisheries.

Model setting and results (LBSPR)

Scenarios

Three different scenarios were applied for the sensitivity analysis for red mullet (Table 8). 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, Finally, the third scenario used the same parameters as scenario 1 but a preliminary length at first maturity from ICAMAR data.

Table 8. 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)	k	M	L_{mat50} (mm)	L_{mat95} (mm)
MUT	1	345	0.340	0.420	137	150.7
MUT	2	330	0.380	0.430	137	150.7
MUT	3	345	0.340	0.420	120	132.5

Fitted data

The length frequency distribution fit per year is shown in Figure 19. The model generally follows the mode for all years, slightly underestimating the number of individuals for some length classes, mostly in 2020, 2021 and 2022.

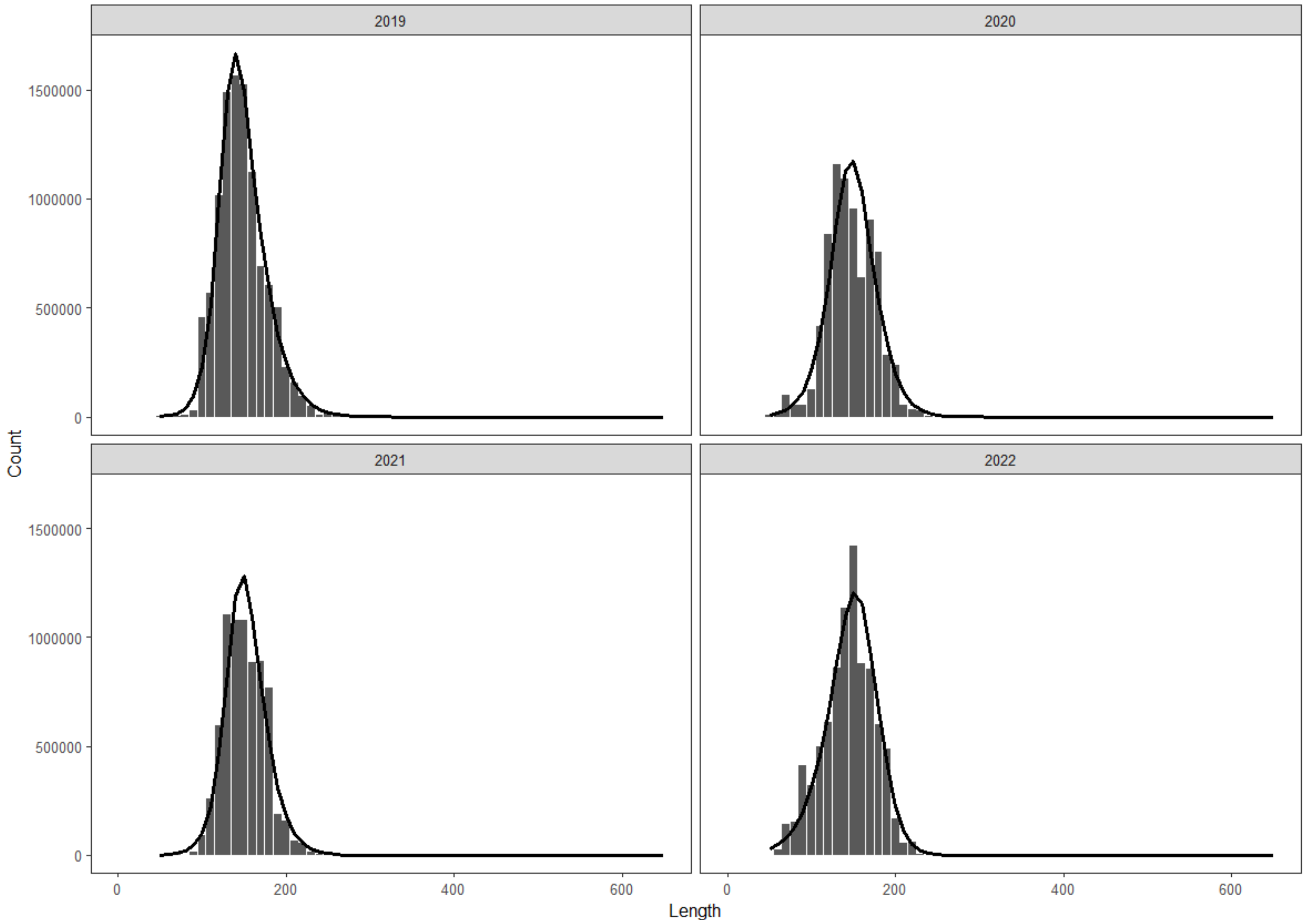

Figure 19. Fit of the data using the LBSPR model for red mullet for each studied year (2019-2022). Grey columns indicate length frequencies. Black lines indicate the fit of the model.

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 20. For the different scenarios, the model outputs reveal that the fishery is fishing similar to or above L_{mat50} in scenario 1 and 2 but below L_{mat50} in scenario 2.

Table 9. Red mullet (MUT) length (mm) in different studied scenarios (1-3). L_{mat50}: length at 50% maturity. SL_{50}: length at 50% of selectivity resulting from LBSPR outputs in each studied year (2019-2022).

Species	Scenario	L_{mat50}	SL_{50}			
			2019	2020	2021	2022
MUT	1	137	127.65	141.65	139.81	159.95
MUT	2	137	125.12	136.86	136.21	153.55
MUT	3	120	127.37	141.30	139.54	159.76

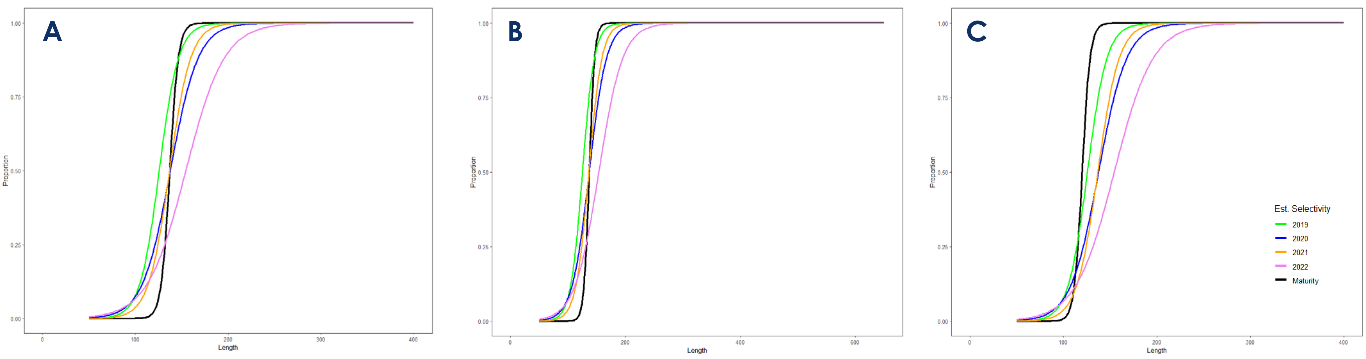

Figure 20. Length curves for red mullet. Black line shows the length curve at maturity. Color lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (A), scenario 2 (B) and scenario 3 (C).

Table 10. Red mullet (MUT) estimated values for Spawning Potential Ratio (SPR) and relative fishing mortality (F/M) in each studied year (2019-2022) for each scenario (1-3).

Scenario		SPR				F/M			
Species		2019	2020	2021	2022	2019	2020	2021	2022
MUT	1	0.05	0.05	0.05	0.04	5.71	8.00	7.75	12.78
MUT	2	0.06	0.04	0.05	0.04	5.18	6.76	6.70	10.15
MUT	3	0.06	0.06	0.06	0.05	5.71	7.98	7.74	12.73

Referent 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 10). The Kobe plot for red mullet (Figure 21) 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.

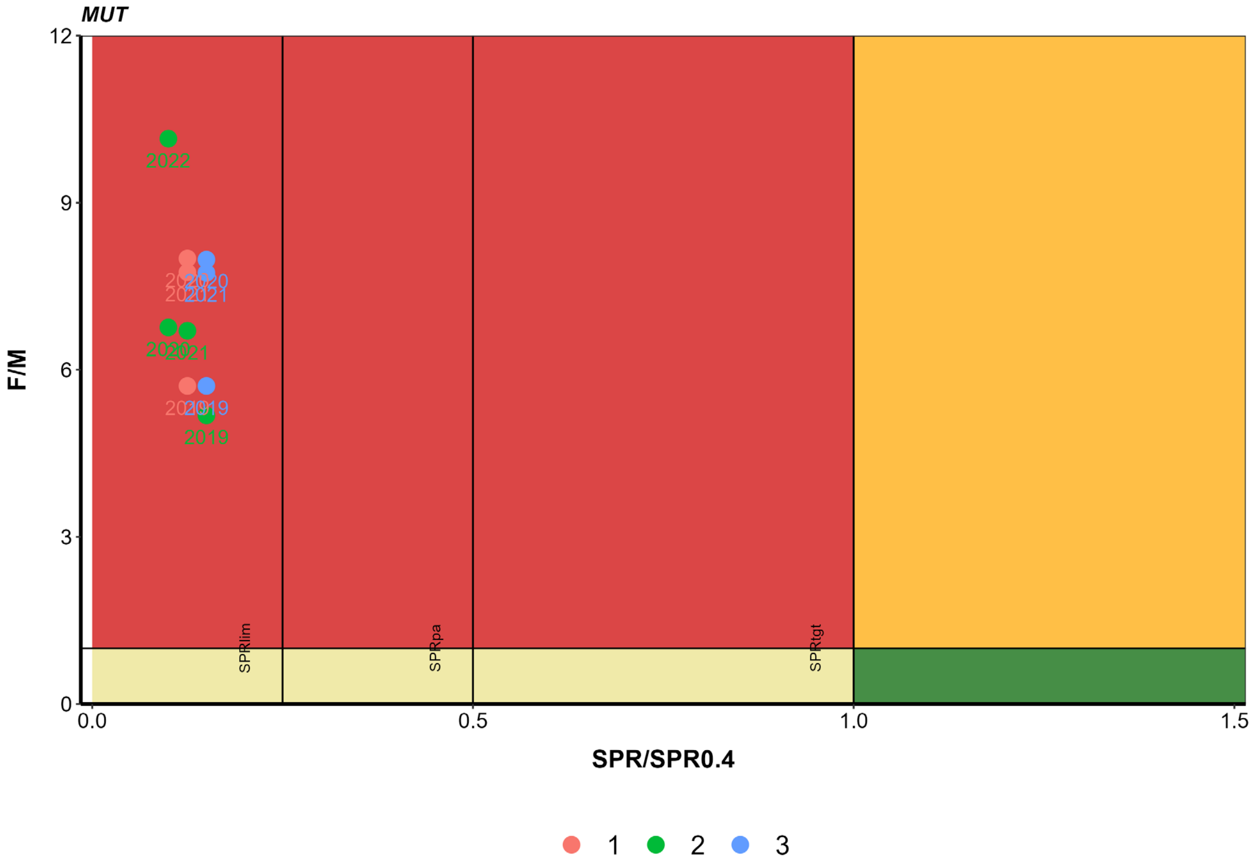

Figure 21. Kobe plot for red mullet by scenario (1-3) and year. SPRlim: limit spawning potential ratio, SPRpa: precautory aproach spawning potential ratio, SPRtgt: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

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

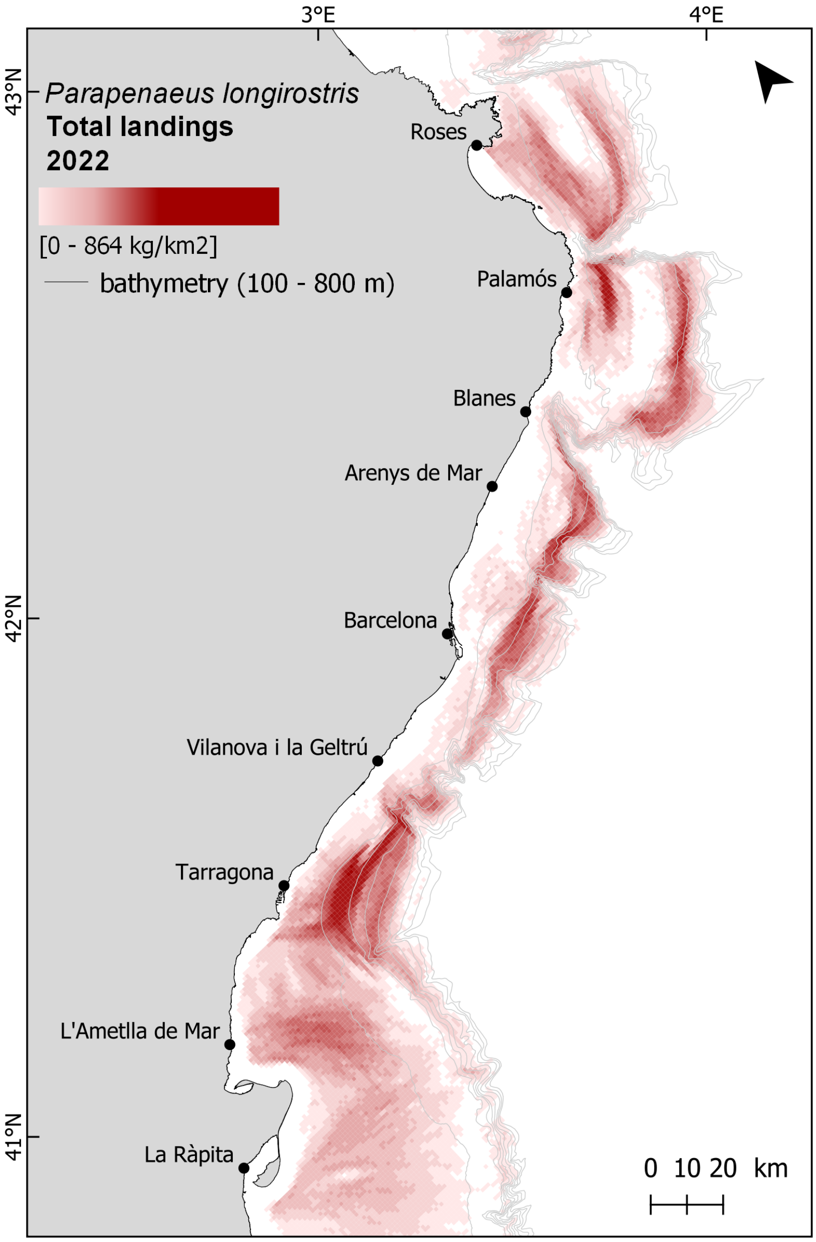

Figure 22. Spatial distribution of total landings for deep-water rose shrimp in the Catalan fishing grounds (N GSA6) in 2022.

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 22. 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 2022 are shown in Figure 23. The species shows a clear increase in landings since 2016, with the highest value in 2021.

Figure 24 shows deep-water rose shrimp landing distribution by métier from 2019 to 2022. The highest landings are obtained with bottom trawlers, specifically for deeper shelf and upper slope *métiers*.

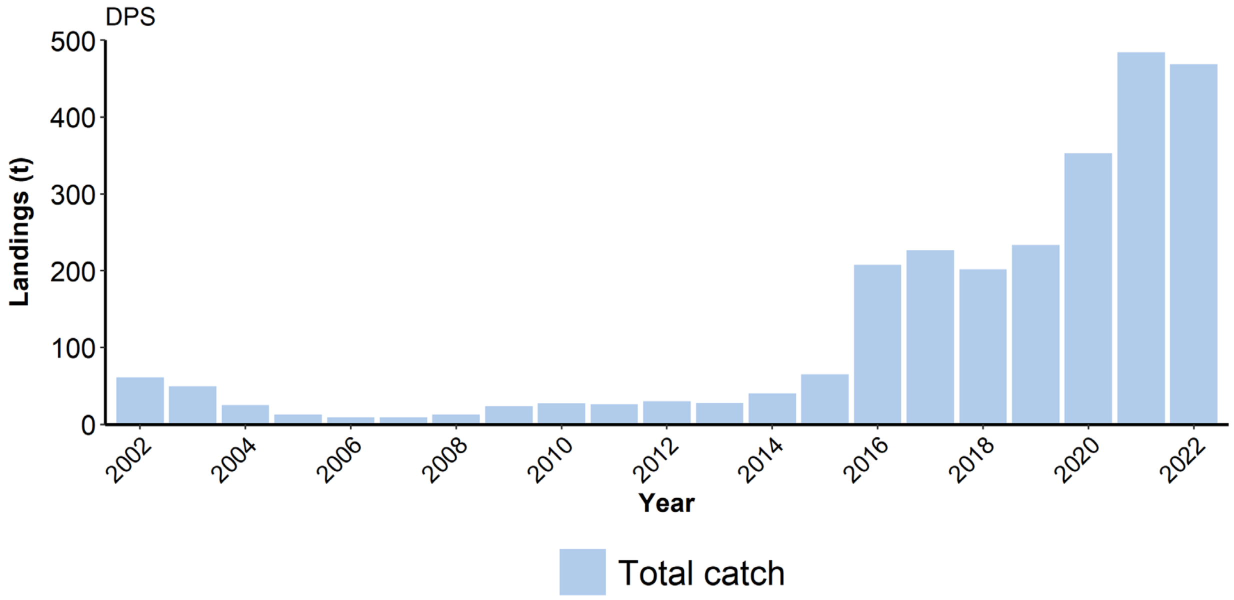

Figure 23. Landings (t) for deep-water rose shrimp in Catalonia from 2019 to 2022.

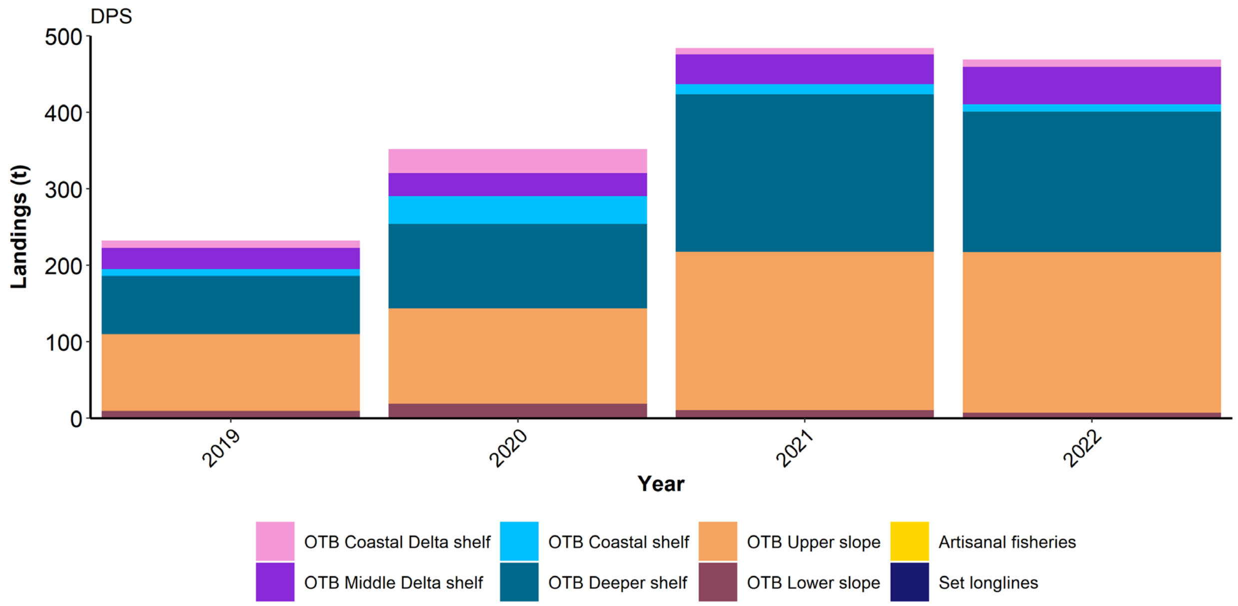

Figure 24. Landings (t) for deep-water rose shrimp in Catalonia from 2019 to 2022 by *métier* and fishing gear. OTB: bottom trawling.

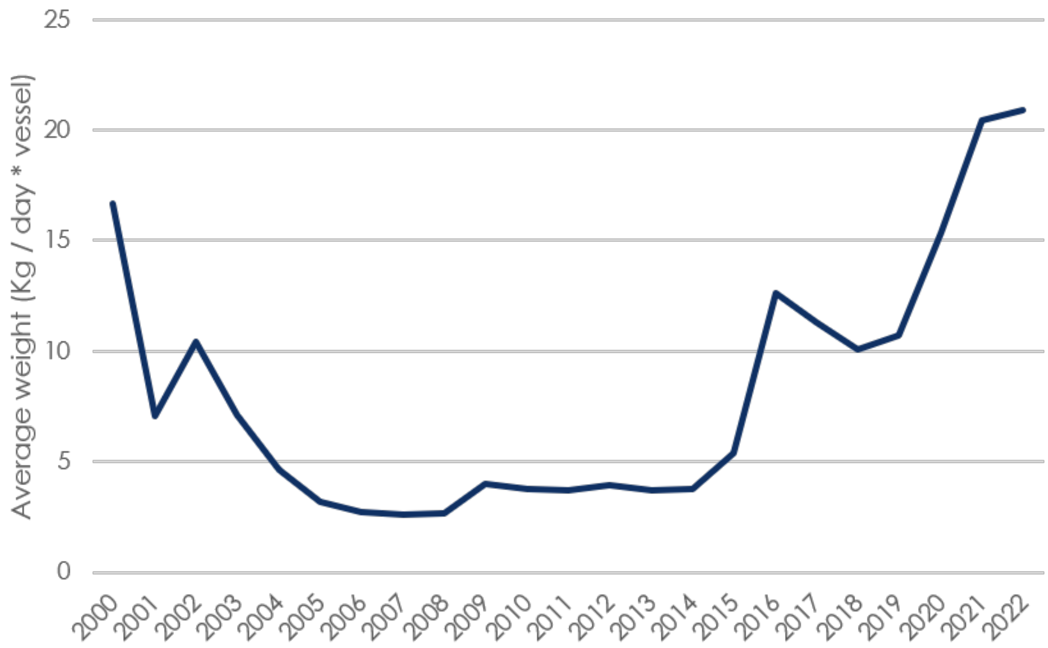

Figure 25. Landings per unit of effort (average weight in Kg/day*vessel) for deep-water rose shrimp in Catalonia.

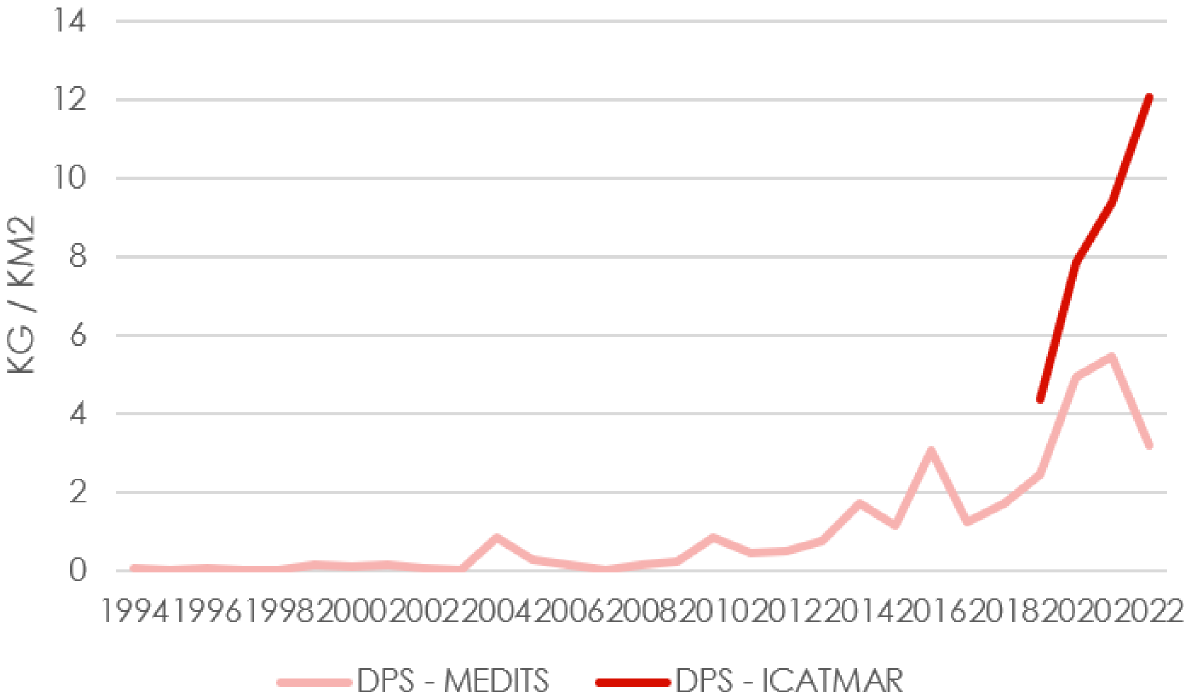

Figure 26. Biomass index (mass in kg/area in km^2) for deep-water rose shrimp in Catalonia. The index from MEDITS is plotted from 1994-2022 whereas the index from ICATMAR is plotted from 2019-2022.

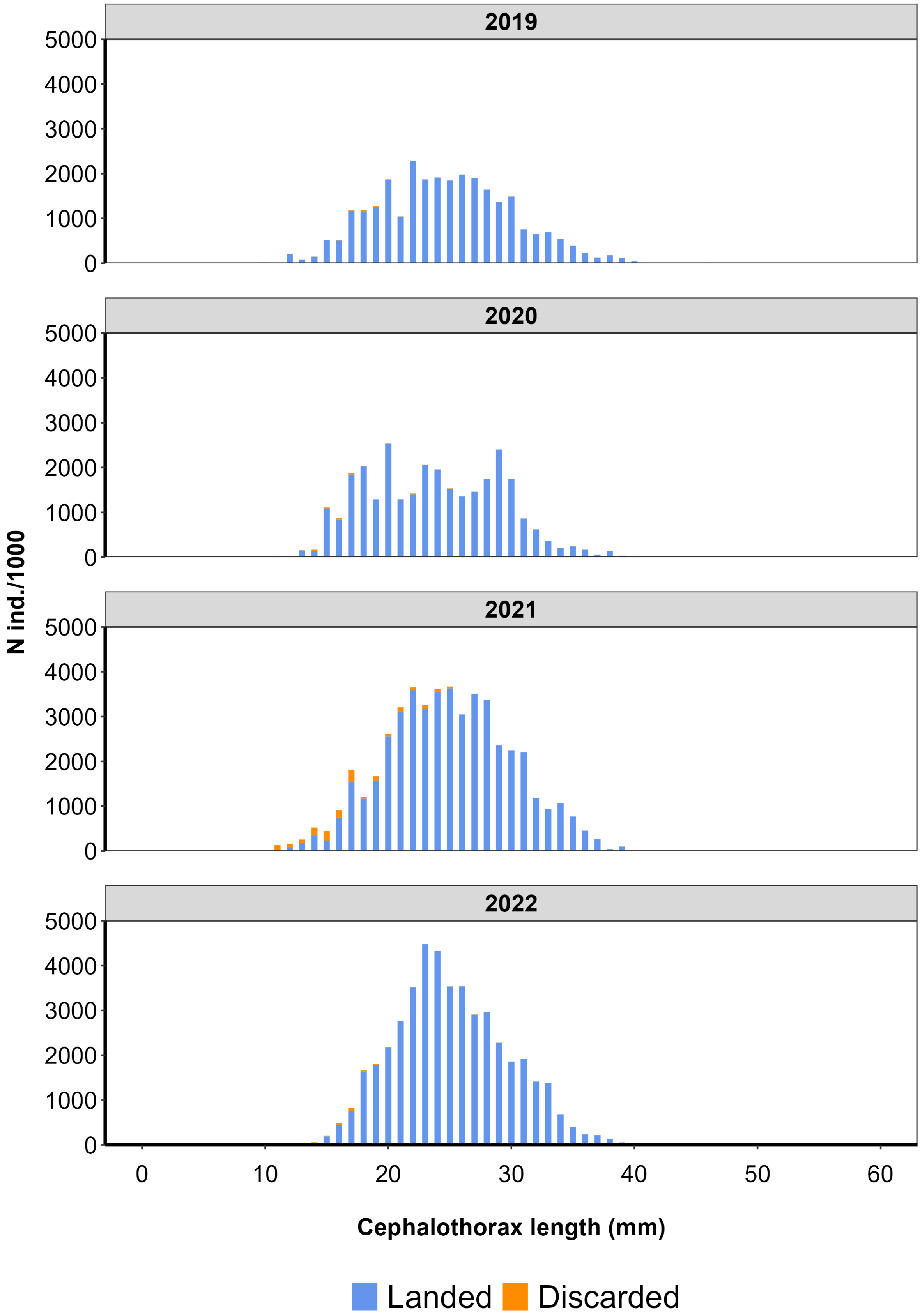

Figure 27. Annual length frequency distributions of deep-water rose shrimp from bottom trawling. The data is raised from ICATMAR data and details landed and discarded specimens.

Table 11. Number of deep-water rose shrimp individuals sampled with bottom trawlers 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

The historical landings per unit of effort (Figure 25) show a very similar and constant trend from 2004 to 2015. Thereafter, the effort increased greatly.

The MEDITS biomass index was available for Catalonia since 1994 and was compared to the ICATMAR biomass index, which is calculated since 2019 (Figure 26). The trend is positive in both cases, indicating an increase in biomass. However, in the MEDITS index, the biomass decreased in the last two years.

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 27. A decrease in small-length classes is observed in 2022. The medium-length classes are more abundant in 2021 and 2022.

Model setting and results (LBSPR)

Scenarios

Four different scenarios were applied for the sensitivity analysis for deep-water rose shrimp (Table 12). Scenarios 1 and 3 used growth parameters and natural mortality from STECF whereas scenarios 2 and 4 used GFCM stock assessment data. Scenario 1 and 2 used maturity data from GFCM stock assessment but 3 and 4 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)	k	M	L_{mat50} (mm)	L_{mat95} (mm)
DPS	1	45	0.71	0.760	25.6	43.6
DPS	2	44	0.67	0.760	25.6	43.6
DPS	3	45	0.71	0.760	17.05	29
DPS	4	44	0.67	0.760	17.05	29

Fitted data

The length frequency distribution fit per year is shown in Figure 28. 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.

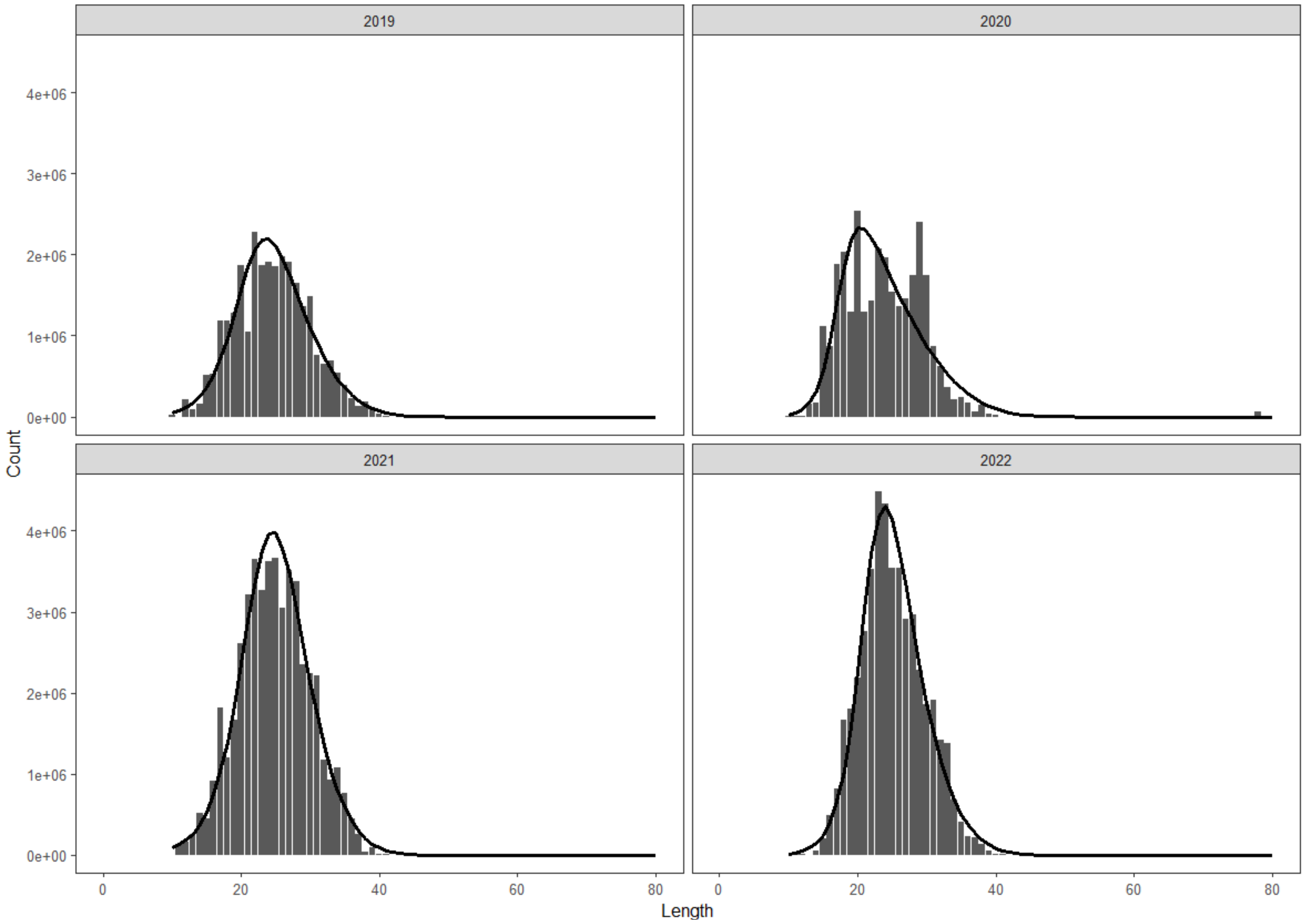

Figure 28. Fit of the data using the LBSPR model for deep-water rose shrimp for each studied year (2019-2022). Grey columns indicate length frequencies. Black lines indicate the fit of the model.

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 29. 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 (the scenario 4 plot is not shown because it is the same L_{mat50} as input data).

Table 13. Deep-water rose shrimp (DPS) cephalothorax length (mm) in different studied scenarios (1-3). L_{mat50}: length at 50% maturity. SL_{50}: length at 50% of selectivity resulting from LBSPR outputs in each studied year (2019-2022).

Species	Scenario	L_{mat50}	SL_{50}			
			2019	2020	2021	2022
DPS	1	25.6	21.92	19.08	23.46	22.23
DPS	2	25.6	21.86	18.91	23.42	22.20
DPS	3	17.05	21.86	18.98	23.41	22.19
DPS	4	17.05	21.79	18.79	23.36	22.16

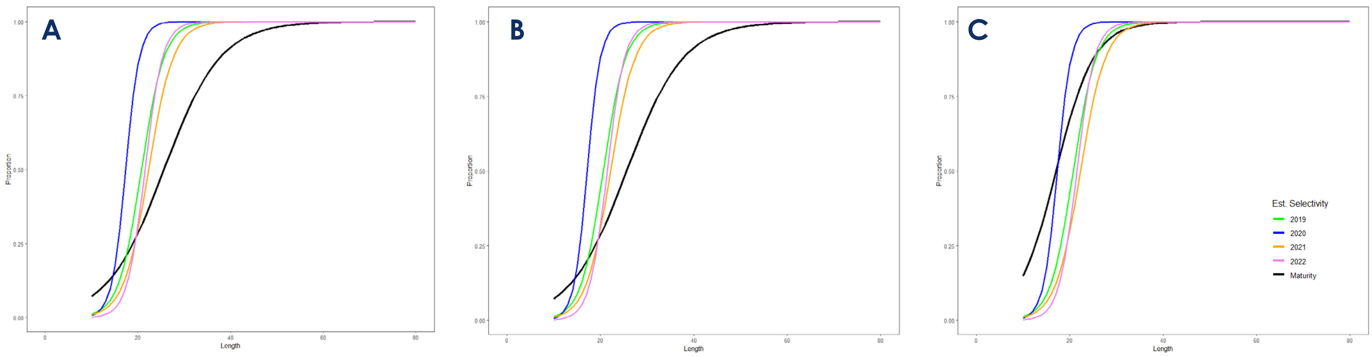

Figure 29. Length curves for deep-water rose shrimp. Black line shows the length curve at maturity. Color lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (A), scenario 2 (B) and scenario 3 (C).

Table 14. Deep-water rose shrimp (DPS) estimated values for Spawning Potential Ratio (SPR) and relative fishing mortality (F/M) in each studied year (2019-2022) for each scenario (1-3).

Scenario		SPR				F/M			
Species		2019	2020	2021	2022	2019	2020	2021	2022
DPS	1	0.12	0.12	0.11	0.11	3.54	2.98	4.37	3.88
DPS	2	0.14	0.15	0.13	0.13	3,08	2,55	3.84	3.41
DPS	3	0.16	0.16	0.15	0.15	3.49	2.92	4.31	3.84
DPS	4	0.18	0.19	0.17	0.17	3.04	2.50	3.79	3.37

Referent 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 (Table 14). The Kobe plot for deep-water rose shrimp (Figure 30) shows the stock status throughout the different years, with a negative trend. In all cases, the stock status is located in the red zone, meaning that it is overfished and under overfishing.

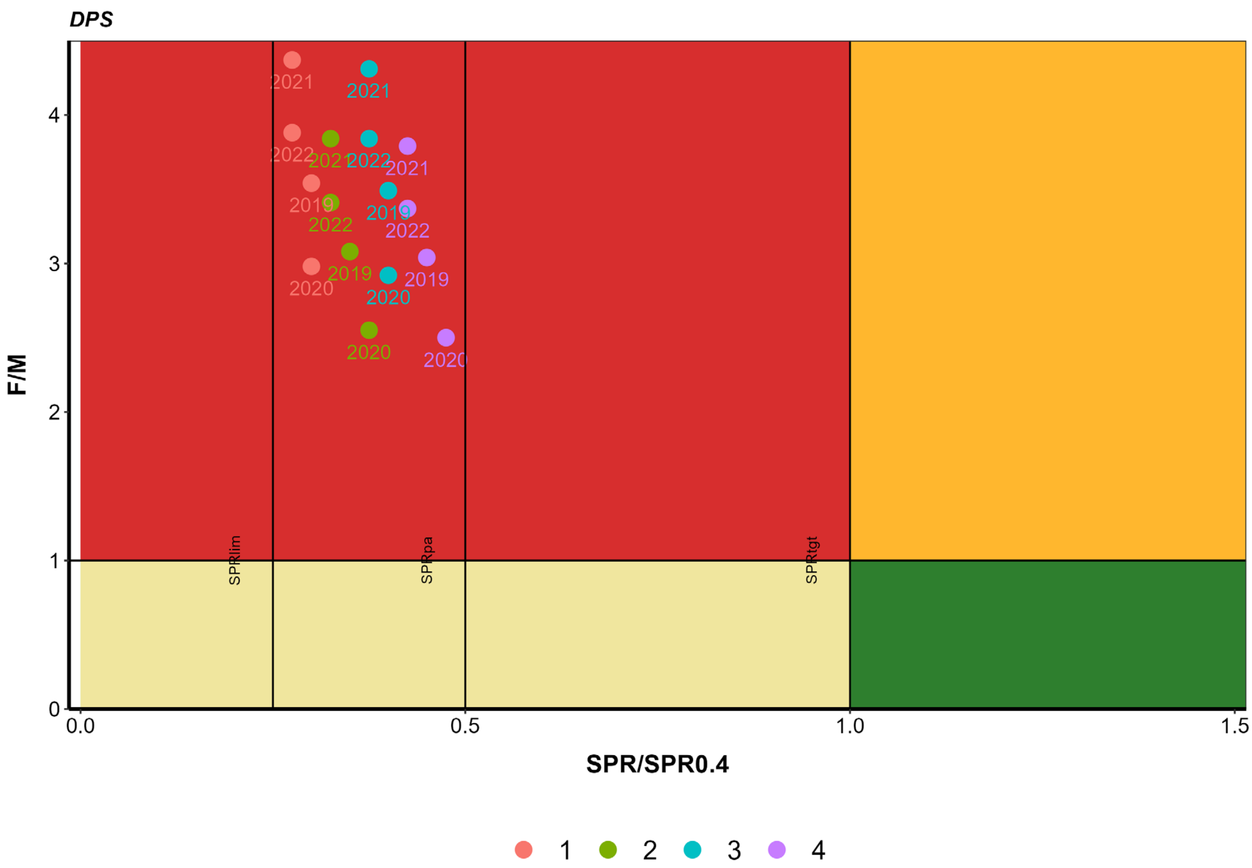

Figure 30. Kobe plot for deep-water rose shrimp by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{pa}: precautory aproach spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

Norway lobster (*Nephrops norvegicus*) NEP

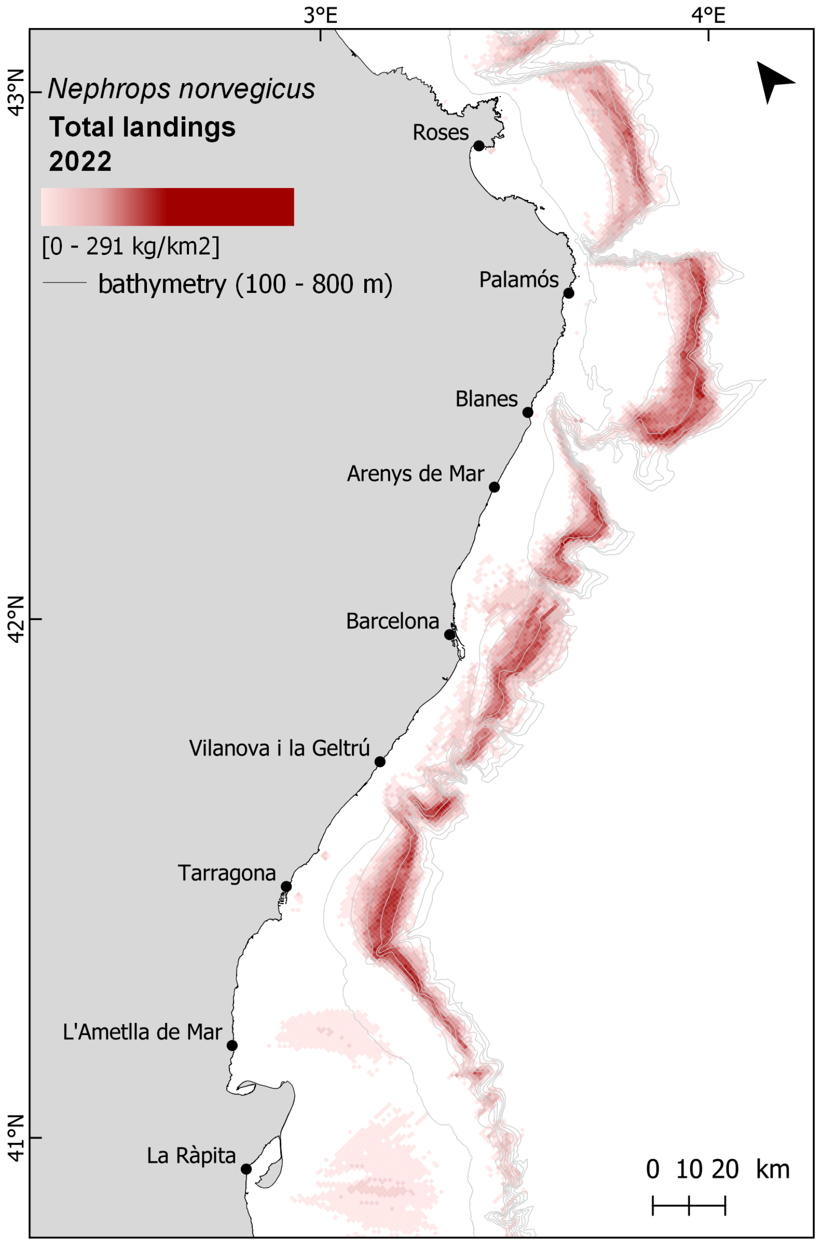

Figure 31. Spatial distribution of total landings for Norway lobster in the Catalan fishing grounds (N GSA6) in 2022.

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 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 31. 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 2022 are shown in Figure 32. The species shows a decreasing trend in landings, especially since 2015, with the lowest value recorded in 2021.

Figure 33 shows the Norway lobster landing distribution by *métier* from 2019 to 2022. The highest landings are obtained with bottom trawlers, specifically for upper slope métiers.

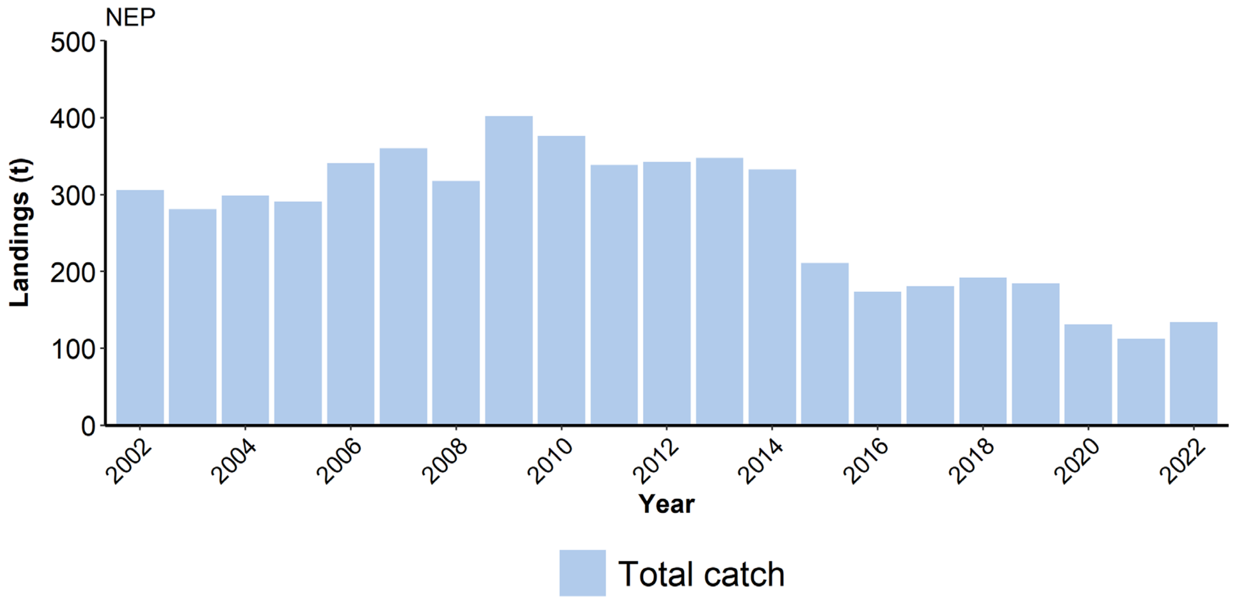

Figure 32. Landings (t) for Norway lobster in Catalonia from 2019 to 2022.

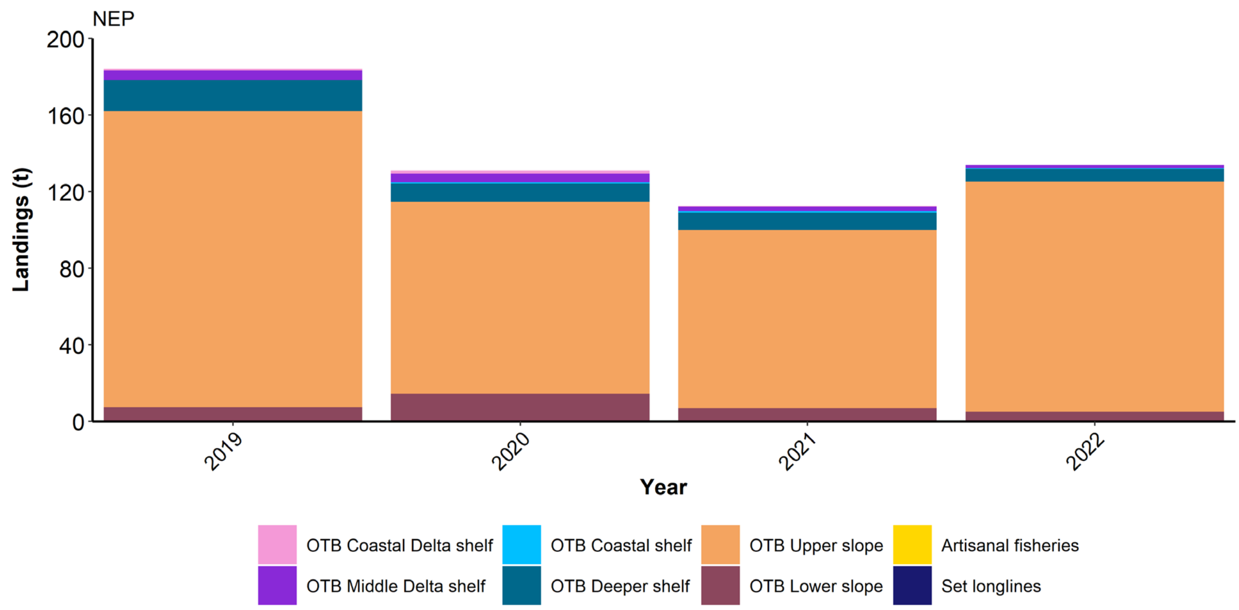

Figure 33. Landings (t) for Norway lobster in Catalonia from 2019 to 2022 by *métier* and fishing gear. OTB: bottom trawling.

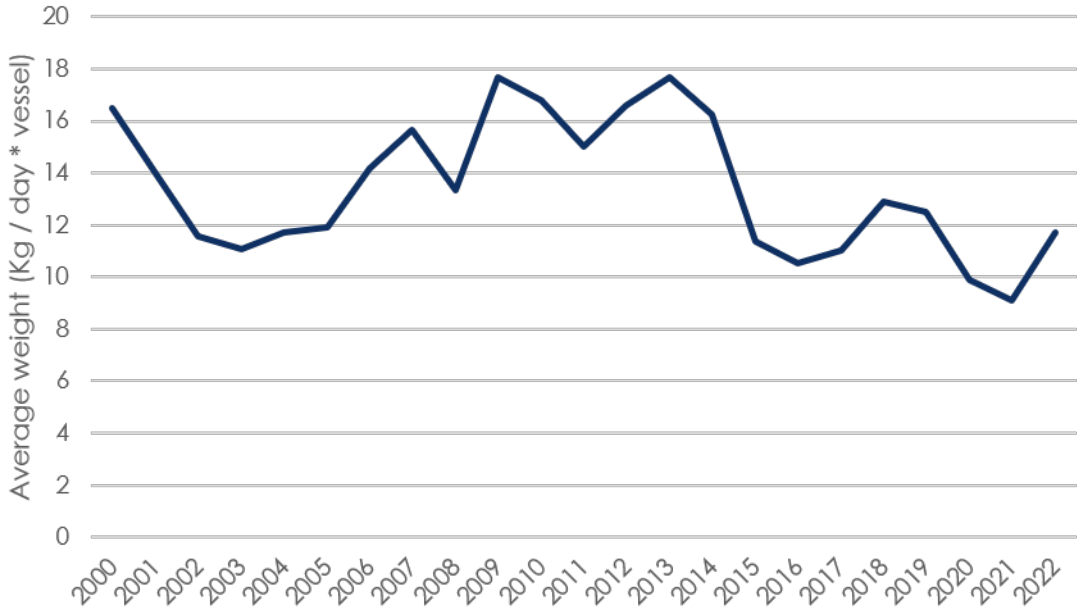

Figure 34. Landings per unit of effort (average weight in kg/day*vessel) for Norway lobster in Catalonia.

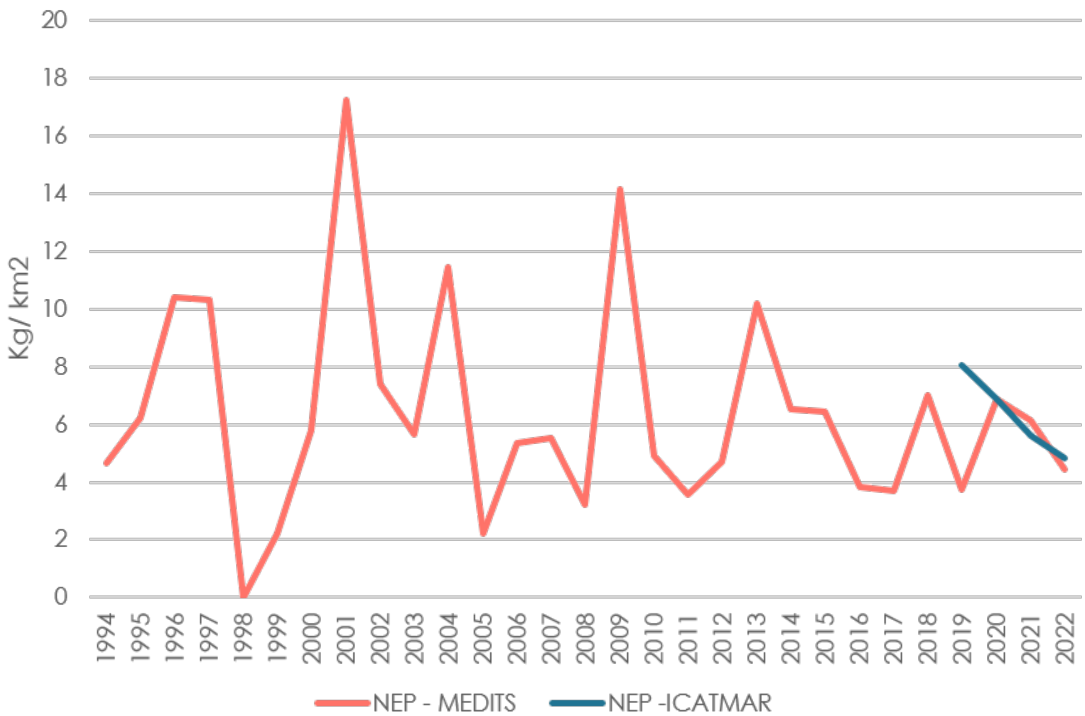

Figure 35. Biomass index (mass in kg/area in km^2) for Norway lobster in Catalonia. The index from MEDITS is plotted from 1994-2022 whereas the index from ICATMAR is plotted from 2019-2022.

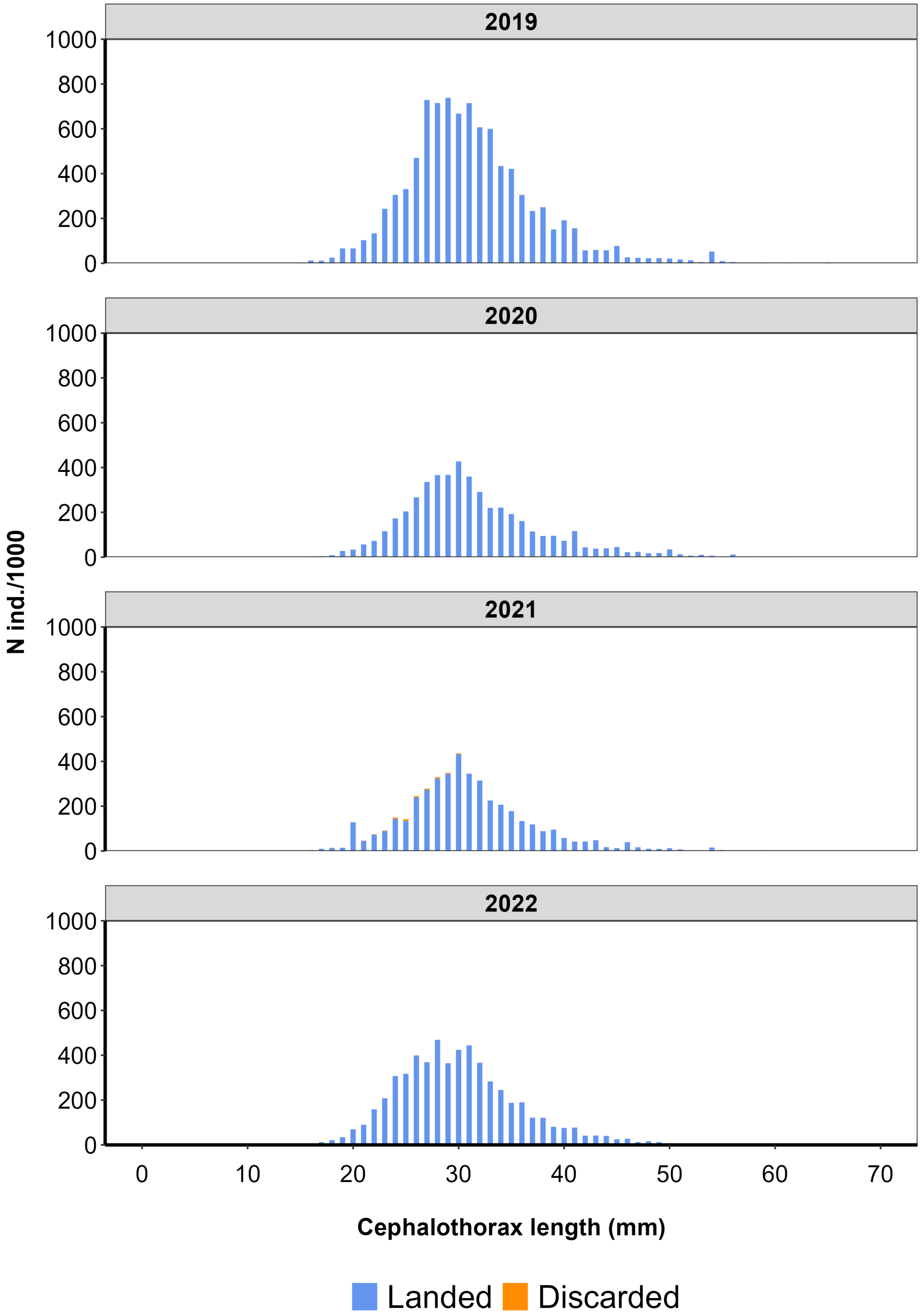

Figure 36. Annual length frequency distributions of Norway lobster from bottom trawling. The data is raised from ICATMAR data and details landed and discarded specimens.

Table 15. Number of Norway lobster individuals sampled with bottom trawlers 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

The historical landings per unit of effort (Figure 34) show a constant trend since 2014. Afterwards, the effort decreased.

The MEDITS biomass index was available for Catalonia since 1994 and was compared to the ICATMAR biomass index, which is calculated since 2019 (Figure 35). The trend is negative in both cases.

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 36. A decrease in number is observed.

Model setting and results (LBSPR)

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, 23-07).

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)	k	M	L_{mat50} (mm)	L_{mat95} (mm)
NEP	1	86.1	0.126	0.50	32.5	36.0
NEP	2	86.1	0.126	0.50	25.6	28.4
NEP	3	86.1	0.126	0.50	24.8	27.4

Fitted data

The length frequency distribution fit per year is shown in Figure 37. The model generally follows the mode for all years.

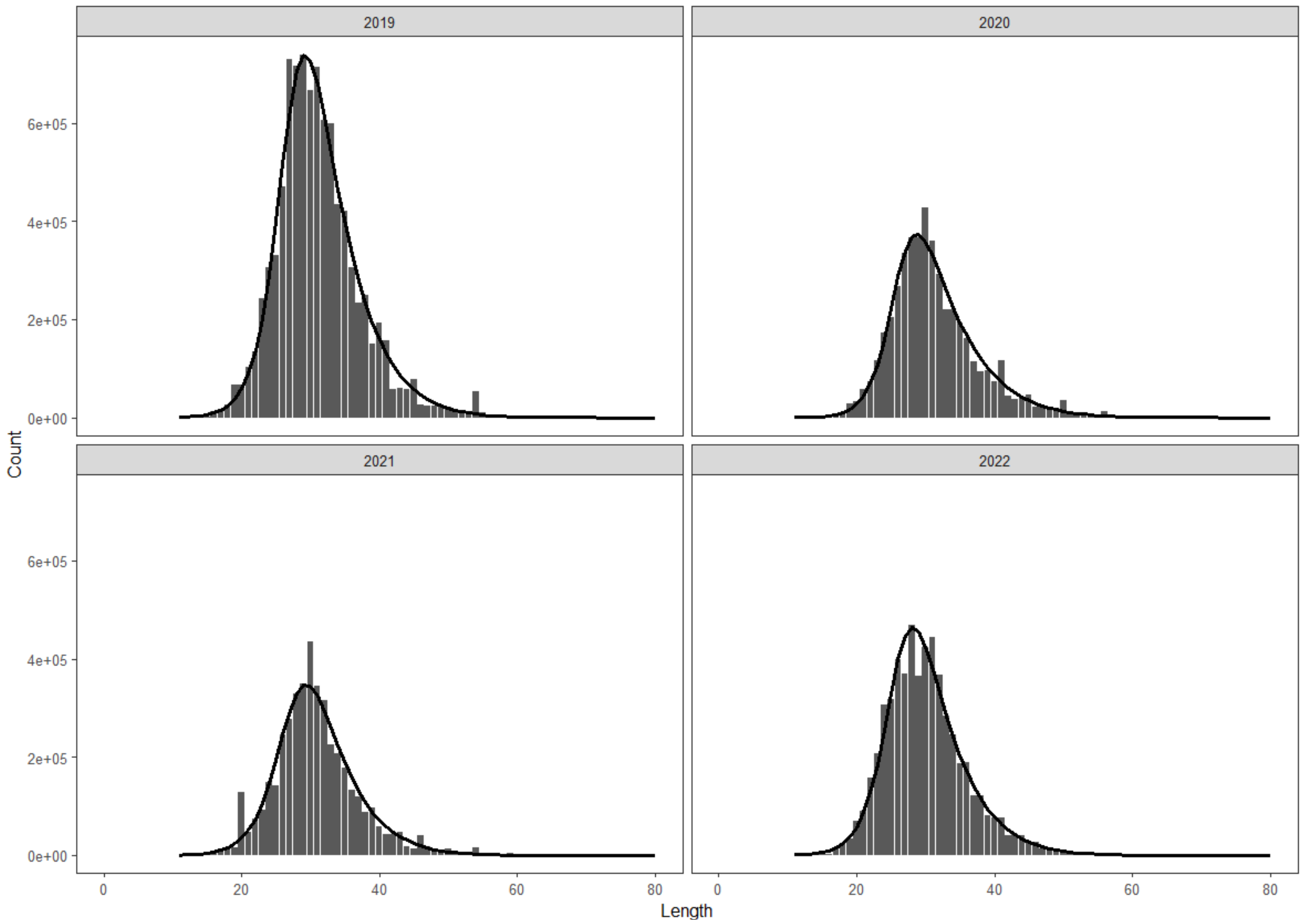

Figure 37. Fit of the data using the LBSPR model for Norway lobster for each studied year (2019-2022). Grey columns indicate length frequencies. Black lines indicate the fit of the model.

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 38. For scenario 1, the model reveals that the fishery is fishing below L_{mat50} whereas for scenarios 2 and 3, it is fishing around L_{mat50}.

Table 17. Norway lobster (NEP) cephalothorax length (mm) in different studied scenarios (1-3). L_{mat50}: length at 50% maturity. SL50: length at 50% of selectivity resulting from LBSPR outputs in each studied year (2019-2022).

Species	Scenario	L_{mat50}	SL_{50}			
			2019	2020	2021	2022
NEP	1	32.5	27.3	26.5	27.6	26.2
NEP	2	25.6	27.3	26.5	27.6	26.2
NEP	3	24.8	27.0	26.2	27.3	26.0

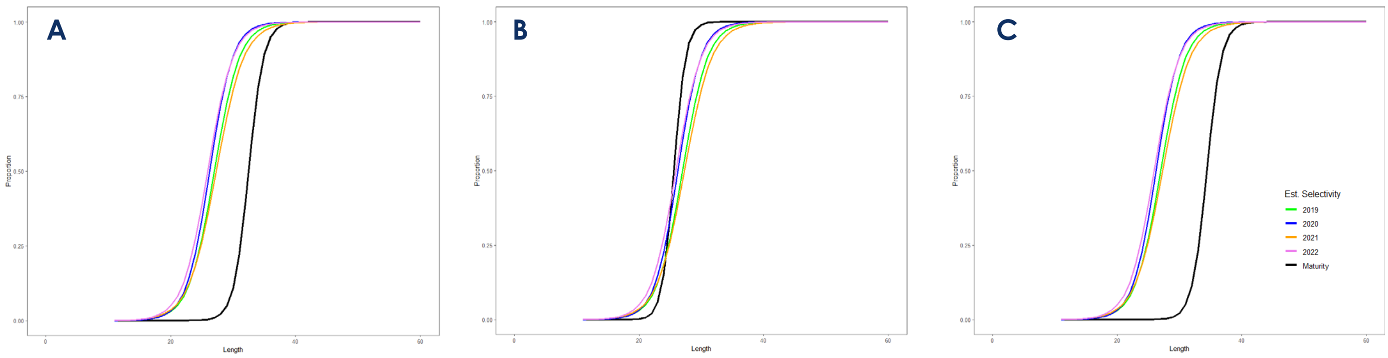

Figure 38. Length curves for Norway lobster. Black line shows the length curve at maturity. Color lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (A), scenario 2 (B) and scenario 3 (C).

Table 18. Norway lobster (NEP) estimated values for Spawning Potential Ratio (SPR) and relative fishing mortality (F/M) in each studied year (2019-2022) for each scenario (1-3).

Scenario		SPR				F/M			
Species		**2019**	**2020**	**2021**	**2022**	**2019**	**2020**	**2021**	**2022**
NEP	1	0.14	0.16	0.13	0.12	1.84	1.51	2.04	1.93
NEP	2	0.21	0.24	0.20	0.19	1.83	1.50	2.03	1.92
NEP	3	0.23	0.26	0.22	0.20	1.58	1.30	1.75	1.67

Referent 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 and 3, the stock is similar or above SPR_{pa} (=0.2) (Table 18). The Kobe plot for Norway lobster (Figure 39) 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.

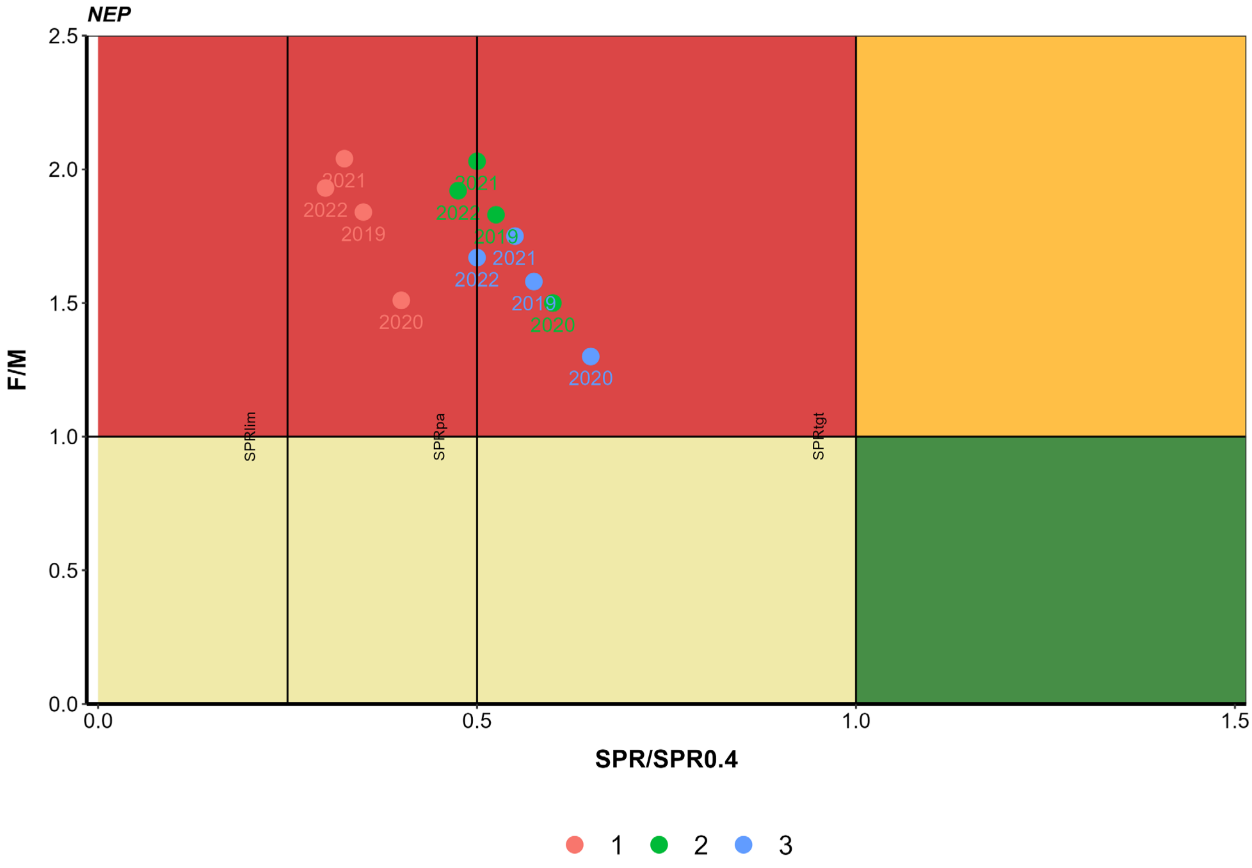

Figure 39. Kobe plot for Norway lobster by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{pa}: precautory aproach spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

Blue and red shrimp (*Aristeus antennatus*) ARA

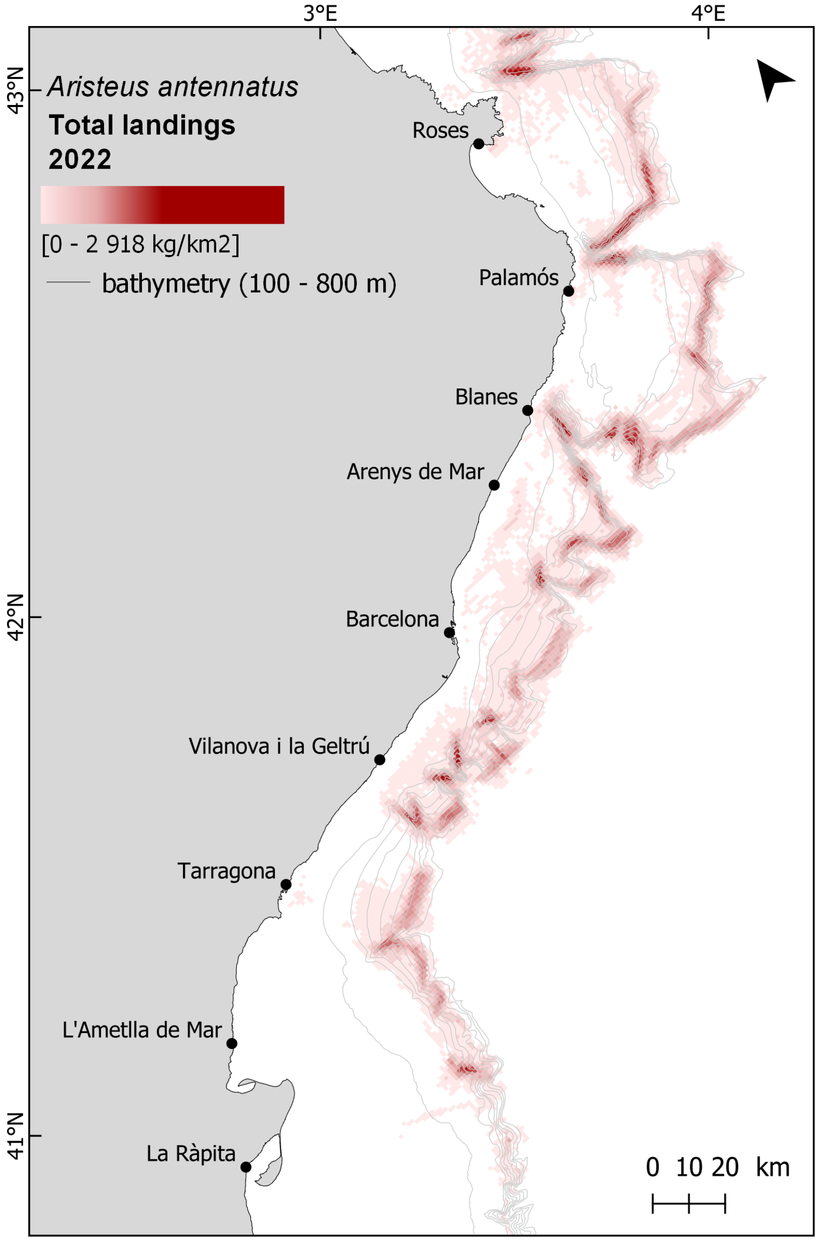

Figure 40. Spatial distribution of total landings for Blue and red shrimp in the Catalan fishing grounds (N GSA6) in 2022.

The blue and red shrimp presents sexual dimorphism, with females reaching larger sizes than males. To analyze 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, 23-07), 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 40. 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 2022 are shown in Figure 41. 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.

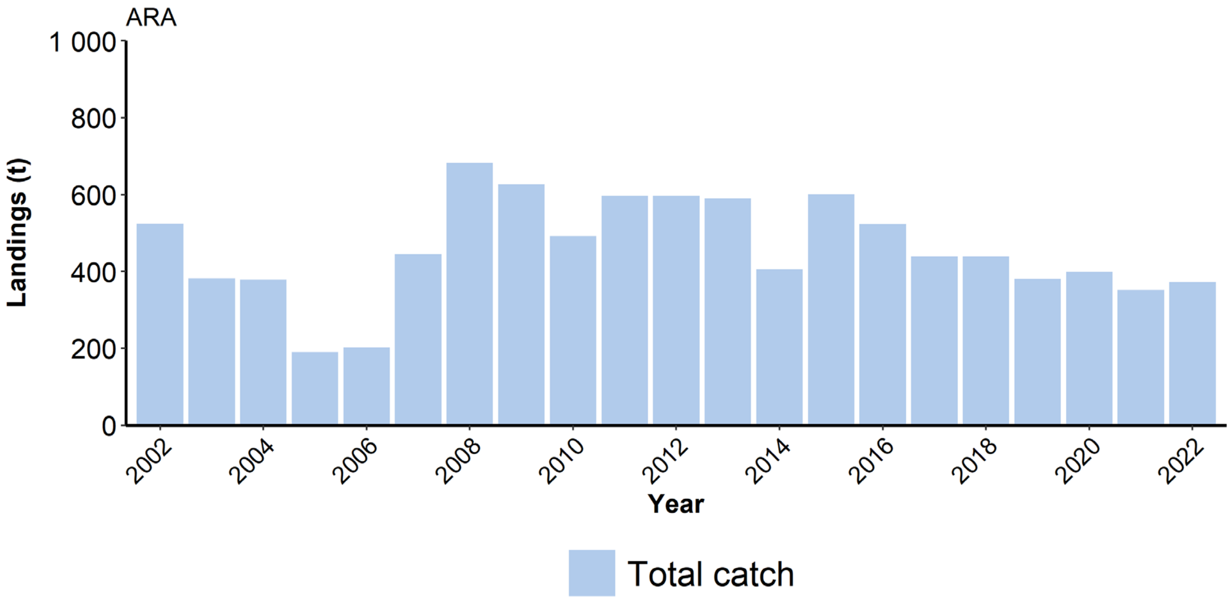

Figure 41. Landings (t) for blue and red shrimp in Catalonia from 2002 to 2022.

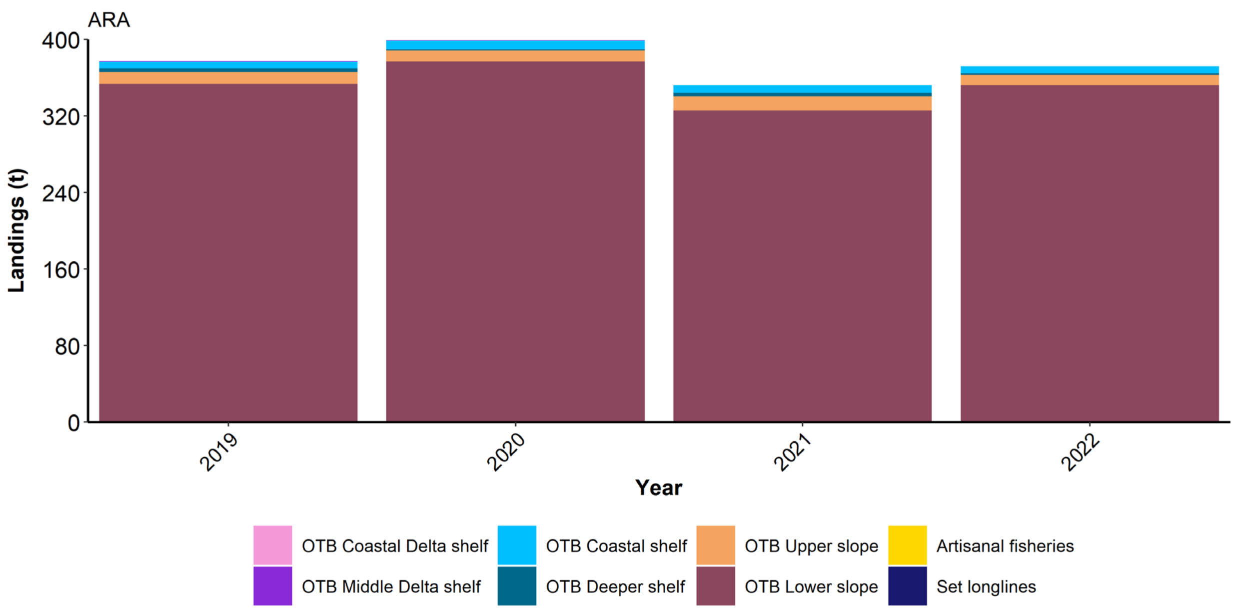

Figure 42. Landings (t) for blue and red shrimp in Catalonia from 2019 to 2022 by *métier* and fishing gear. OTB: bottom trawling.

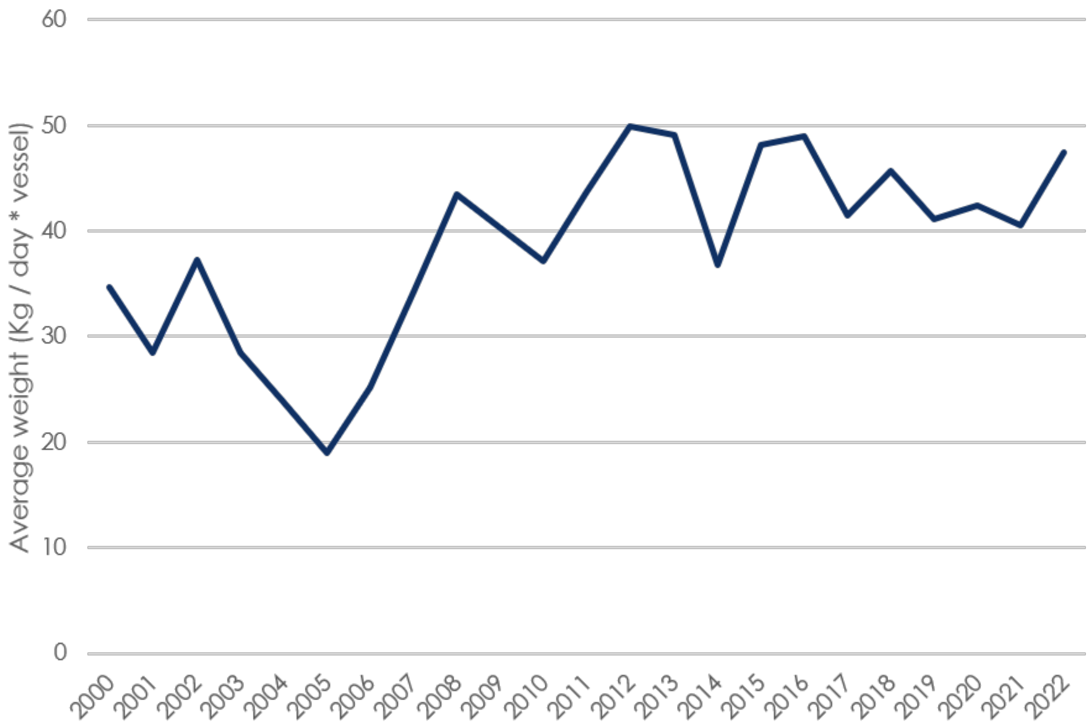

Figure 43. Landings per unit of effort (average weight in kg/day*vessel) for blue and red shrimp in Catalonia.

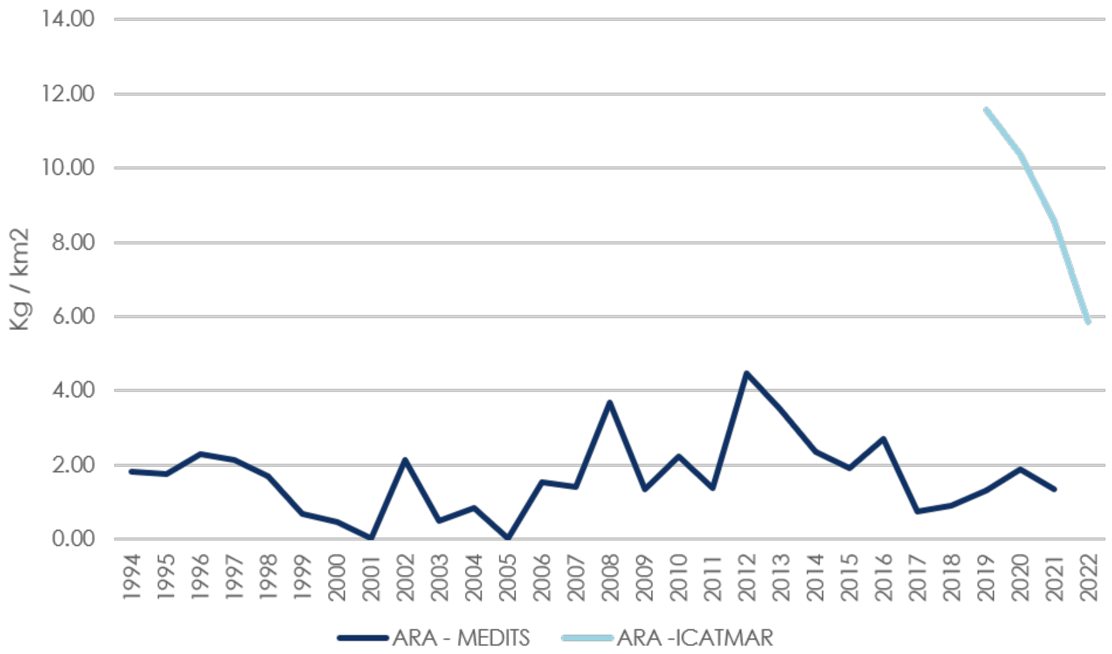

Figure 44. Biomass index (mass in kg/area in km^2) for blue and red shrimp in Catalonia. The index from MEDITS is plotted from 1994-2022 whereas the index from ICATMAR is plotted from 2019-2022.

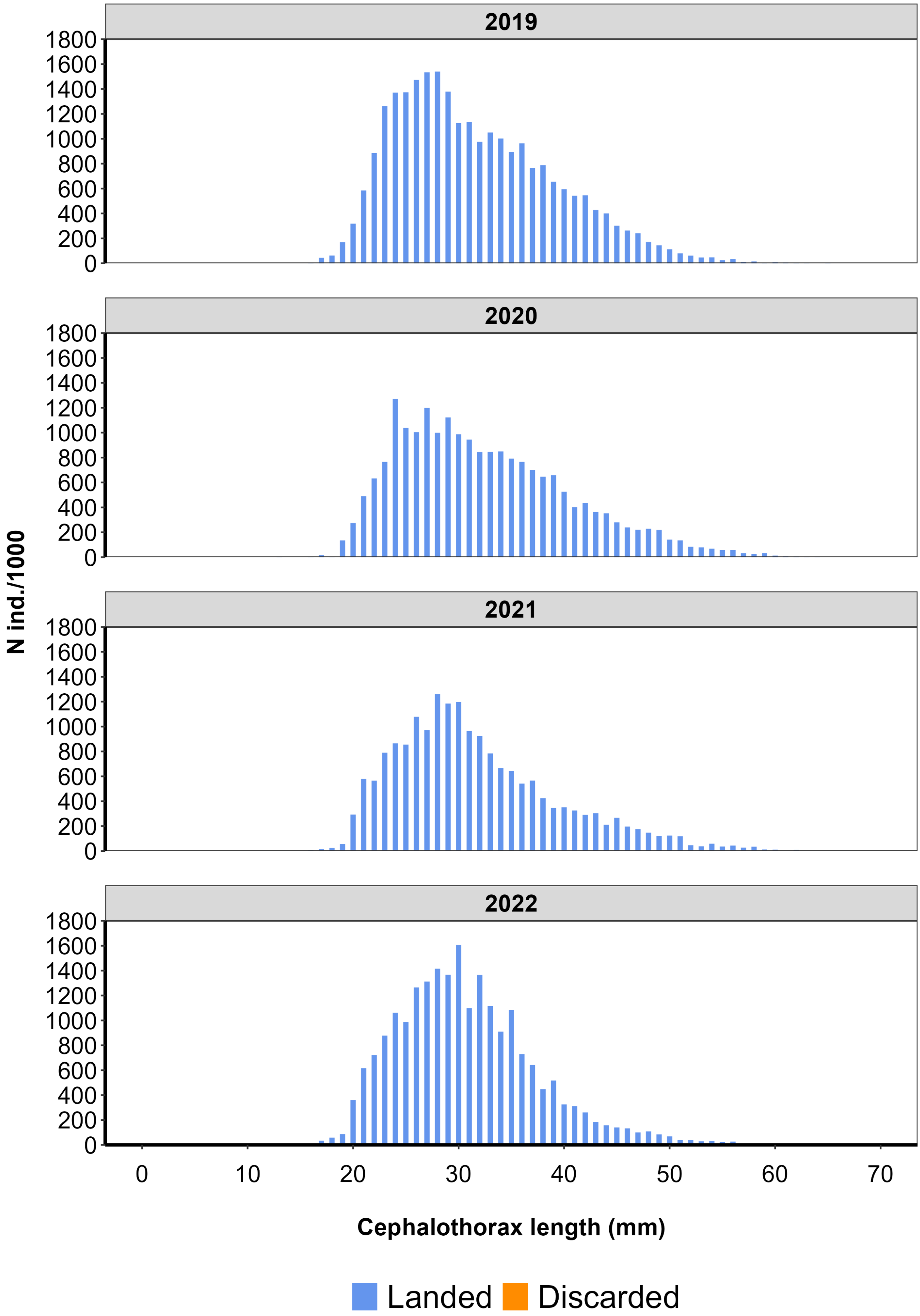

Figure 45. Annual length frequency distributions of blue and red shrimp from bottom trawling. The data is raised from ICATMAR data and details landed and discarded specimens.

Table 19. Number of blue and red shrimp individuals sampled with bottom trawlers 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	1056	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	467	12
Bottom trawl	2022	North	889	921	934	746	15
Bottom trawl	2022	Center	835	532	663	431	11

Figure 42 shows the blue and red shrimp landing distribution by *métier* from 2019 to 2022, with the highest landings obtained with bottom trawlers, especially for lower slope *métier*.

The historical landings per unit of effort (Figure 43) show a relatively constant trend since 2010.

The MEDITS biomass index was available for Catalonia since 1994 and was compared to the ICATMAR biomass index, which is calculated since 2019 (Figure 44). According to the MEDITS index, the biomass was near zero during some years (i.e. 2001 and 2005), with more or less stable biomass in the last five years. However, according to ICATMAR biomass index, the biomass was greater and had a decreasing trend.

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 45. A decrease in bigger individuals is observed whereas there is an increase of the smaller ones.

Model setting and results (LBSPR)

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, 23-07).

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)	k	M	L_{mat50} (mm)	L_{mat95} (mm)
ARA	1	77	0.380	0.46	20.0	23.1
ARA	2	77	0.380	0.46	25.5	29.4
ARA	3	77	0.380	0.46	25.5	27.5

Fitted data

The length frequency distribution fit per year is shown in Figure 46. The model generally follows the mode for all years but overestimates some length classes in the middle mode part.

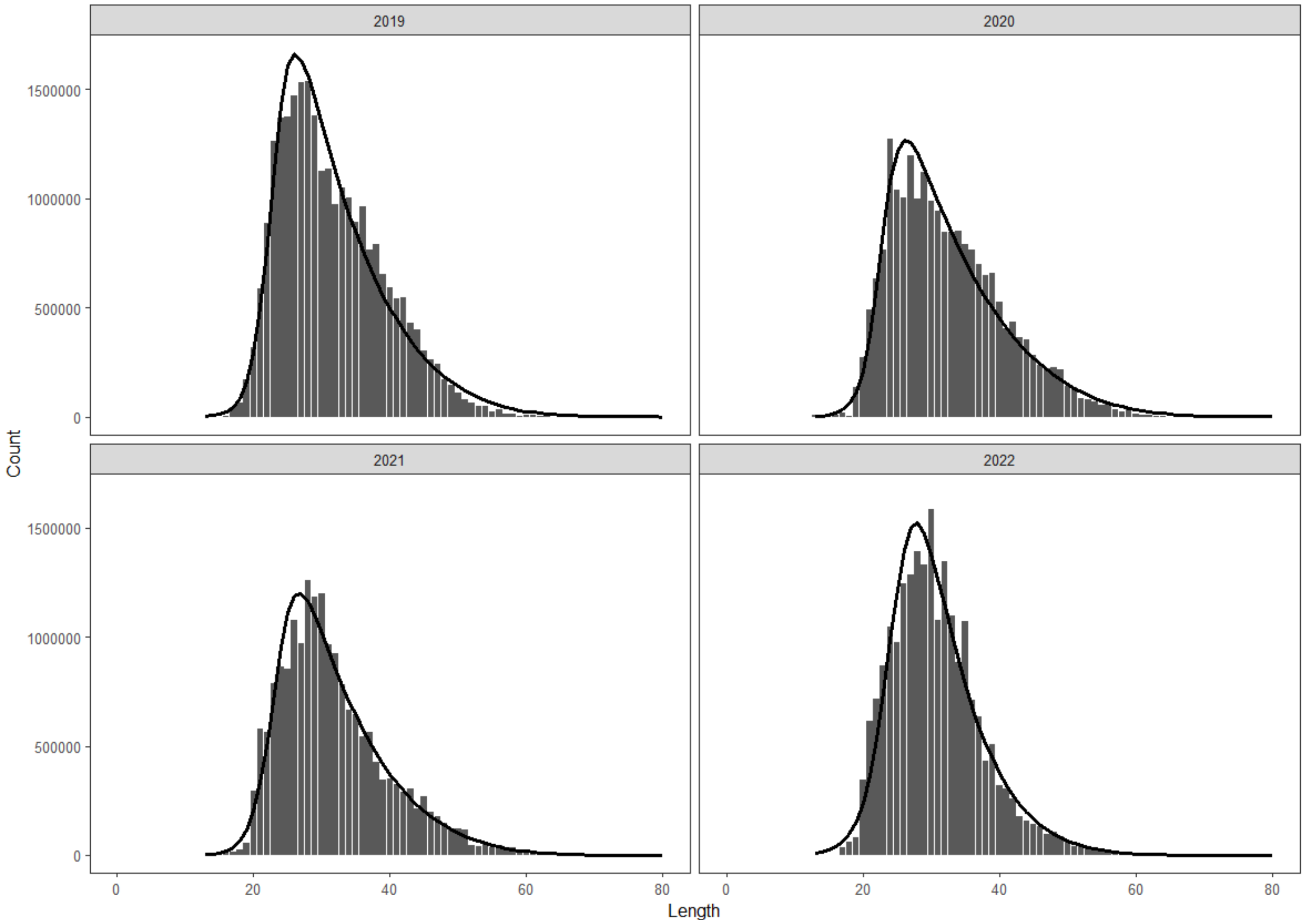

Figure 46. Fit of the data using the LBSPR model for blue and red shrimp for each studied year (2019-2022). Grey columns indicate length frequencies. Black lines indicate the fit of the model.

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 47. Each scenario peovides 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}.

Table 21. Blue and red shrimp (ARA) cephalothorax length (mm) in different studied scenarios (1-3). L_{mat50}: length at 50% maturity. SL50: length at 50% of selectivity resulting from LBSPR outputs in each studied year (2019-2022).

Species	Scenario	L_{mat50}	SL_{50}			
			2019	2020	2021	2022
ARA	1	20	23.09	23.06	23.60	25.15
ARA	2	25.5	23.1	23.07	23.61	25.17
ARA	3	23.51	23.12	23.09	23.64	25.19

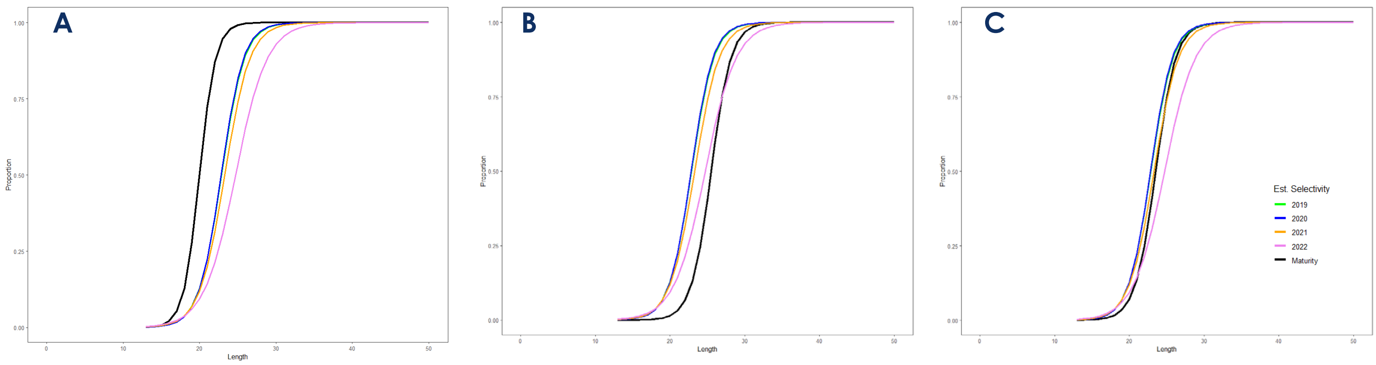

Figure 47. Length curves for blue and red shrimp. Black line shows the length curve at maturity. Color lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (A), scenario 2 (B) and scenario 3 (C).

Table 22. Blue and red shrimp (ARA) estimated values for Spawning Potential Ratio (SPR) and relative fishing mortality (F/M) in each studied year (2019-2022) for each scenario (1-3).

Scenario		SPR				F/M			
Species		2019	2020	2021	2022	2019	2020	2021	2022
ARA	1	0.08	0.10	0.08	0.06	3.39	2.89	3.52	5.02
ARA	2	0.07	0.09	0.07	0.05	3.45	2.94	3.58	5.11
ARA	3	0.07	0.09	0.07	0.05	3.47	2.96	3.61	5.14

Referent points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is below SPR_{lim} (=0.1) and near to SPR_{lim} in 2020 (Table 22). The Kobe plot for blue and red shrimp (Figure 48) 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.

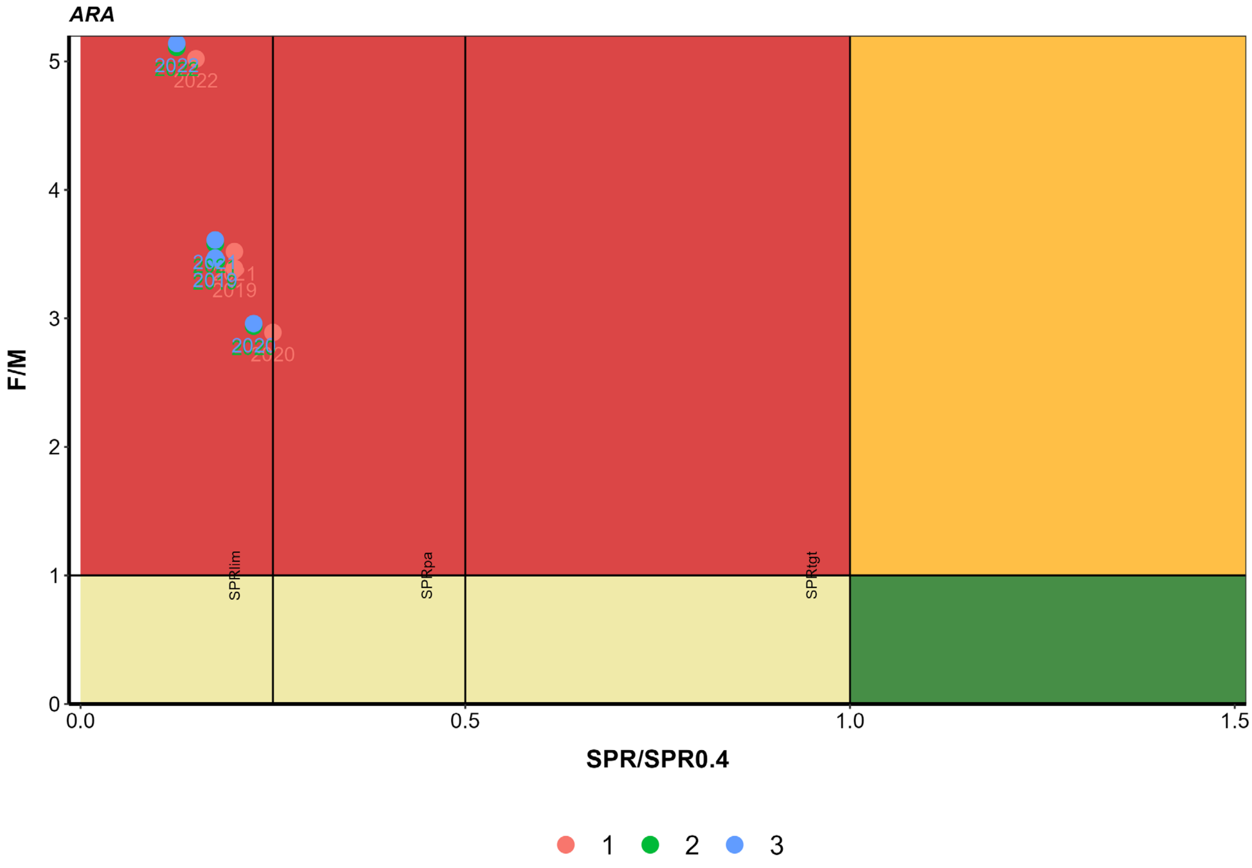

Figure 48. Kobe plot for blue and red shrimp by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{pa}: precautory aproach spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

European sardine (*Sardina pilchardus*) PIL

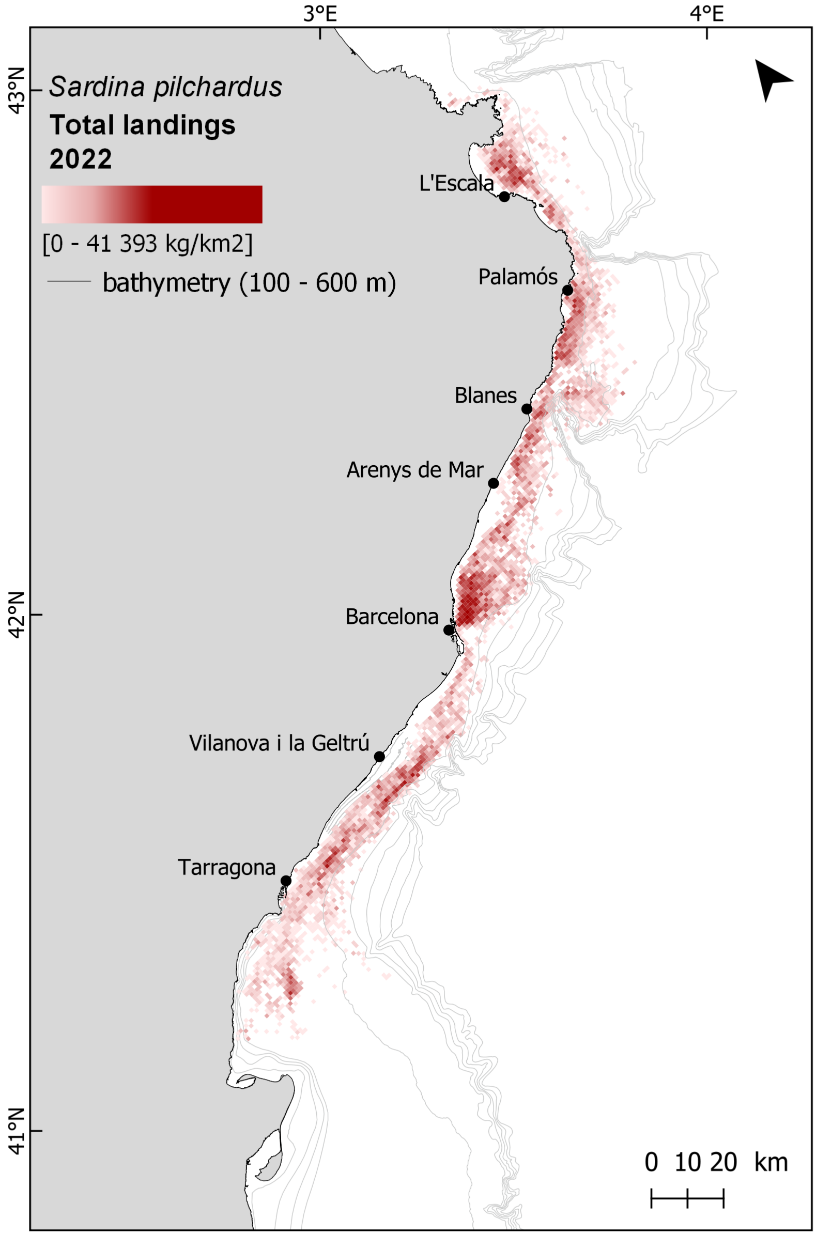

Figure 49. Spatial distribution of total landings for European sardine in the Catalan fishing grounds (N GSA6) in 2022.

The reproduction of the European sardine occurs between November and February (ICATMAR, 23-07), 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 49) 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 2022 are shown in Figure 50. The total catch peaked in 2007 with a great decrease from 2008 to 2010. Afterwards, the landings remained more or less stable.

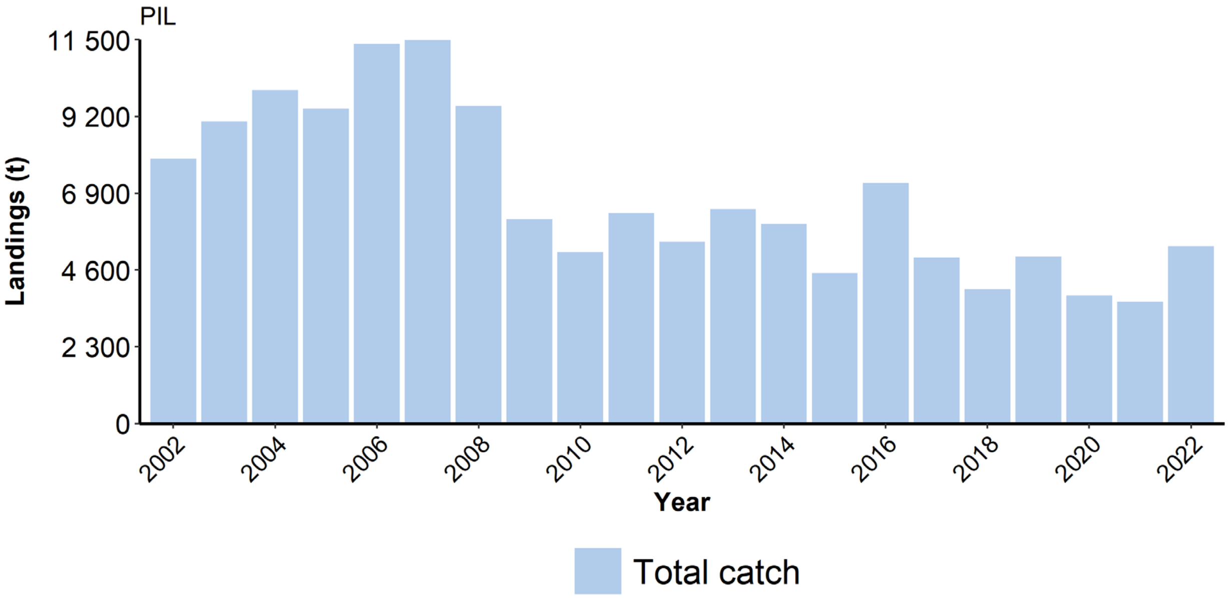

Figure 50. Landings (t) for European sardine in Catalonia from 2002 to 2022.

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 51. The size classes with greater frequencies are about 125 - 130 mm in total length.

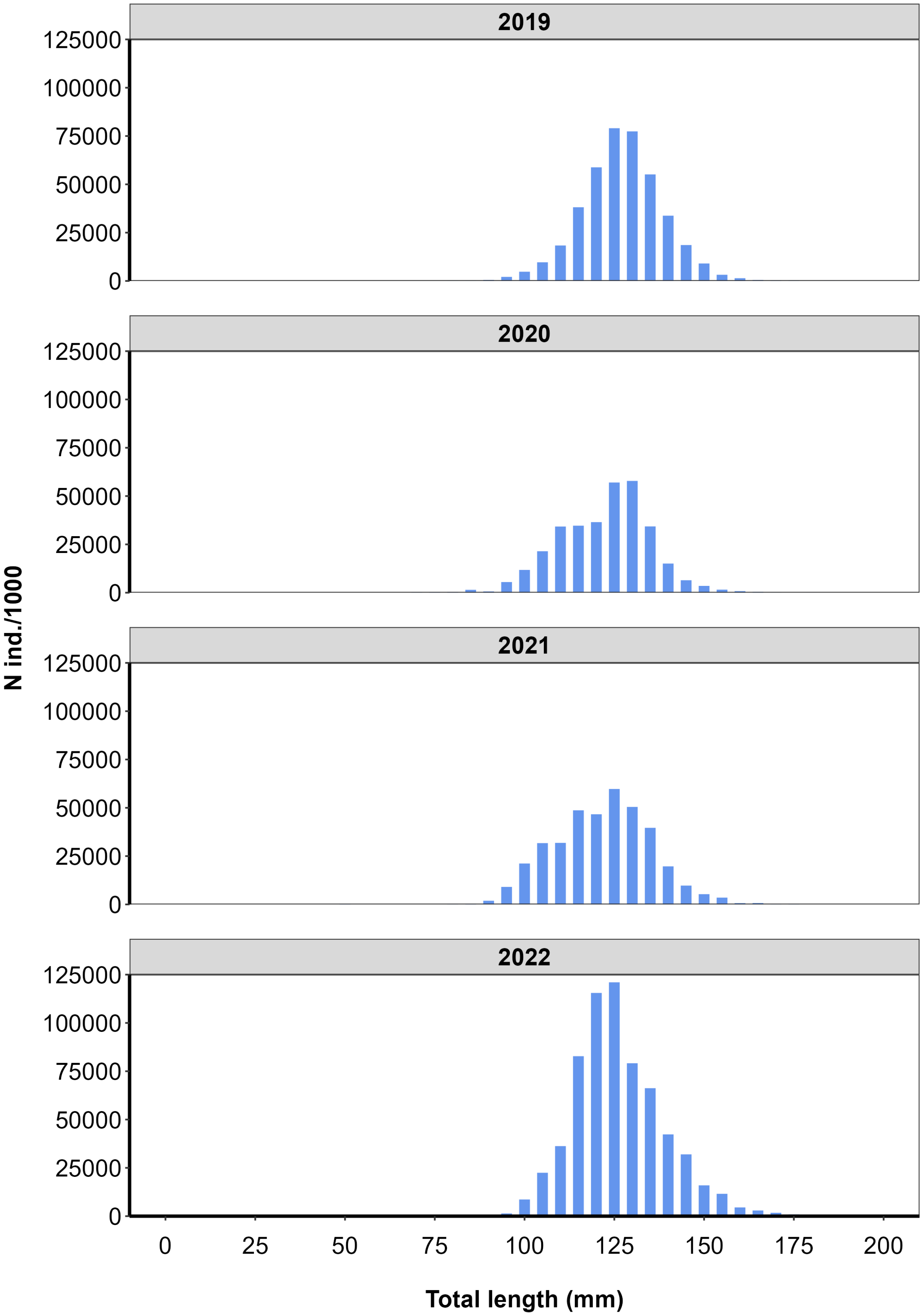

Figure 51. Annual length frequency distributions of European sardine from purse seining. The data is raised from ICATMAR data.

Table 23. Number of European sardine individuals sampled with purse seiners by zone and season using both ICATMAR monitoring data (on board) and commercial landing (fish markets) used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N on board samplings
			Number individuals sampled				
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 (on board)	2022	North	581	497	750	11	17
Purse seine (on board)	2022	Center	0	267	193	0	4

Model setting and results (LBSPR)

Scenarios

Six scenarios were applied considering different growth parameters and natural mortality from GFCM working groups (Table 24). In scenarios 5 and 6, L_{mat50} correspond to ICATMAR data (ICATMAR, 23-07).

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	L_{inf} (mm)	k	M	L_{mat50} (mm)	L_{mat95} (mm)
PIL	1	184	0.512	0.70	113	135
PIL	2	209	0.472	0.70	112	133
PIL	3	184	0.512	0.70	112	133
PIL	4	209	0.472	0.70	113	135
PIL	5	184	0.512	0.70	107.8	128.3
PIL	6	209	0.472	0.70	107.8	128.3

Fitted data

The length frequency distribution fit per year is shown in Figure 52. 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.

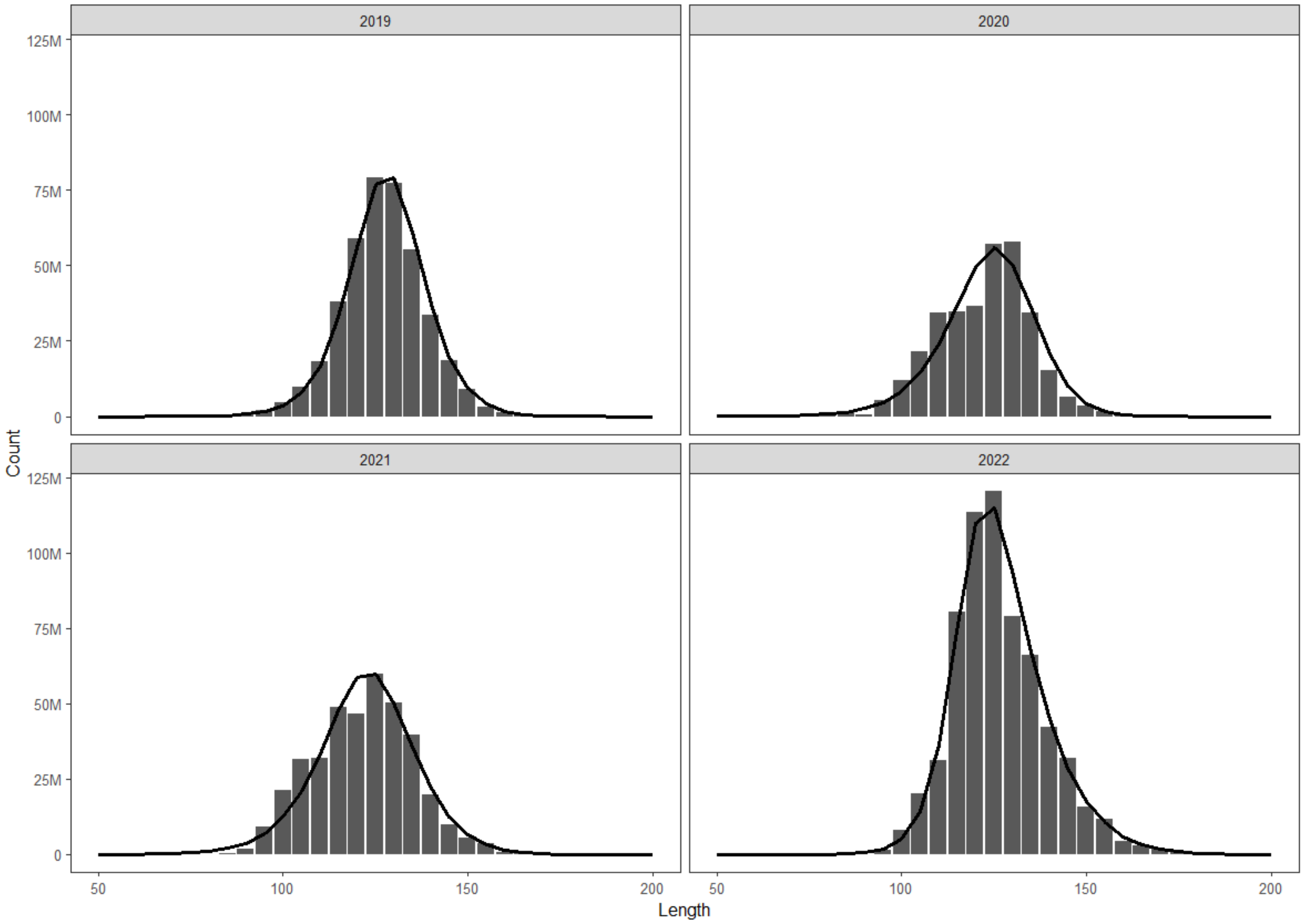

Figure 52. Fit of the data using the LBSPR model for European sardine for each studied year (2019-2022). Grey columns indicate length frequencies. Black lines indicate the fit of the model.

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 5 in Figure 53. In all scenarios, the fishery is fishing above or similar to L_{mat50}.

Table 25. European sardine (PIL) length (mm) in different studied scenarios (1-6). L_{mat50}: length at 50% maturity. SL_{50}: length at 50% of selectivity resulting from LBSPR outputs in each studied year (2019-2022).

Species	Scenario	L_{mat50}	SL_{50}			
			2019	2020	2021	2022
PIL	1	113	126.67	128.01	123.01	118.35
PIL	2	112	126.75	128.12	123.42	118.60
PIL	3	112	126.74	128.11	123.18	118.41
PIL	4	113	126.73	128.10	123.38	118.57
PIL	5	107,8	126.67	128.02	123.07	118.36
PIL	6	107,8	126.74	128.10	123.40	118.59

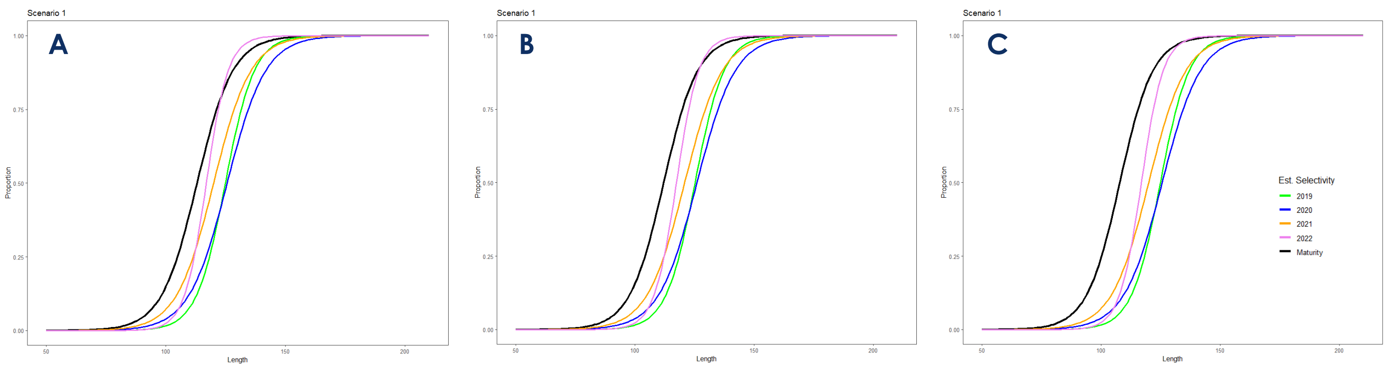

Figure 53. Length curves for European sardine. Black line shows the length curve at maturity. Color lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (A), scenario 2 (B) and scenario 5 (C).

Table 26. European sardine (PIL) estimated values for Spawning Potential Ratio (SPR) and relative fishing mortality (F/M) in each studied year (2019-2022) for each scenario (1-3).

Scenario		SPR				F/M			
Species		2019	2020	2021	2022	2019	2020	2021	2022
PIL	1	0.22	0.19	0.19	0.24	7.09	9.77	6.51	3.70
PIL	2	0.15	0.12	0.13	0.16	9.31	12.63	8.59	5.03
PIL	3	0.22	0.18	0.19	0.24	7.24	9.97	6.65	3.78
PIL	4	0.15	0.12	0.13	0.16	9.30	12.62	8.59	5.02
PIL	5	0.24	0.20	0.20	0.25	7.25	9.98	6.66	3.08
PIL	6	0.16	0.14	0.14	0.17	9.30	12.62	8.59	5.02

Referent points

Even though the model is very sensitive to changes in growth parameters and maturity, the stock is below SPR_{tgt} (=0.4) (Table 26). For scenarios 2, 4 and 5, the stock is between SPR_{lim} and SPR_{pa}. For scenarios 1 and 3, the stock is around SPR_{pa}. For scenario 5, the stock has the same value or is above SPR_{pa}, depending on each year. The Kobe plot for European sardine (Figure 54) 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.

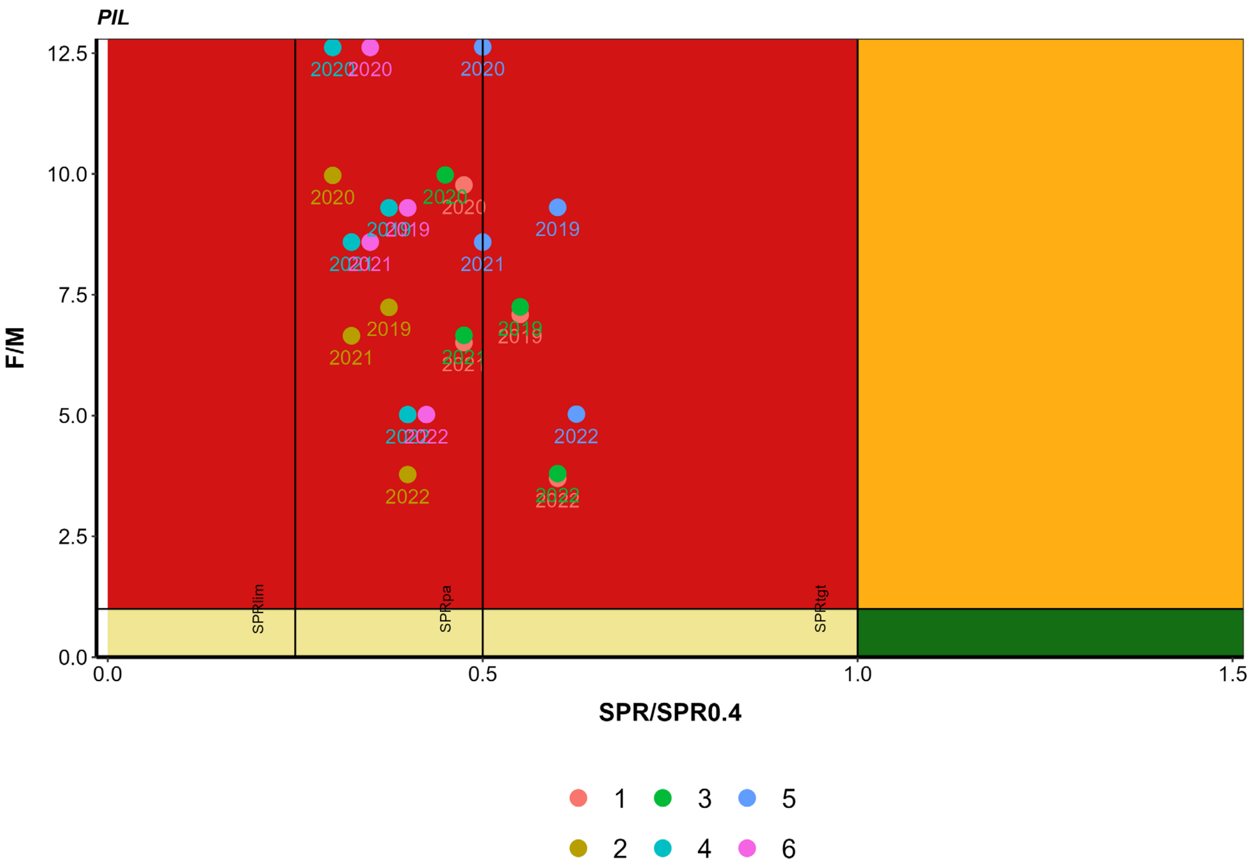

Figure 54. Kobe plot for European sardine by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{pa}: precautory aproach spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

Anchovy (*Engraulis encrasicolus*) ANE

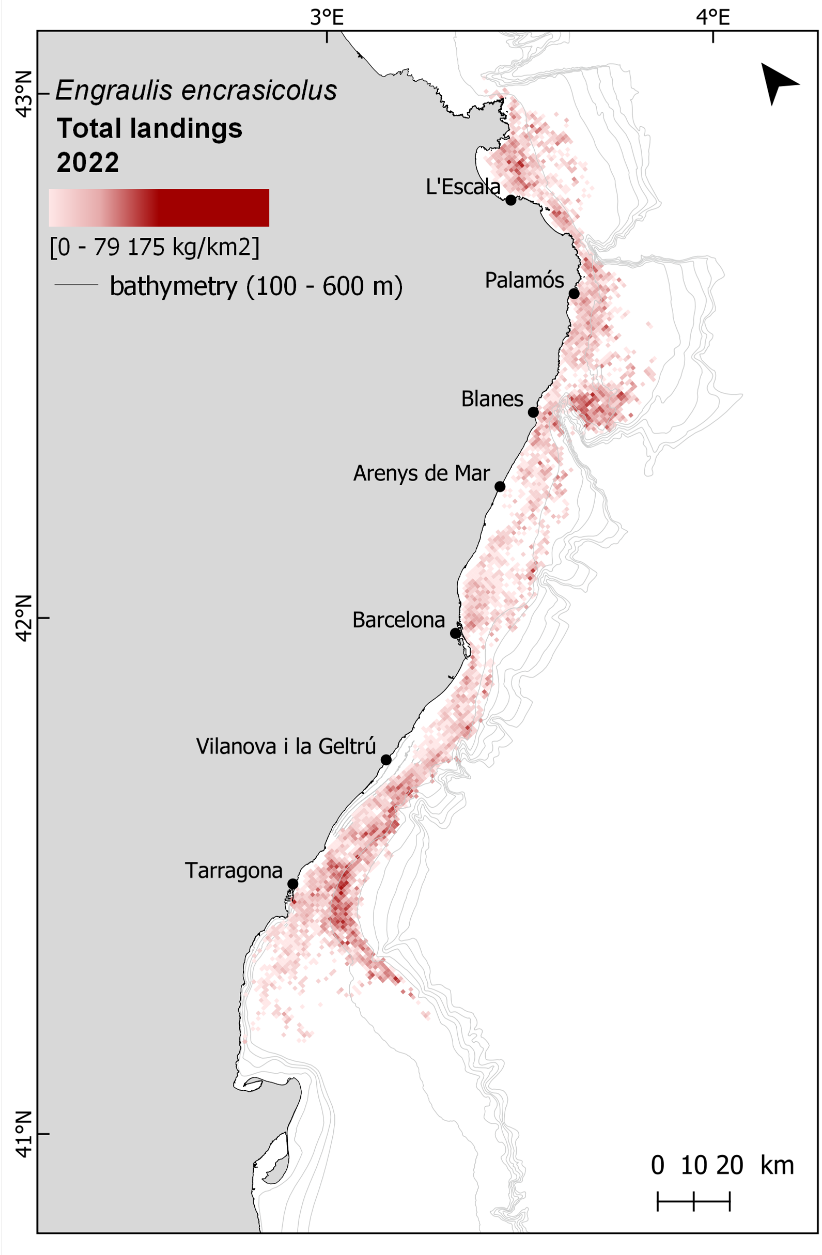

Figure 55 Spatial distribution of total landings for anchovy in the Catalan fishing grounds (N GSA6) in 2022.

The reproduction of the European anchovy occurs between May and September (ICATMAR, 23-07), and recruitment is observed afterwards, in autumn and winter.

Input data

The spatial distribution of total landings for anchovy in the Catalan fishing grounds (Figure 55) 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 2022 are shown in Figure 56. From 2002 to 2008, there was a decrease in landings. Afterwards, the landings increased until 2018, when they inverted the trend and decreased again.

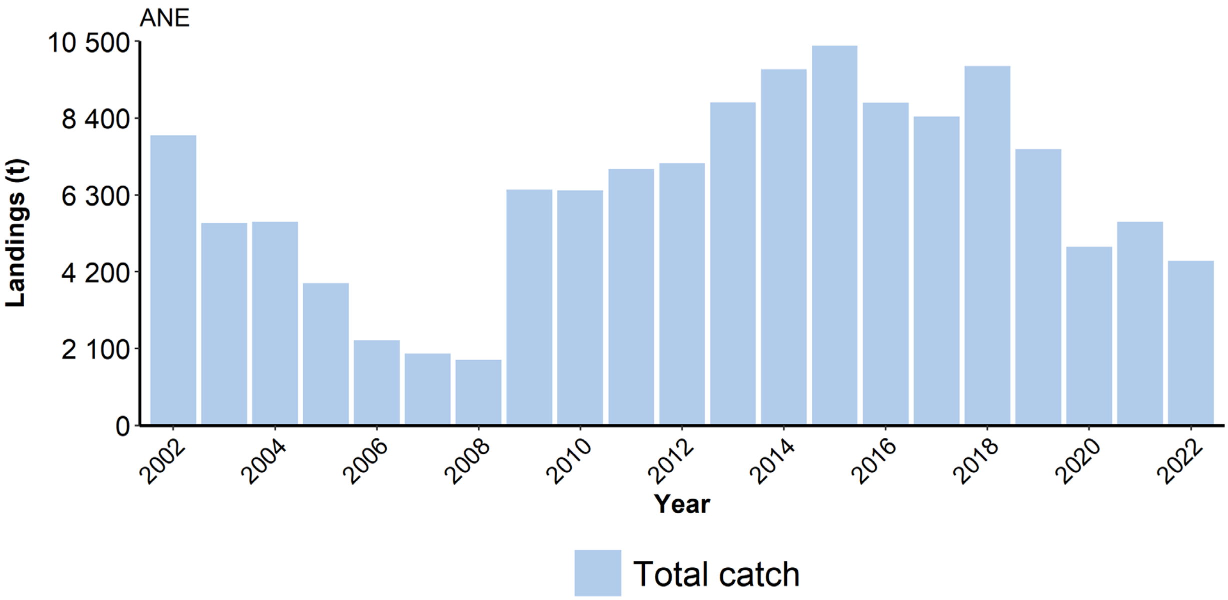

Figure 56 Landings (t) for anchovy in Catalonia from 2002 to 2022.

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 57. 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.

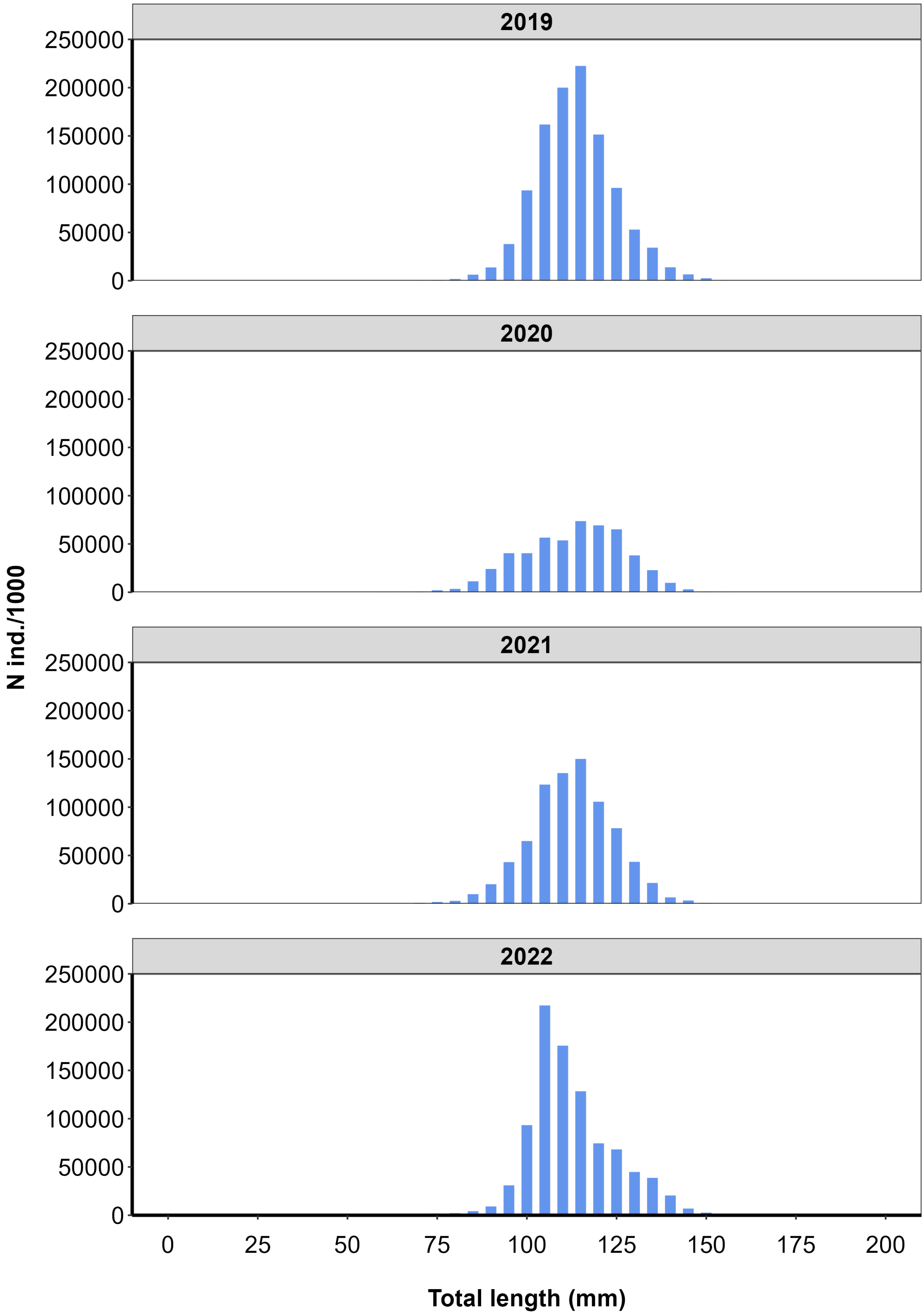

Figure 57. Annual length frequency distributions of anchovy from purse seining. The data is raised from ICATMAR data.

Table 27. Number of anchovy individuals sampled with purse seiners by zone and season using both ICATMAR monitoring data (on board) and commercial landing (fish markets) used to raise the length frequencies.

Fishery	Year	Zone	Winter	Spring	Summer	Autumn	N on board samplings
			Number individuals sampled				
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 (on board)	2022	North	1755	153	939	573	15
Purse seine (on board)	2022	Center	430	383	471	834	9

Model setting and results (LBSPR)

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, 23-07).

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	L_{inf} (mm)	k	M	L_{mat50} (mm)	L_{mat95} (mm)
ANE	1	155	0.533	0.76	99	117
ANE	2	155	0.533	0.76	96	114
ANE	3	155	0.533	0.76	97	113

Fitted data

The length frequency distribution fit per year is shown in Figure 58.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.

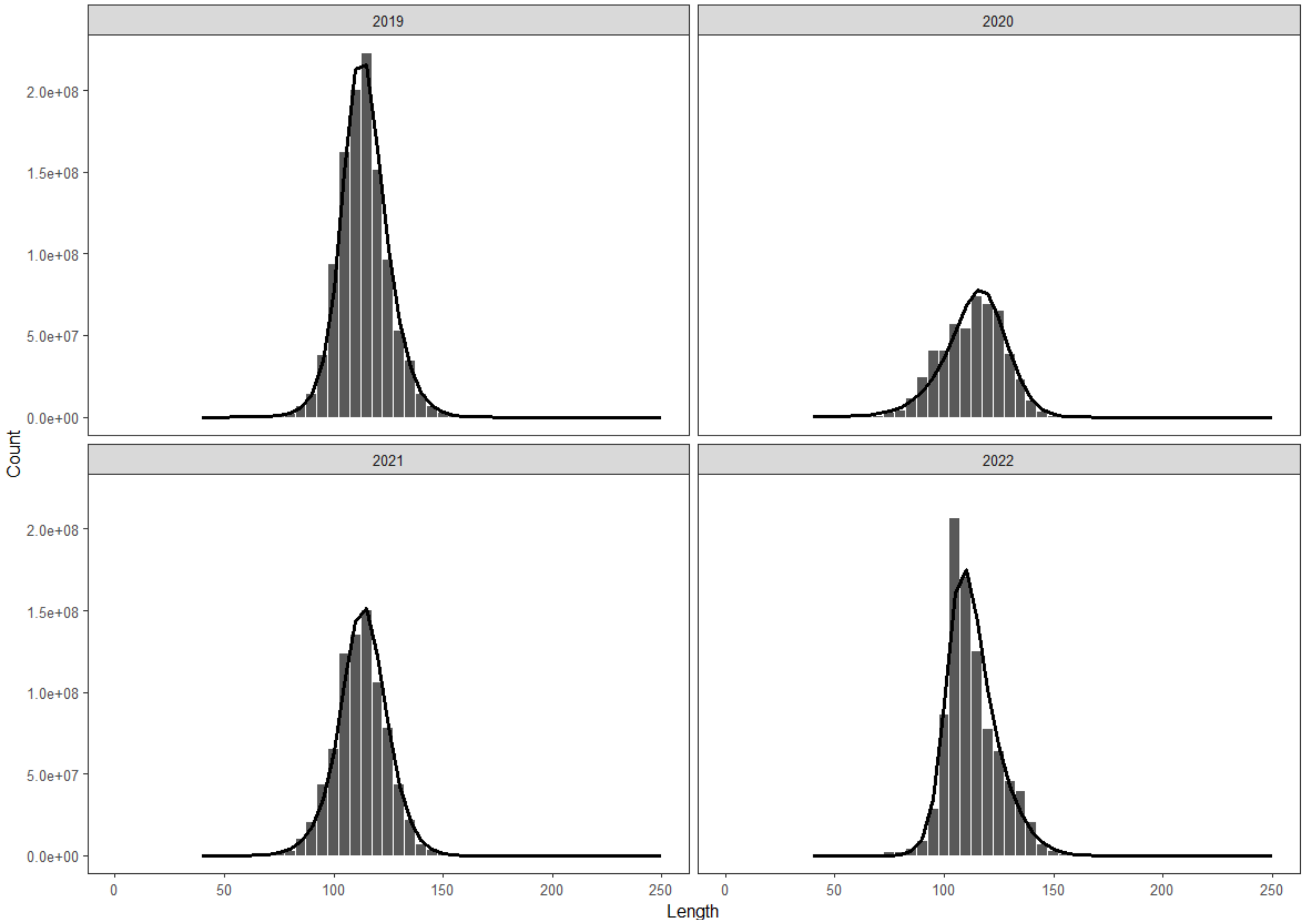

Figure 58. Fit of the data using the LBSPR model for anchovy for each studied year (2019-2022). Grey columns indicate length frequencies. Black lines indicate the fit of the model.

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 59. In all scenarios, the fishery is fishing above or similar to L_{mat50}.

Table 29. Anchovy (ANE) length (mm) in different studied scenarios (1-6). L_{mat50}: length at 50% maturity. SL_{50}: length at 50% of selectivity resulting from LBSPR outputs in each studied year (2019-2022).

Species	Scenario	L_{mat50}	SL_{50}			
			2019	2020	2021	2022
ANE	1	99	109.67	122.72	112.95	103.36
ANE	2	96	107.79	117.86	110.43	102.24
ANE	3	97	109.65	122.63	112.91	103.36

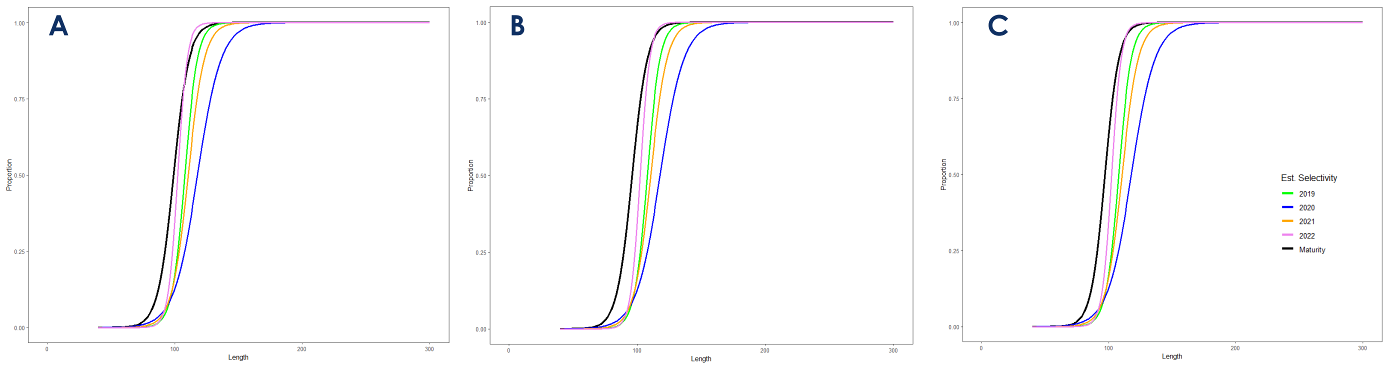

Figure 59. Length curves for anchovy. Black line shows the length curve at maturity. Color lines show the estimated selectivity at length curve predicted by the LBSPR model for each year in scenario 1 (A), scenario 2 (B) and scenario 5 (C).

Table 30. Anchovy (ANE) estimated values for Spawning Potential Ratio (SPR) and relative fishing mortality (F/M) in each studied year (2019-2022) for each scenario (1-3).

		SPR				F/M			
Species		2019	2020	2021	2022	2019	2020	2021	2022
ANE	1	0.31	0.32	0.30	0.33	3.82	6.81	5.02	2.38
ANE	2	0.32	0.33	0.30	0.34	3.90	6.99	5.12	2.43
ANE	3	0.33	0.34	0.31	0.35	3.79	6.76	4.99	2.37

Referent 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 2022 (Table 30). The Kobe plot for anchovy (Figure 60) 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.

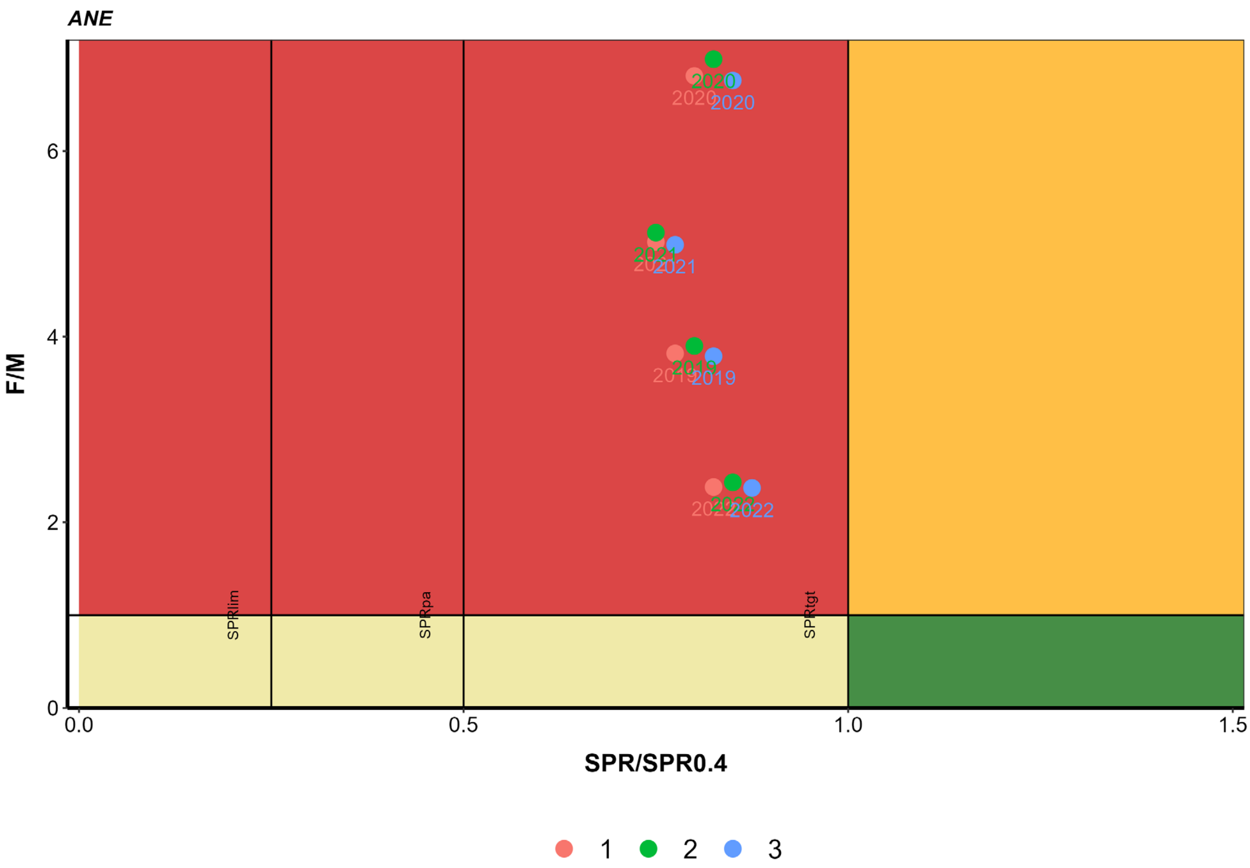

Figure 60. Kobe plot for anchovy by scenario (1-3) and year. SPR_{lim}: limit spawning potential ratio, SPR_{pa}: precautory aproach spawning potential ratio, SPR_{tgt}: target spawning potential ratio, F: fishing mortality, M: natural mortality, and F/M: relative fishing mortality.

SECTION 4
Conclusions and comments

Methodological Remarks

This report is improved from the previous one because new methodologies were used. These methodologies include the use of machine learning to assign *métiers* to landings in 2022, a script to raise the LFD along with discard data, and new data available including nominal CPUE, biomass index (MEDITS and ICATMAR data) and the calculation of L_{mat50} with ICATMAR data for some species.

LBSPR, a length-based method, was chosen to perform the stock assessment for the MAP species, and sardine and anchovy were also evaluated for the first time with ICATMAR's data. However, 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 live 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.

In LBSPR, SPR estimation is conditioned to the L_{mat50} parameter and FM estimations to growth parameters, meaning that the model could be unstable. Also, the M/K ratio could affect the importance of the adult's contribution.

SPICT, a surplus production model, was applied for hake to test the influence of a long time series of data, such as landings and biomass index. SPICT does not consider length structure but biomass. Therefore, the model cannot consider if the population is more or less truncated. On the other hand, the advantage of this model is the possibility of using the landings time series, which is much longer and allows to have a wider view of the history of the species.

The results for SPiCT need to be considered as work in progress, which is why no advice can be given based on them. Subsequent work will explore working with longer index time series as well as the potential use of other indices.

Different sensitivity analyses were applied for both LBSPR and SPICT because the models had assumptions and limitations, and the uncertainty was considered in the calculations.

Conclusions

Different scenarios were performed for each species (scenarios with both bibliographic biological parameters and updated values calculated from the ICATMAR data collection in the area assessed). The model results vary greatly highlighting the importance to re-estimate biological parameters of the species to have up-to-date data and obtain more realistic results (ICATMAR, 23-09).

The advice drawn from these models should be considered as qualitative, with the stocks being overexploited in all cases. Despite some stocks seem to have improved their status, others are nearby to SPR_{pa} and SPR_{tgt} referent points. In detail, SPRs for red mullet (MUT), hake (HKE) and blue and red shrimp (ARA) are under $B_{lim;}$ whereas deep-water rose shrimp (DPS), Norway lobster (NEP), European sardine (PIL), and anchovy (ANE) SPRs are above B_{lim}.

The monitoring program will continue to reach long-term data collection and be able to apply more complex models, such as integrated stock assessment models (i.e. stock synthesis model SS3).

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Annexes

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.

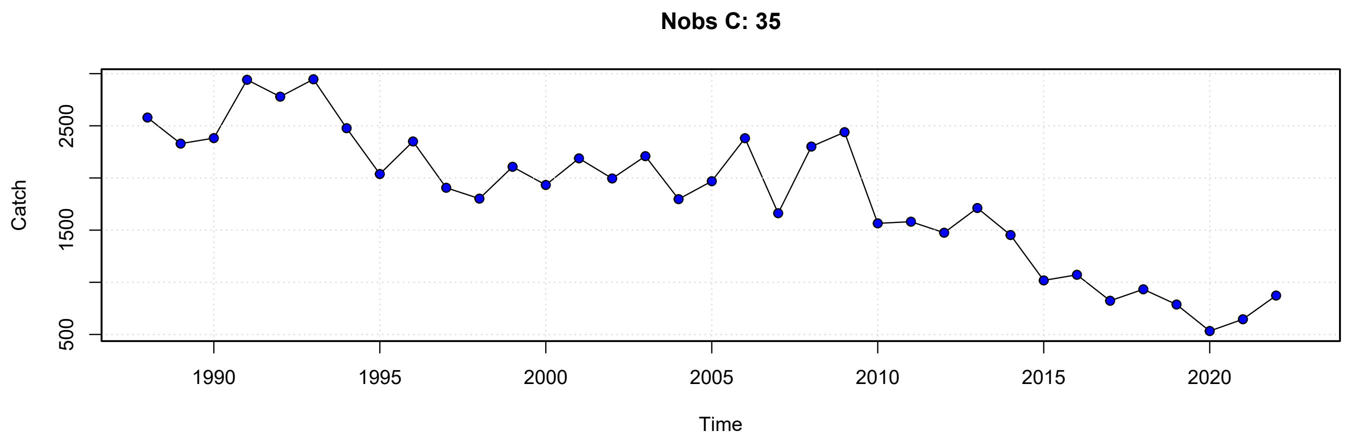
The SPiCT model can reference points with uncertainties and includes observation error and process errors.

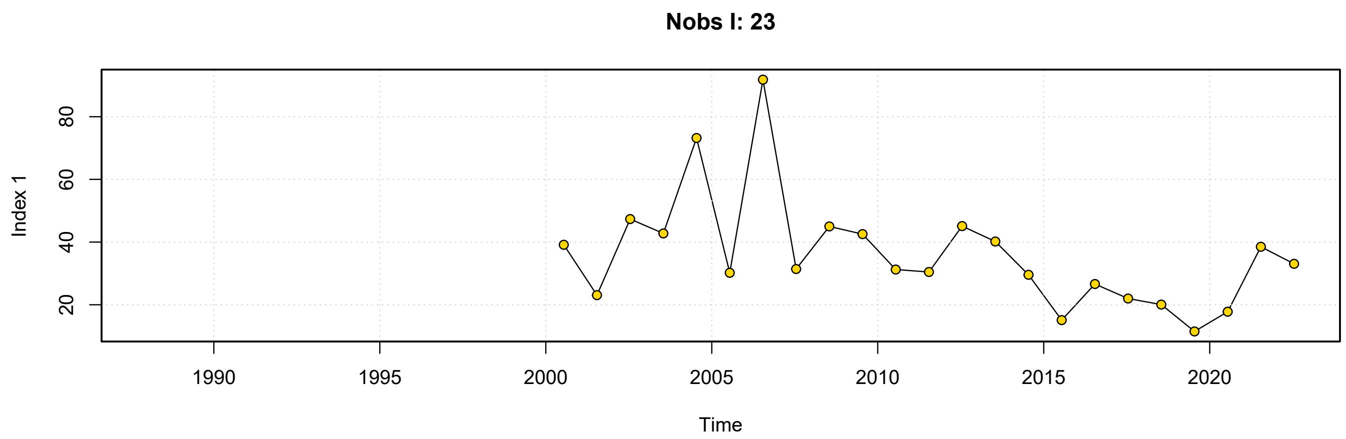
Hake assessment

The input data used consisted on landing data and biomass estimated from surveys as tuning indexes. Some priors were also used to run the model. A variety of scenarios combining the different input data were tested to assess the sensitivity of the model.

Data and parameters

The input data (Annex 1) consisted on a landings time series from 1988 onwards and a biomass index to tune the model. The data for the biomass index was derived from MEDITS bottom trawl survey from 2000.





Annex 1. Input data for SPiCT model for hake. Top: catch in tones per year since 1988 and bottom: index data of biomass derived from MEDITS since 2000.

Scenarios

Multiple scenarios were tested, including those with the combinations of different lengths for landing time series, different priors, and prior's values.

Landings data:

- Series from 1988
- Serie from 2000

Index data:

- Biomass data from MEDITS survey
- Biomass data from ICATMAR survey

Priors:

- Observation error in catch
- Observation error in indices
- Population growth
- Depletion prior
- Shape of the production curve
- Process error
- Error in fishing mortality

After all the analyses, a single scenario could not be chosen. Despite that the model seemed to be stable, it showed sensibility to the decision of BKfrac prior value, which informs of the depletion level of the stock right before the beginning of the time series in 1988. It is assumed that BKfrac value should be lower than 0.5 (stock depletion level of 50% or higher). However, it is not possible to assure an exact depletion level before the time series. Hence, the decision was to choose three scenarios with a range of depletion value greater than 50% (70%, 60% and 50%, BKfrac values of 0.3, 0.4 and 0.5, respectively). From here on, the scenario presented in the main text is the one assuming 60% of depletion (Scenario 2, BKfrac 0.4) before the time series. The results for the other two scenarios are in figures from Annex 12.

Model performance

The main settings of the SPiCT model include catch error (0.05), process error (0.15), observation error (0.3) for the index, B/K fraction (0.3, 0.4, 0.5 depending on scenario), logn (2) to resemble the Schaefer production model and r (0.16 from FishLife hierarchical life-history metanalysis).

The chosen scenario met most of the model diagnostics (Annex 2 & Annex 3), even though the catch series failed to meet one-step-ahead residual, because fishery is essentially not random. The model provided good retrospective analysis (Annex 4) and hindcasting diagnostics (Annex 5).

Results

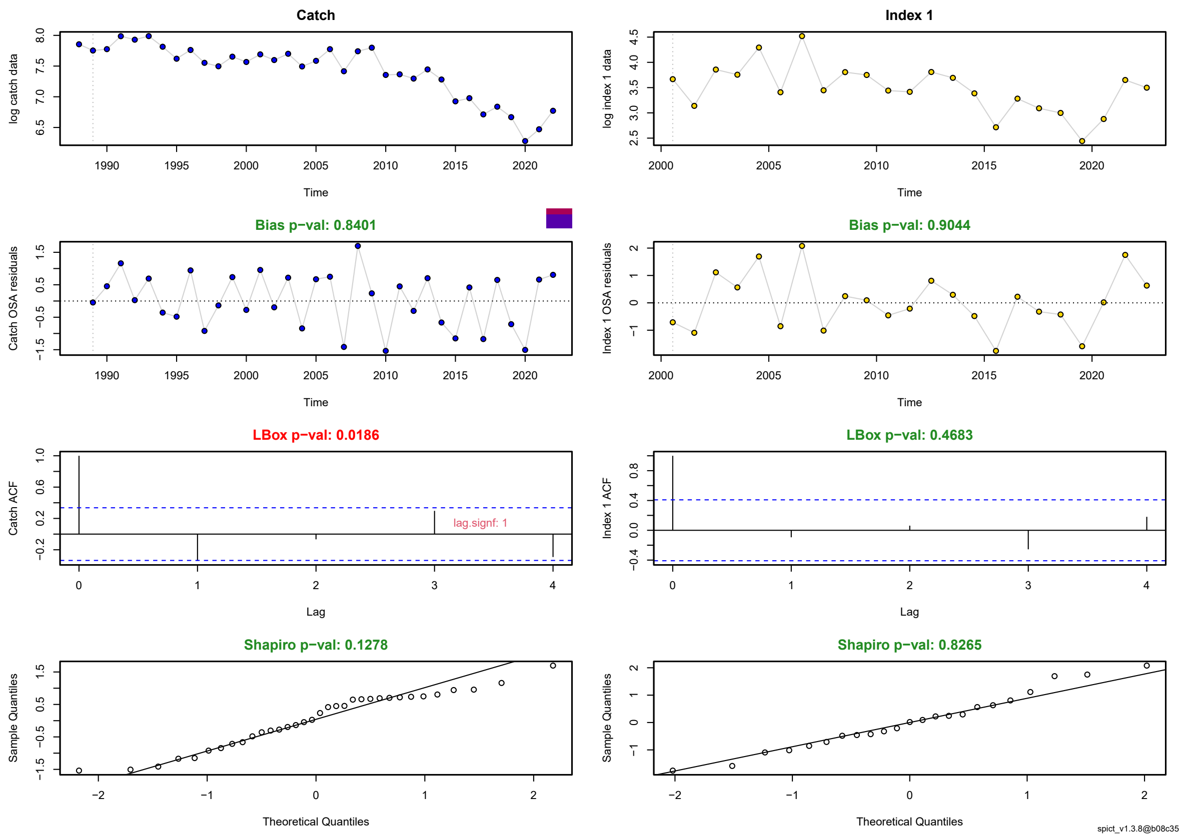
Annex 6 shows that the biomass is found under the reference point throughout all the time series. Likewise, fishing mortality was found above the reference point, except in 2020, when it was located under the reference point. A decreasing trend of the catches can be seen from the beginning of the time series, presenting values under the MSY in nearly all the data points.

<u>Diagnosis of stock status</u>: the stock is considered in overexploitation (Annex 8, Annex 9 & Annex 10).

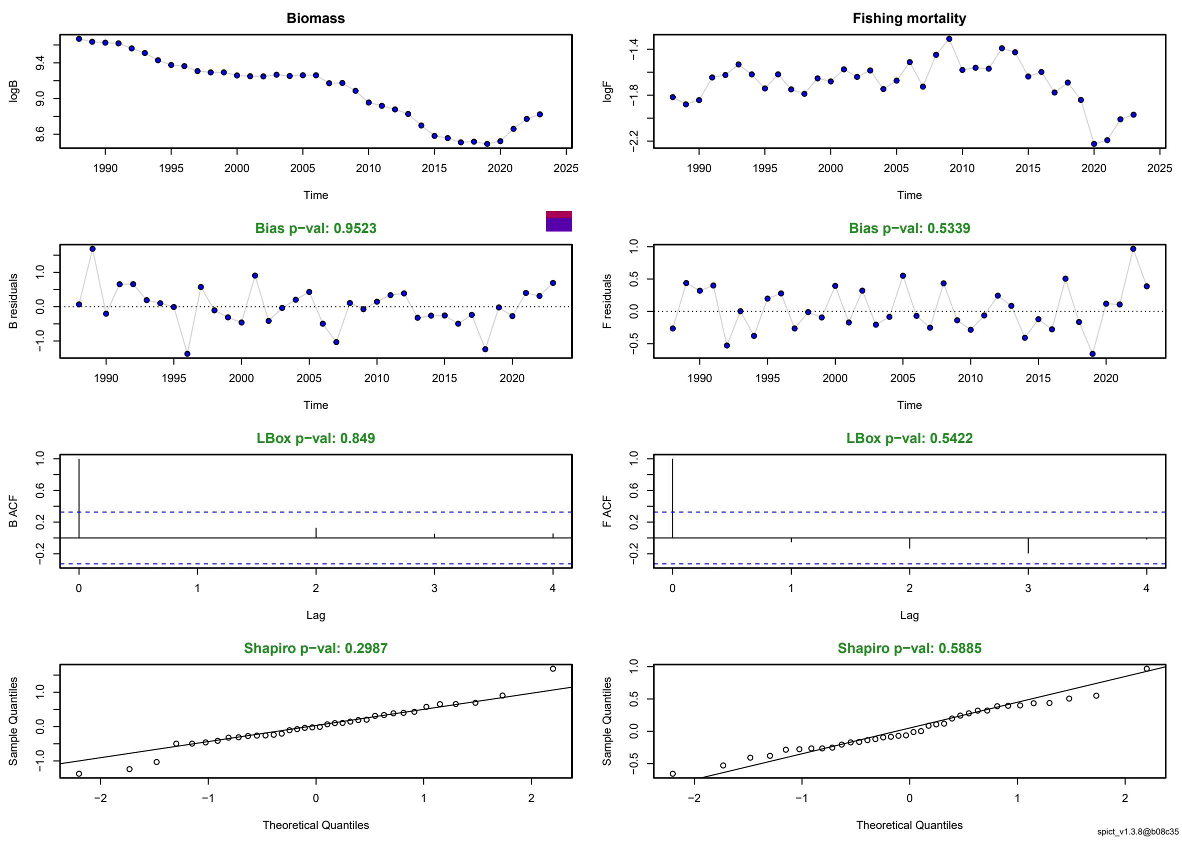
As seen in Table 7 and Annex 8, Annex 9 and Annex 10, in two of the three scenarios (scenarios 2 and 3), the biomass is above B_{lim}, whereas the other one (scenario 1) has a biomass value slightly under the B_{lim}. As commented before, these variations in biomass are caused by the different values tested for BKfrac prior, which informs on the depletion level of the stock before the starting year of the time series used in the model.

Comparative plot

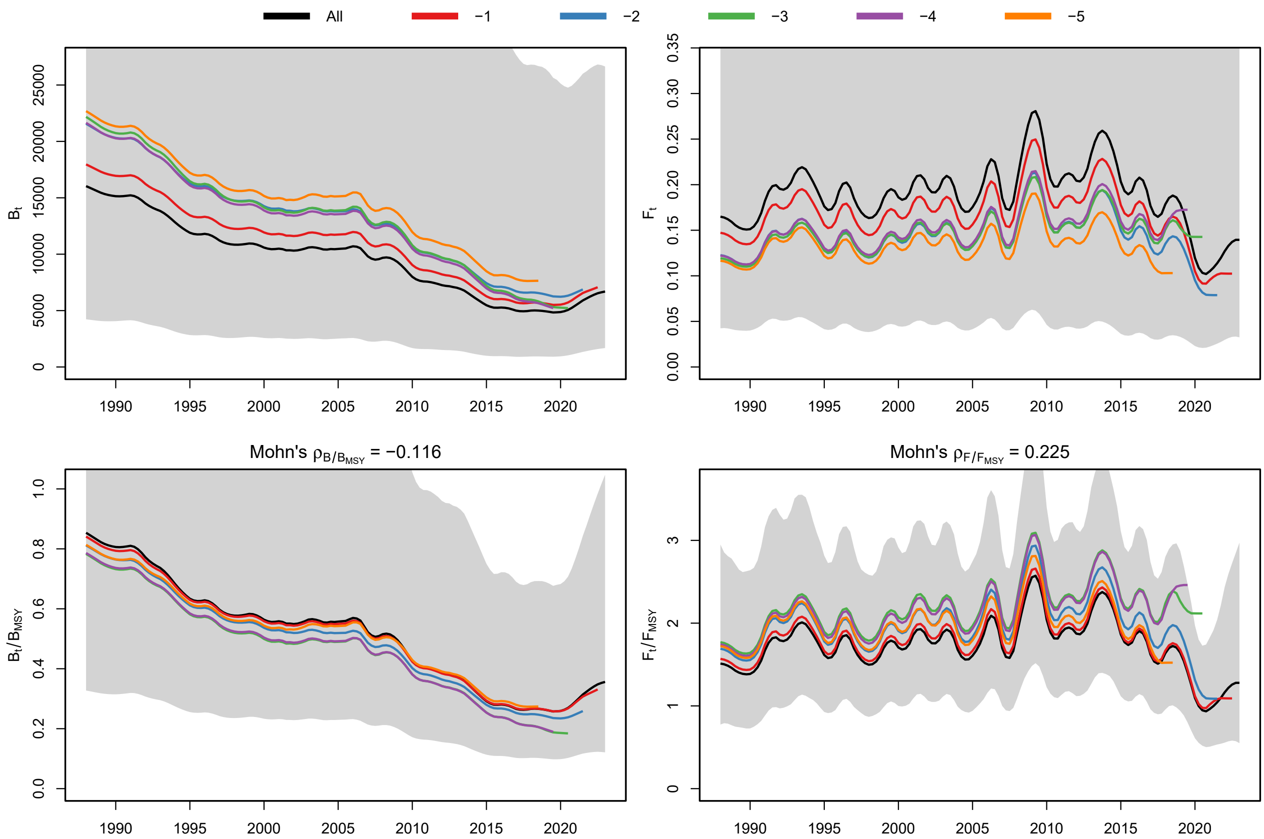
The comparison of chosen scenarios can be seen in Annex 11. Overall, the estimates for the three scenarios follow the same patter. However, some differences can be seen on relative biomass and fishing mortality values, hence, exposing the sensitivity of the model in front of different values of BKfrac.



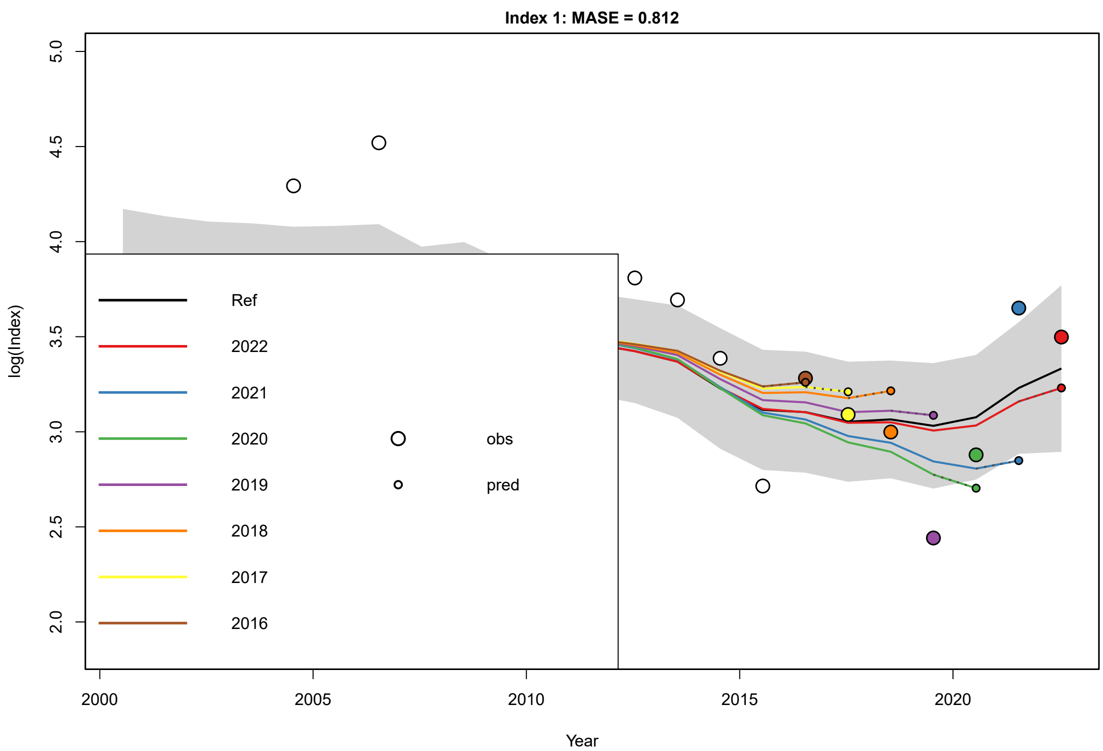
Annex 2. One-step-ahead residuals for the model.



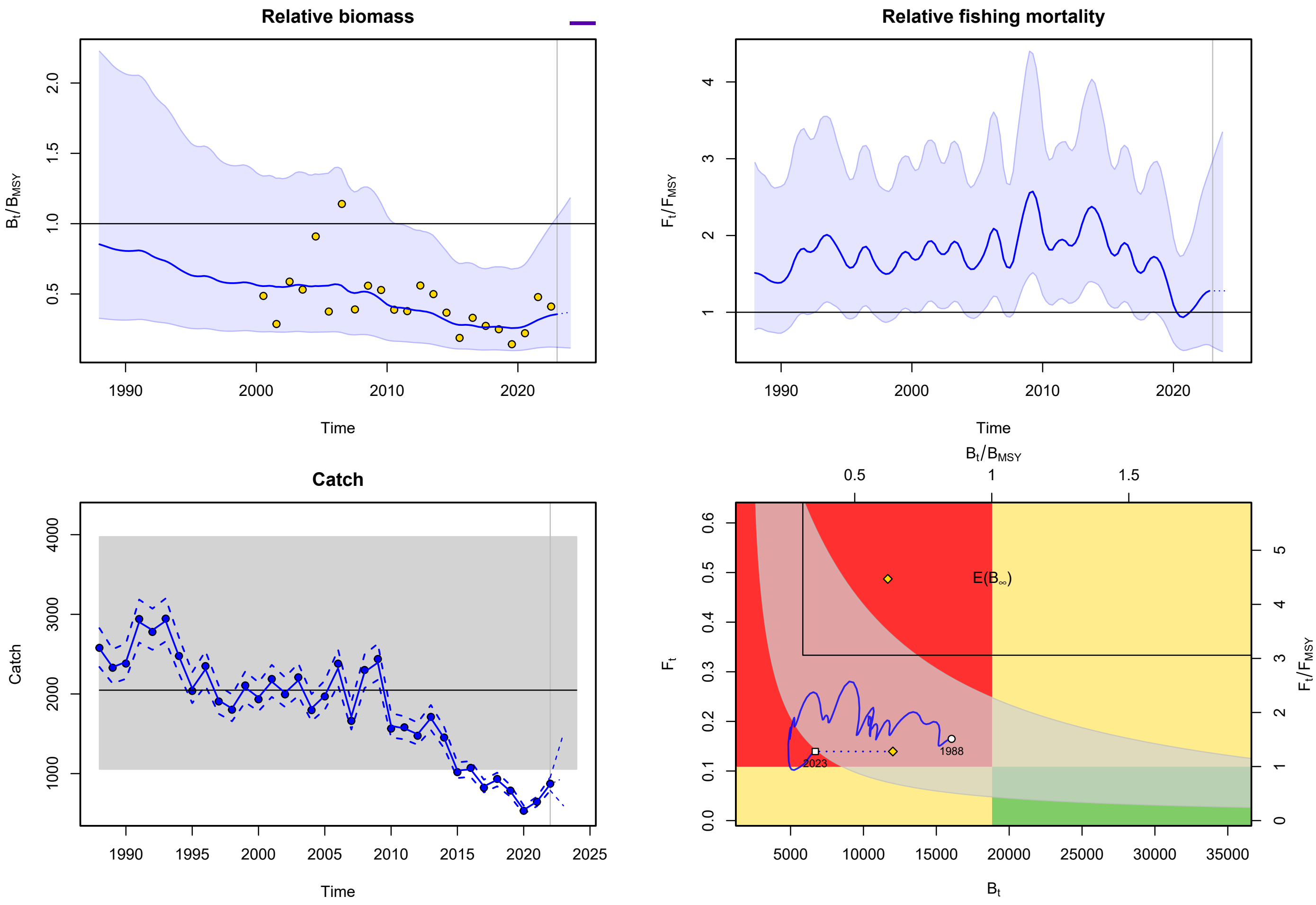
Annex 3. Process error deviations for the model.



Annex 4. Retrospective analysis.



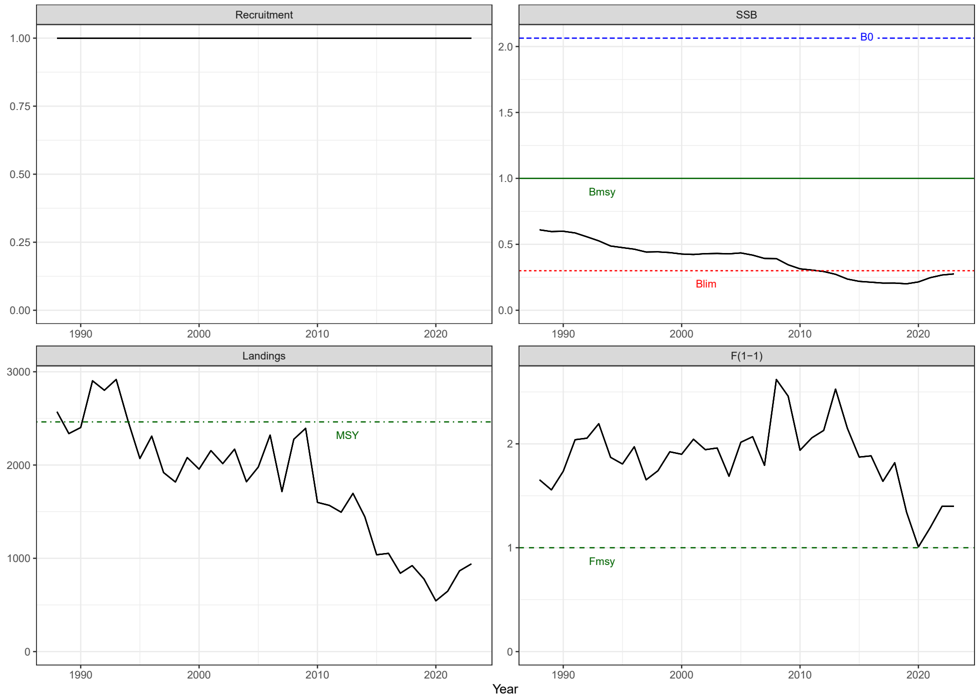
Annex 5. Hindcasting for the model.



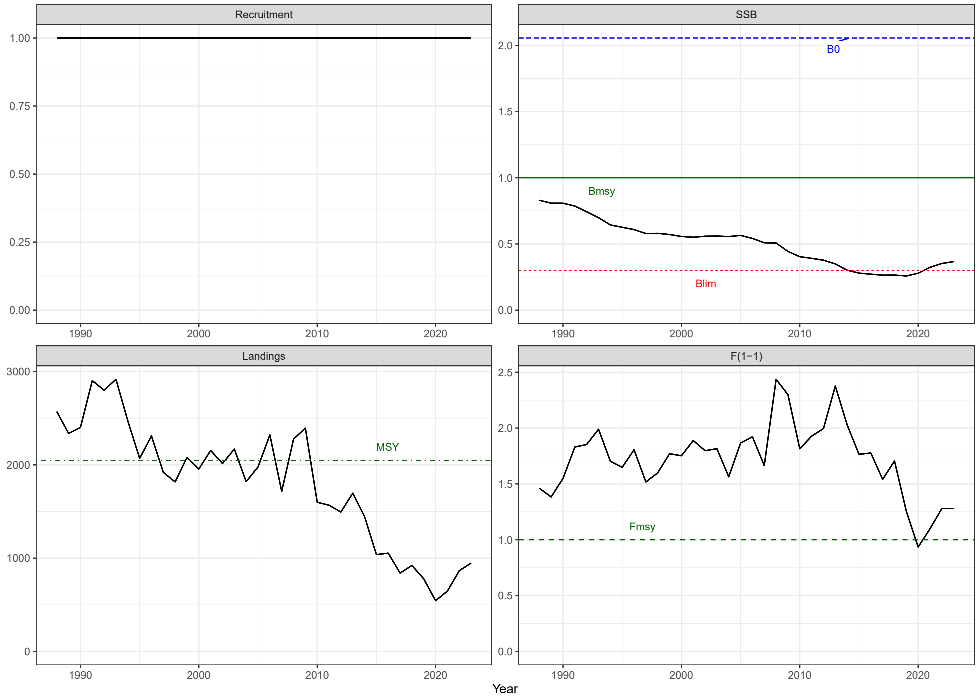
Annex 6. Stock assessment summary for hake by SPiCT model.

Annex 7. Summary table with stock status for hake considering F_{target}, B_{target}, $B_{threshold}$ and B_{limit} and $F_{current}$ and $B_{current}$ for the reference year 2022. Status of the stock and advice are based on the framework for describing stock status and providing management advice in relation to reference points by the General Fishery Commission for the Mediterranean (GFCM).

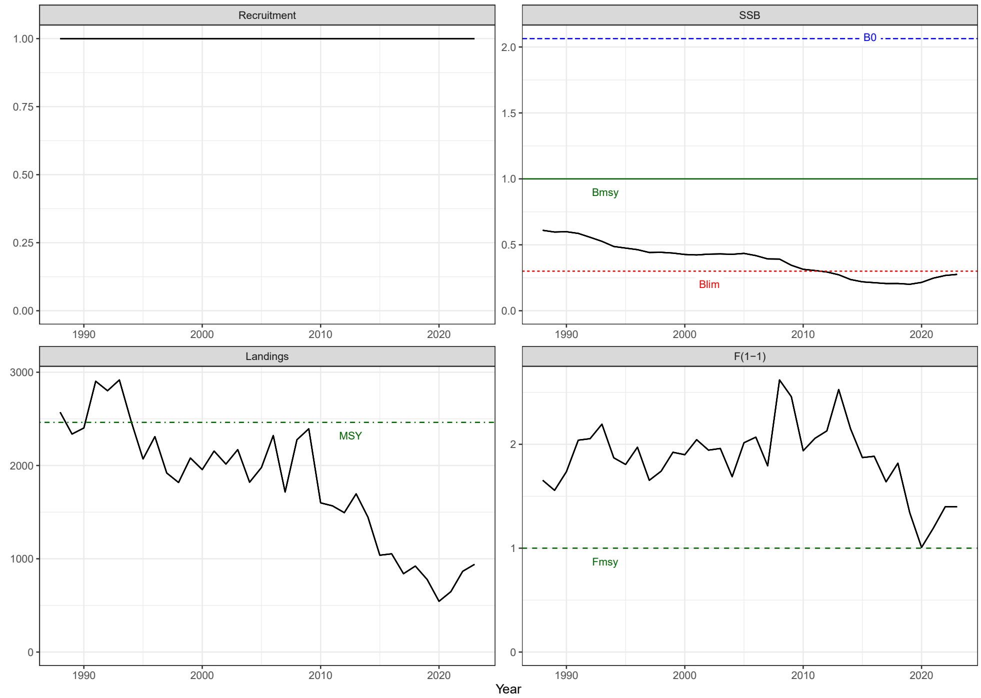
	Scenario 1 (BK 0.3)	Scenario 2 (BK 0.4)	Scenario 3 (BK 0.5)
$B_{current\ (2022)}/B_{msy}$	0.27	0.35	0.41
$F_{current\ (2022)}/F_{msy}$	1.4	1.28	1.2
$B_{current\ (2022)}/B_{pa}$	0.53	0.7	0.83
$B_{current\ (2022)}/B_{lim}$	0.89	1.17	1.38
Status of stock	Depleted and in overexploitation	Overexploited and in overexploitation	Overexploited and in overexploitation
Advice	Implement recovery plan	Reduce fishing mortality immediately	Reduce fishing mortality immediately



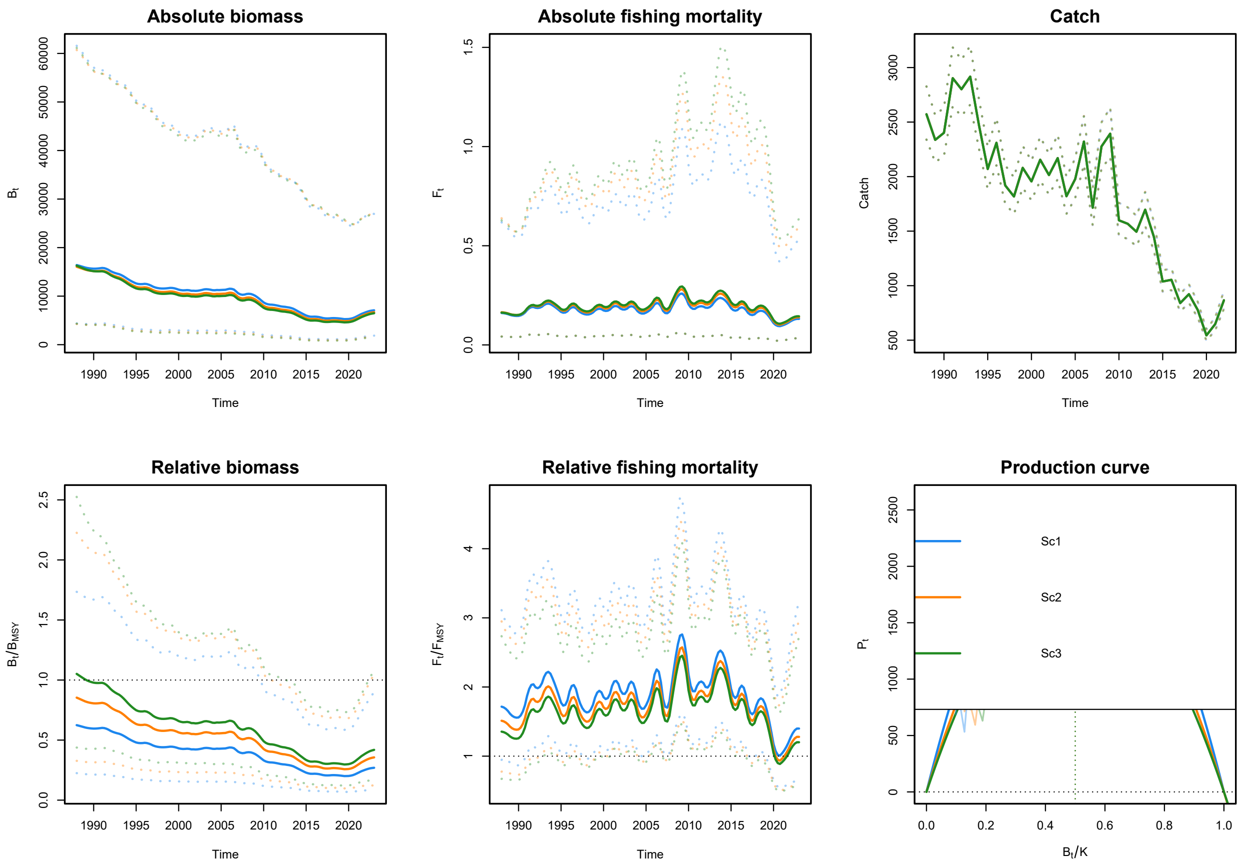
Annex 8. Scenario 1 (BKfrac 0.3). Historical and current stock status of hake regarding F_{msy}, B_{msy} and B_{lim}.



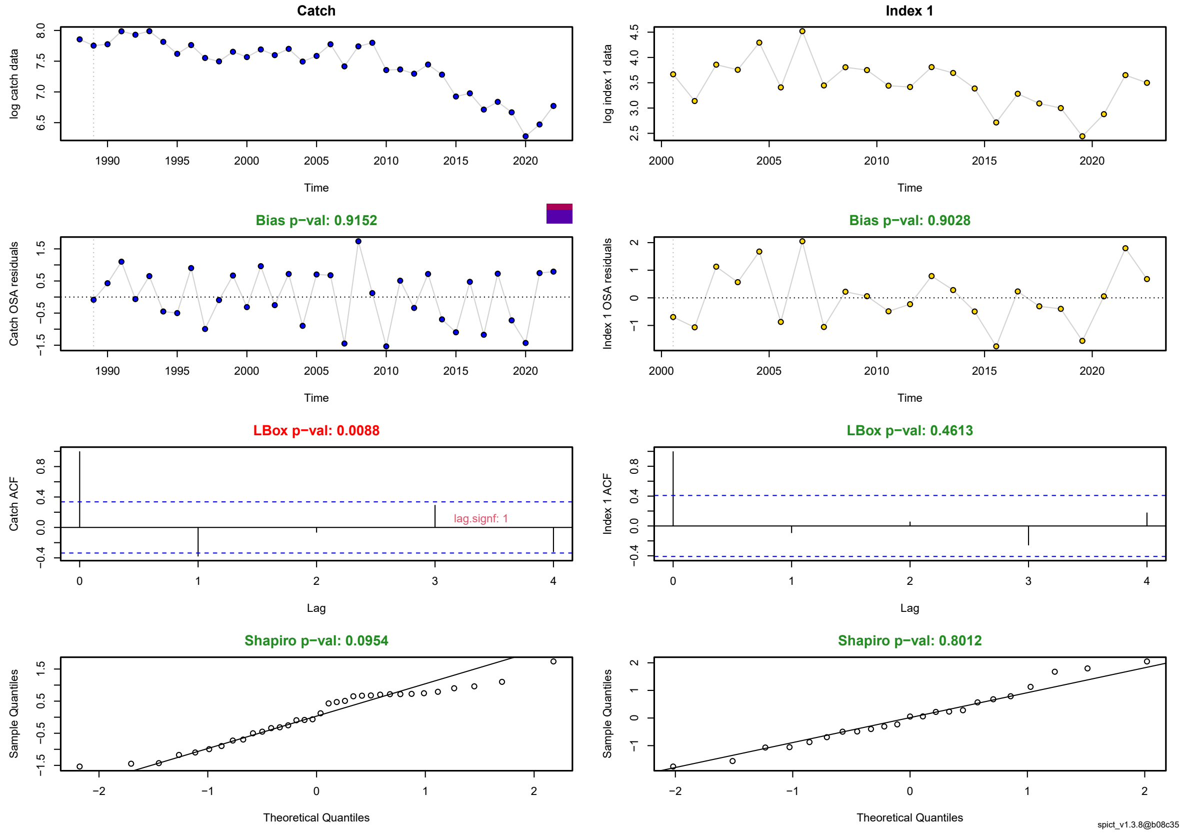
Annex 9. Scenario 2 (BKfrac 0.4). Historical and current stock status of hake regarding F_{msy}, B_{msy} and B_{lim}.



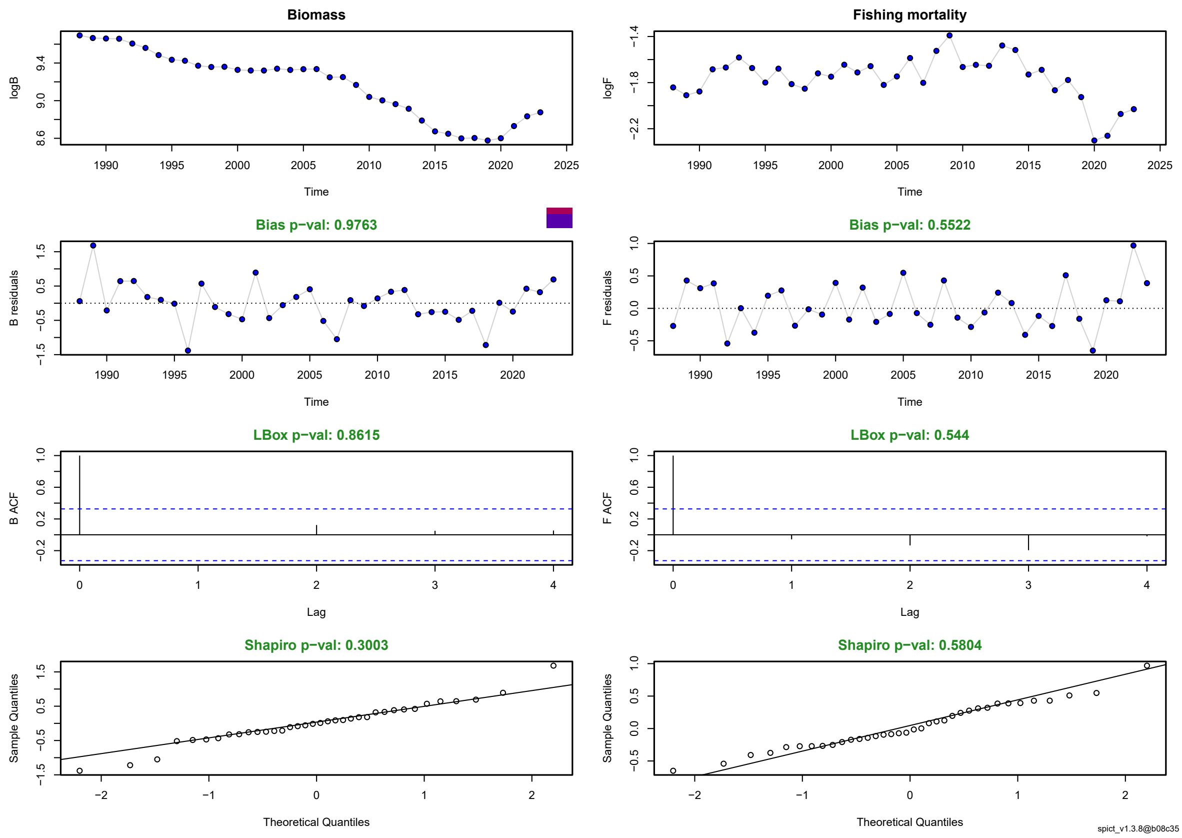
Annex 10. Scenario 3 (BKfrac 0.5). Historical and current stock status of hake regarding F_{msy}, B_{msy} and B_{lim}.



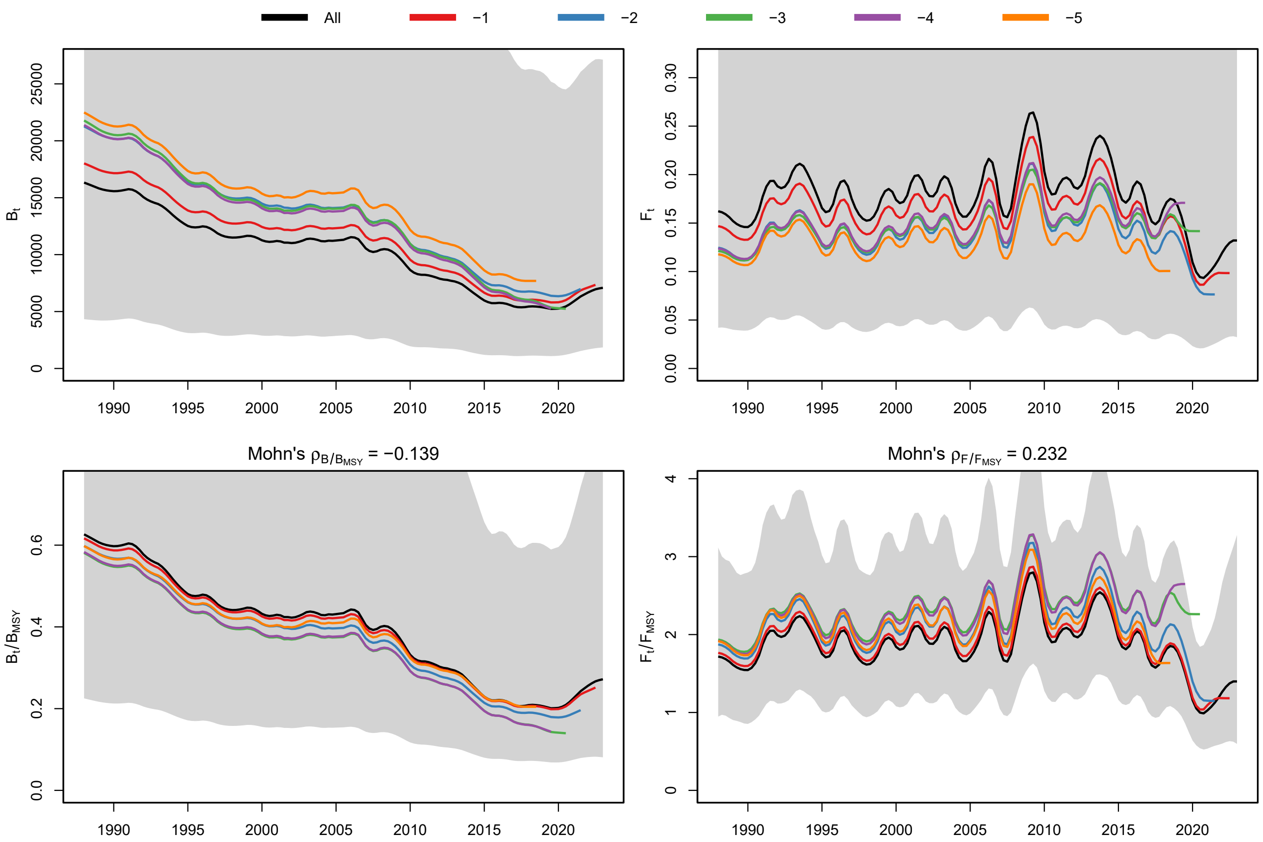
Annex 11. Comparison of the tested scenarios for hake.



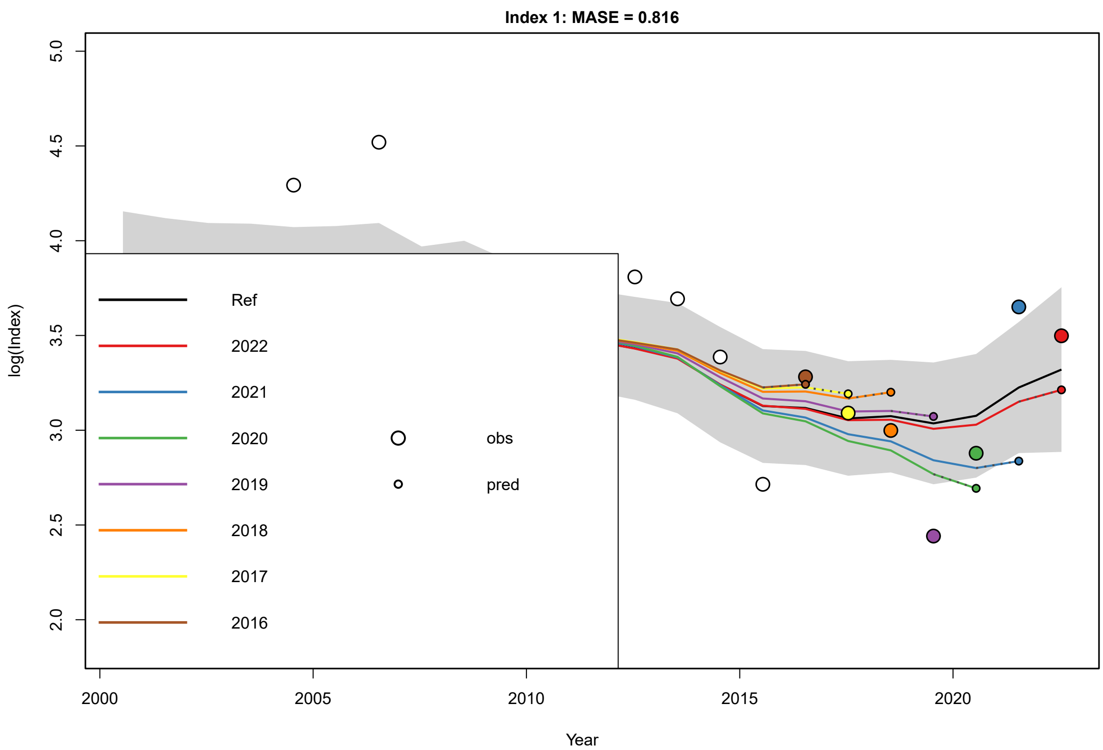
Annex 12. Scenario 1 (BKfrac 0.3). One-step-ahead residuals for the model.



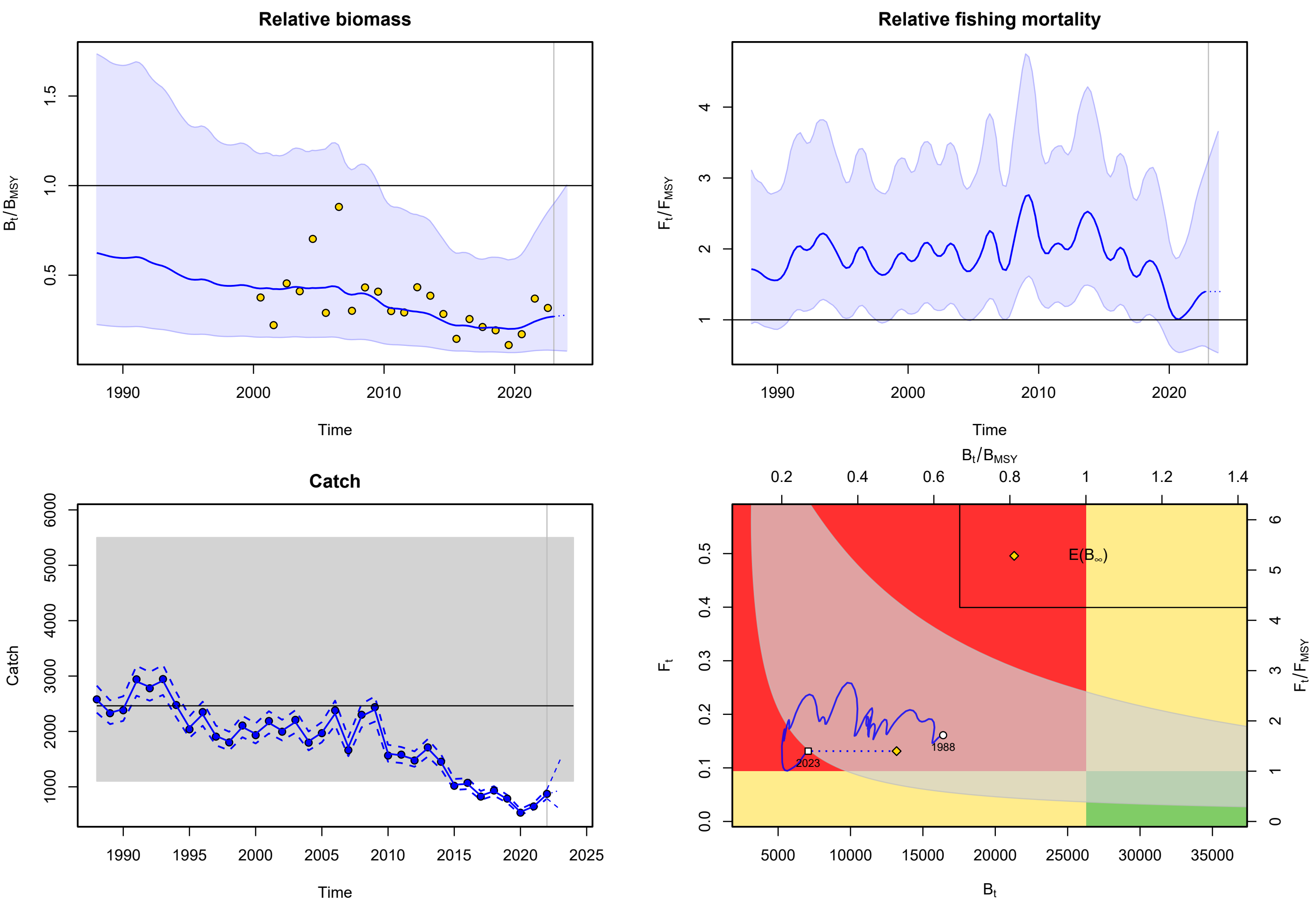
Annex 13. Scenario 1 (BKfrac 0.3). Process error deviations for the model.



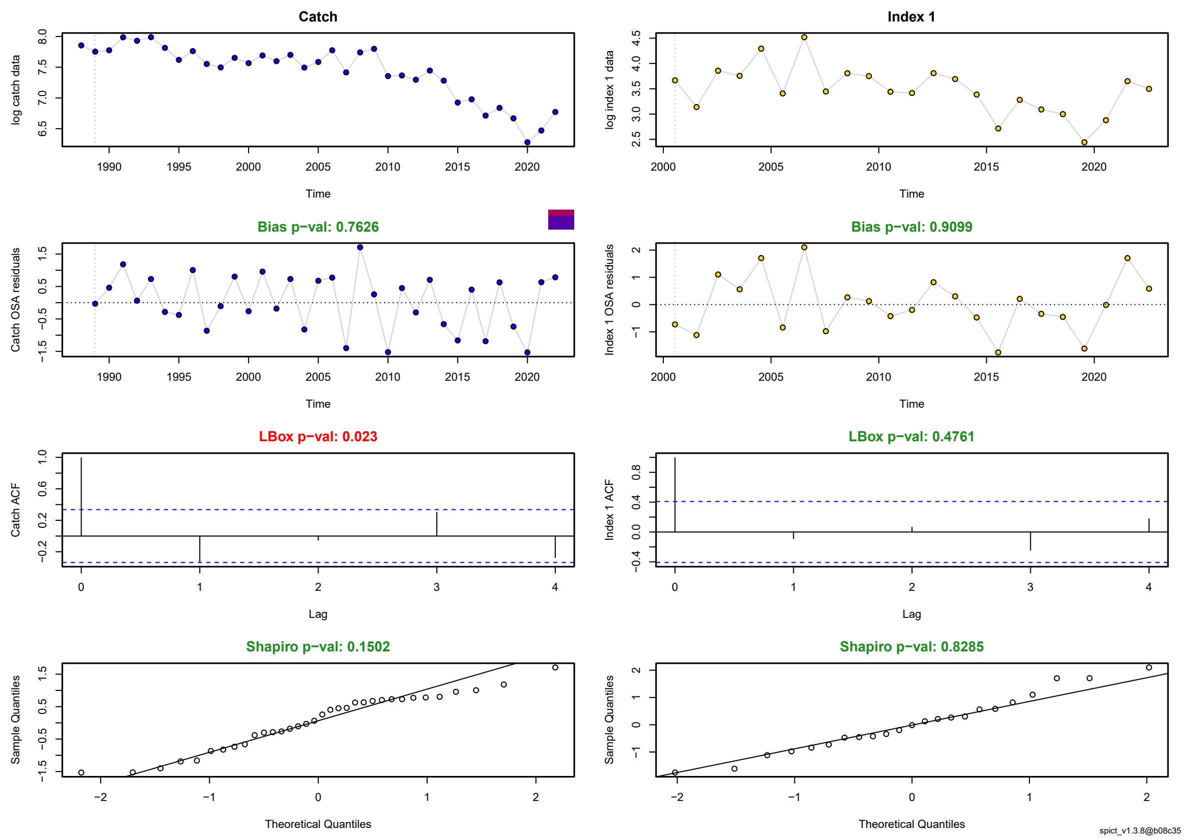
Annex 14. Scenario 1 (BKfrac 0.3). Retrospective analysis.



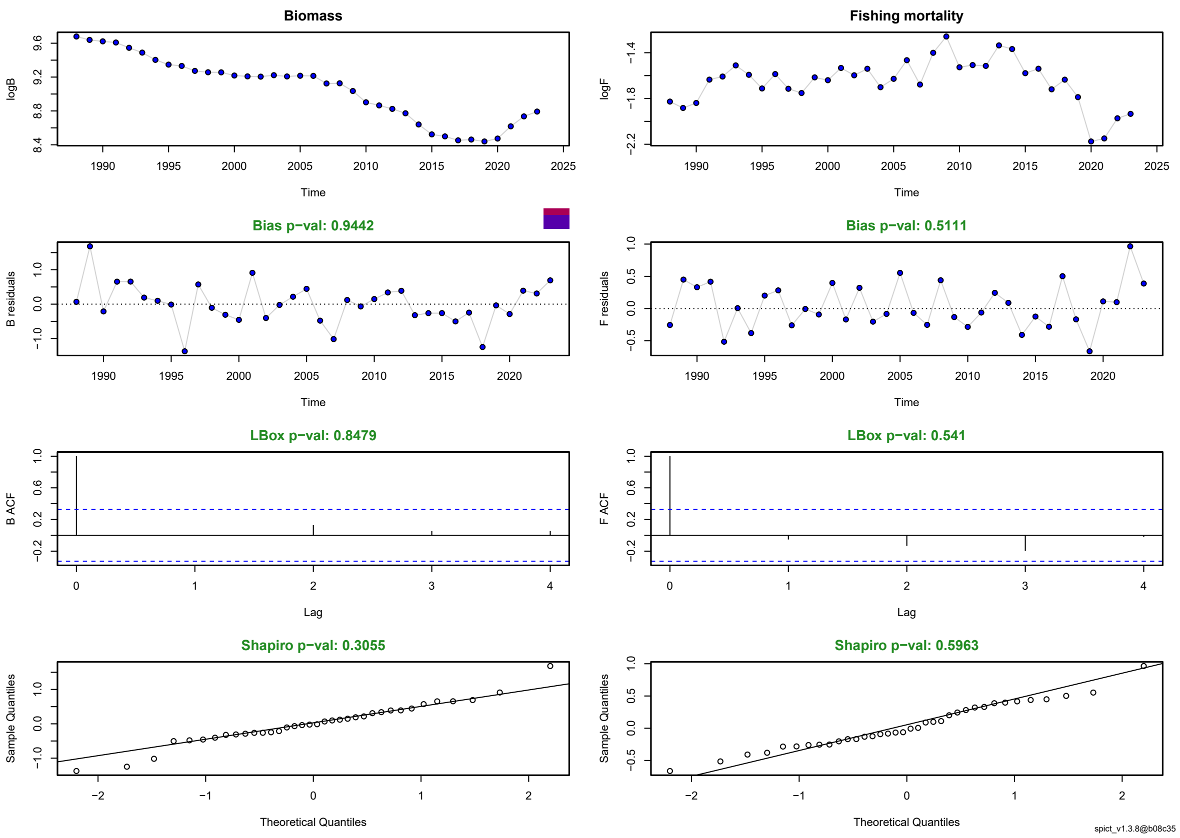
Annex 15. Scenario 1 (BKfrac 0.3). Hindcasting for the model.



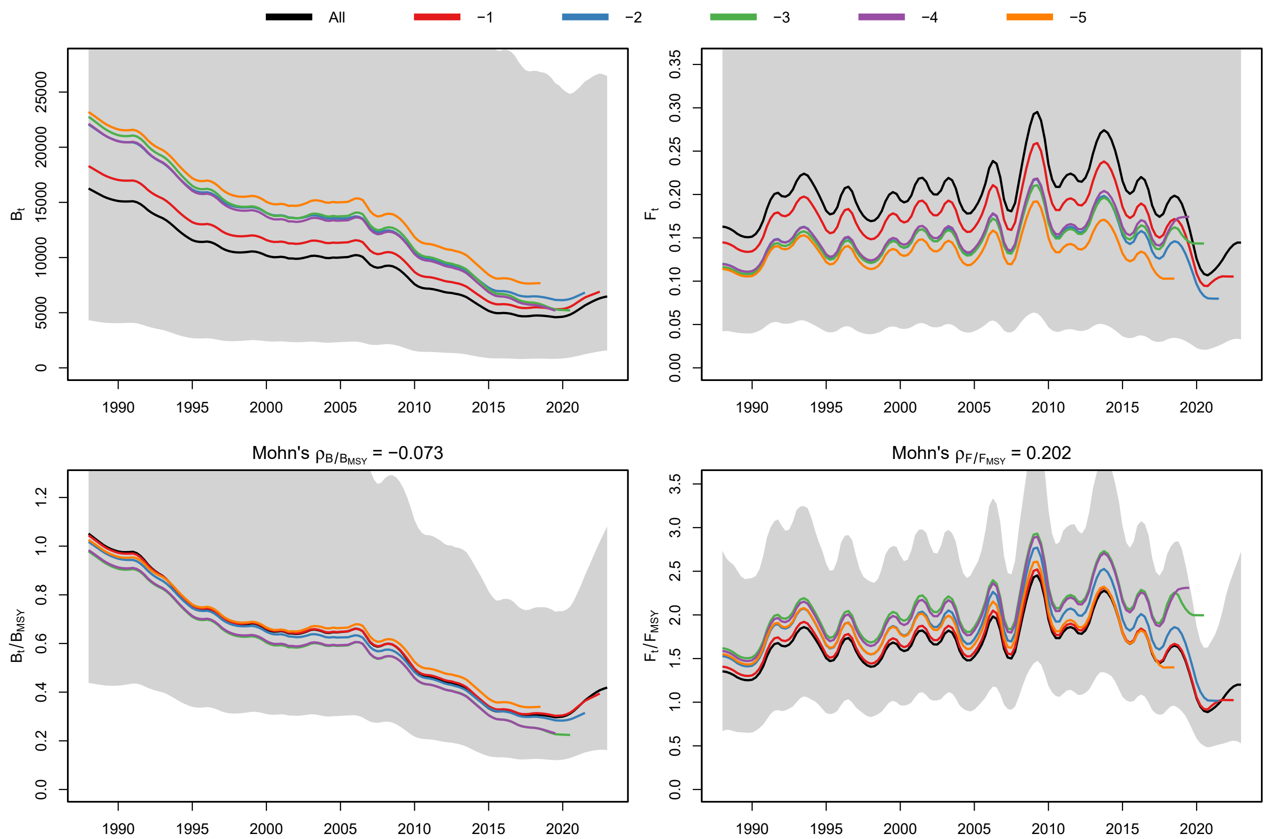
Annex 16. Scenario 1 (BKfrac 0.3). Stock assessment summary for hake by SPiCT.



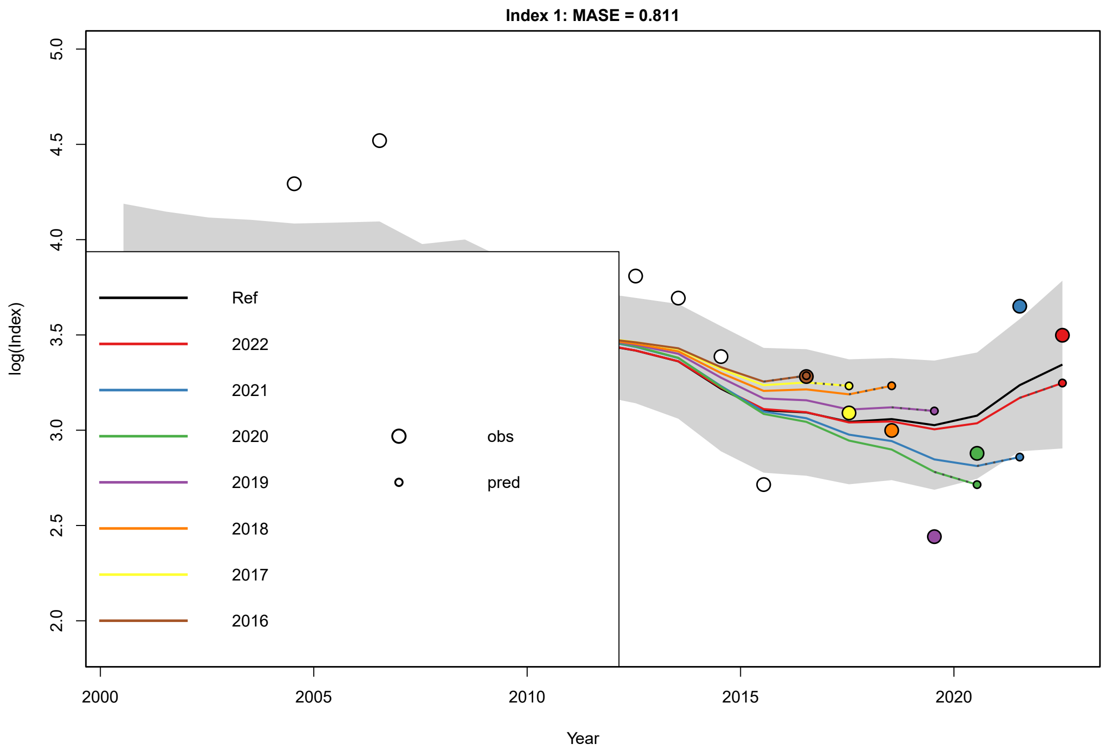
Annex 17. Scenario 2 (BKfrac 0.5). One-step-ahead residuals for the model.



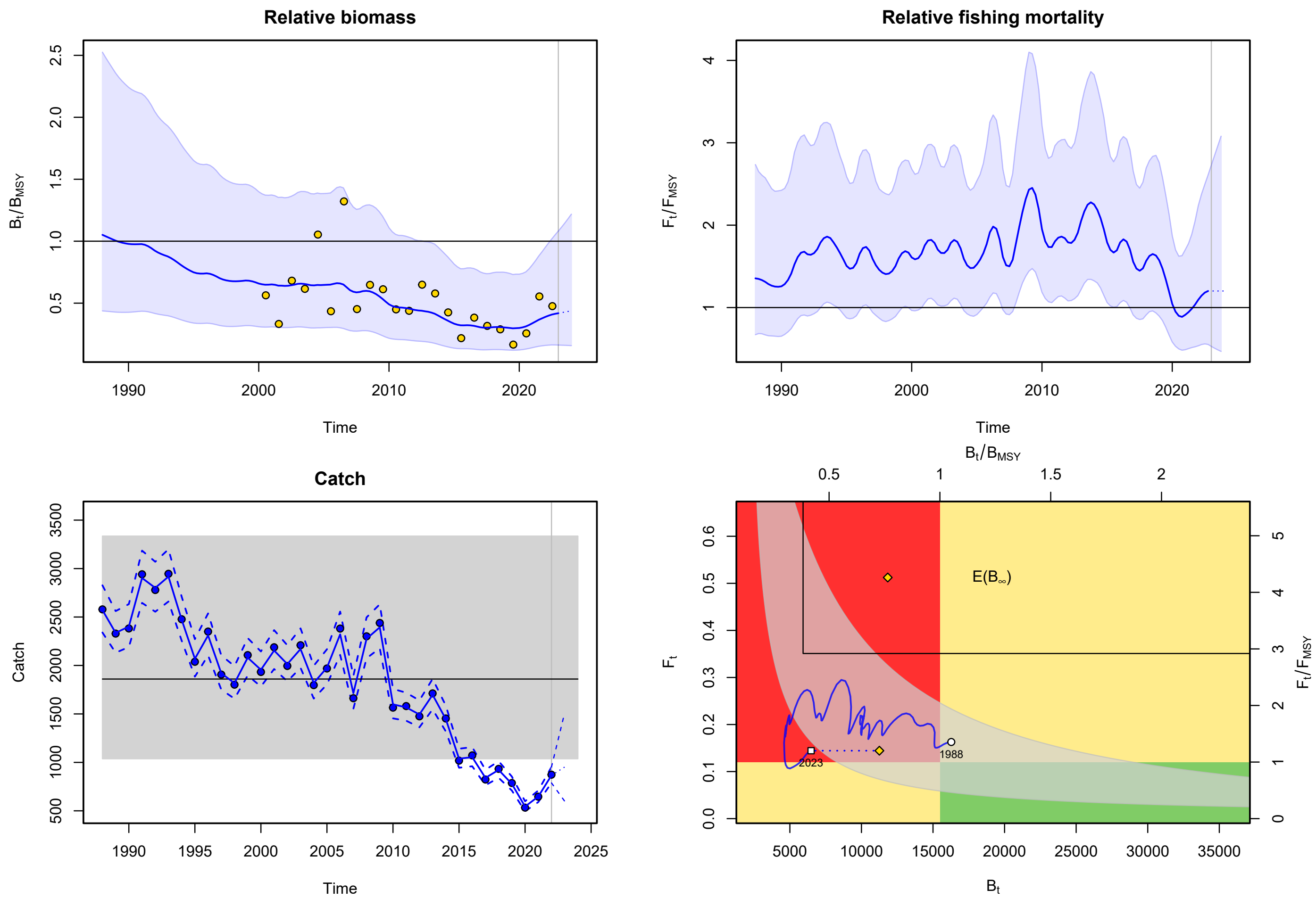
Annex 18. Scenario 2 (BKfrac 0.5). Process error deviations for the model.



Annex 19. Scenario 2 (BKfrac 0.5). Retrospective analysis.



Annex 20. Scenario 2 (BKfrac 0.5). Hindcasting for the model.



Annex 21. Scenario 2 (BKfrac 0.5). Stock assessment summary for hake by SPiCT.

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Co-funded by the European Union

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