BENCHMARK WORKSHOP ON ANCHOVY STOCKS (WKBANSP)

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Contents

i Executive summary

The Benchmark Workshop on anchovy stocks (WKBANSP) evaluated the assessment (input data and methodology), short–term forecast procedures and reference points for two anchovy stocks, Anchovy (*Engraulis encrasicolus*) in Subarea 8 (Bay of Biscay) and Anchovy (*Engraulis encrasicolus*) in Division 9.a (Atlantic Iberian waters). The key focus has been on evaluating stock structure and applying new modelling approaches for the assessments of the stocks. The assessment of anchovy in Subarea 8 was a category 1 assessment using the CBBM model. The assessment for anchovy in 9.a applied two category 3, constant harvest rate rules for short lived stocks, for the western and southern components.

Anchovy in Subarea 8

The previous stock assessment for anchovy in Subarea 8 was carried out using a Bayesian two-stage biomass-based model (CBBM) and used biomass estimates. The new assessment is carried out in the integrated statistical catch at age model Stock Synthesis (SS3) and uses numbers instead of biomass as input data. This model is faster to run and offers more flexibility for modelling the stock and the fishery, and can deal with a wider range of ages, from age 0 to 3+. This shift in the modelling approach required changes in parametrization and in the data inputs. Comparisons were made between SS3 and CBBM outputs using the same input data and showed similar stock trajectories. This assessment uses data by semester and inputs include, commercial fishery data (modelled as independent fleets by semester), two acoustic surveys (PELGAS on adults and JUVENA on recruits) and one daily egg production method spring survey (BIOMAN). Extensive model investigations were conducted and looked at catchability, selectivity, natural mortality, effective sample size and stock recruit modelling. A final model formulation with good diagnostics and acceptable retrospective patterns was discussed and agreed by the group. Further work was carried out on reference points and several options were presented and discussed in detail with the group reaching agreement on the final proposal. Due to time constraints the short term forecast discussions were deferred to WGHANSA. Recommendations for further investigations are outlined in the reviewers' report.

Anchovy in Division 9a

The stock structure of anchovy in division 9a was extensively reviewed. WKBANSP made the decision to split anchovy in 9a into two stocks with separate assessments and advice.

- Anchovy (*Engraulis encrasicolus*) in subdivision 9.a South (Gulf of Cadiz) with advice provided in November.
- Anchovy (*Engraulis encrasicolus*) in subdivision 9.a West (Western Iberian waters) with advice provided in June.

The stock assessment method applied for anchovy in 9aWest and tested in a management strategy evaluation in 2023 is still relevant and no changes were proposed. A separate advice sheet should be produced by WGHANSA and advice provided in June annually.

Anchovy in 9a South is now assessed using the integrated statistical catch at age model SS3. This replaces the previously used GADGET assessment that used age and length information and was used as indicator of stock development. This was applied in a category 3 approach while the new assessment is a full analytical category 1 assessment. The SS3 assessment uses catch at age data by quarter from the commercial fleet, age compositions data from three annual surveys, PELAGO and ECOCADIZ and biomass index from the ECOCADIZ- RECLUTAS which is used as an index of recruitment. SSB estimates from the triennial DEPM survey (BOCADEVA) are also

included in the model. Model explorations examined a number of model and data settings including natural mortality, weight at age, fleet and survey catchability, the use of priors, selectivity and the use of blocks and recruitment assumptions. Following extensive discussions, the final assessment, reference points and short term forecasts following ICES guidelines were agreed by the group. Recommendations for further investigations are outlined in the reviewers report. Advice should be formulated by WGHANSA and provided annually in November.

General findings

Further research on stock connectivity between anchovy in 9a West (9aN, 9a CN, 9aCs) with the northern anchovy populations (in the Division 8c and with the entire stock in subarea 8) should be considered as well as, further research on the connectivity between the stock in 9a South with the populations inhabiting the Atlantic Morocco region.

Further work on management strategies will be required for anchovy in division 9aS and anchovy in subarea 8. For Anchovy in division 9aS, a management strategy evaluation to assess the maximum fishing mortality that can be applied (Fcap), to ensure that in the long-term the risk of falling below B_{lim} is <0.05, should be conducted as soon as possible. The changes made to the assessment of anchovy in subarea 8 during the benchmark could imply changes in the performance of the current management plan in terms of biological risks and expected catches. A re-evaluation of the current management plan incorporating the most recent changes in the assessment should be undertaken as soon as possible.

ii Expert group information

Expert group name	Benchmark workshop on anchovy stocks (WKBANSP)
Expert group cycle	Annual
Year cycle started	2024
Reporting year in cycle	1/1
Chair(s)	Afra Egan (Ireland) Kiersten Curti (USA)
External experts	Andres Uriarte (Spain)
	Stefanie Haase (Germany)
Meeting venue(s) and dates	5 -7 March 2024, data meeting, online 23 -27 September 2024, assessment meeting, Nantes, France

1 Introduction

1.1 General

This report details the outcomes of the benchmark exercise established by ACOM to consider the assessment (input data and methodology), short–term forecast procedures and reference points for two anchovy stocks.

The stocks benchmarked were

- Anchovy (*Engraulis encrasicolus*) in Subarea 8 (Bay of Biscay)
- Anchovy (*Engraulis encrasicolus*) in Division 9.a (Atlantic Iberian waters)

Based on extensive work on stock identity, the benchmark made the decision to split Anchovy (*Engraulis encrasicolus*) in Division 9.a into two stocks;

- Anchovy (*Engraulis encrasicolus*) in subdivision 9.a South (Gulf of Cadiz)
- Anchovy (*Engraulis encrasicolus*) in subdivision 9.a West (Western Iberian waters)

The process was facilitated by two chairs, ICES chair (Afra Egan) and an external chair (Kiersten Curti). Two reviewers participated Andres Uriarte (Spain) and Stefanie Haase (Germany). They were involved throughout the benchmark exercise and provided comment and input during the discussions. Issue lists were compiled for each stock and outlined a range of issues that the expert groups felt should be addressed. These formed the basis for the work carried out by this benchmark.

A data coordination workshop was held online from the 5th-7th March 2024. It was attended by 19 experts online. During the data workshop, the items on the issue lists were considered in detail, in particular the stock identity of anchovy. Presentations were given outlining the different methodologies applied to study stock structure including analysis of survey data, landings data, life history traits, larval dispersal, stable isotope analysis and genetics. The report on stock identity was sent to the Stock Identification methods working group for review. The input data for the assessments was presented and discussed and included detailed analysis of data consistency, survey time series and methodologies as well as previous assessment models tested and applied.

The preparations continued by correspondence with progress discussed at two online update meetings (25th June and 10th September 2024). Prior to the final benchmark meeting, working documents were produced and uploaded to the meeting SharePoint site.

The benchmark assessment meeting was held at IFREMER, Nantes from 23rd – 27th September 2024 and was attended by 11 participants in person and 2 people online. All new data sources and updated timeseries were explored in the context of different model formulations and assumptions. Two follow up meeting were held to finalise assessments, reference points and discussion on short term forecasts.

1.2 Working documents and presentations

Presentations at DEWK:

- Anchovy in 9a Stock Structure
- Northern limit of Bay of Biscay anchovy stock: Are we observing and ongoing expansion?
- Population structure of European anchovy in the northeast Atlantic based on genomic markers.
- PELTIC anchovy expansion
- Assessment history and future plans Anchovy in 9a
- Western Component 9a history and advice
- Anchovy in 9a Southern component input data
- PELGAS acoustic survey for anchovy
- Data consistency analysis of survey age-length data available for the Southern component of anchovy 9a stock
- Introduction to Bay of Biscay anchovy
- Anchovy DEPM in the Bay of Biscay (ICES 8abcd): BIOMAN surveys 1987-2023
- Catch at age data for Bay of Biscay anchovy
- Juvena survey

Working documents presented WKBANSP

Working documents: Anchovy in 27.9.aW (Western Iberian waters)

- Garrido S, Naiara Rodríguez-Ezpeleta, Natalia Díaz, Ana Machado, Tatsuya Sakamoto, Fernando Ramos, Margarita Rincón, Ana Moreno, M Paz Jiménez, Maria Santos, Pablo Carrera, Silvia Rodriguez-Climent, Diana Feijó, Leire Ibabarriaga, Leire Citores, Guillermo Boyra, Erwan Duhamel (2024) Population structure of the European Anchovy (*Engraulis Encrasicolus*) In ICES Division 9a. Working document presented to the ICES Stock Identification Methods Working Group (SIMWG) and ICES Benchmark workshop on anchovy species (WKBANSP).

- Susana Garrido, Laura Wise, Margarita Rincón, Fernando Ramos, Pablo Carrera, Ana Moreno. Investigation of consistency of acoustic surveys targeting anchovy off Western Iberia (JUVESAR/IBERAS, PELACUS, PELAGO). Working document presented to the: ICES Workshop on Anchovy stocks (WKBANSP). 23-27 September 2024.

Working documents: Anchovy in 27.9.aS (Gulf of Cadiz)

- Ramos et al. 2024 WD. Ane.27.9a stock (Anchovy in ICES Division 9a). Southern component (Anchovy in ICES Subdivision 9a South): Fishery, Biological and Surveys data. Data availability and trends.
- Zúñiga et al 2024 WD: Data consistency analysis of survey age-length data available for the Southern component of anchovy 9a stock
- Zúñiga et al 2024 WD: Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).
- Rincón et al 2024 WD: Growth and natural Mortality parameters estimation for anchovy 9a South, 2024

- Rincón 2024 WD: Comparison of Gadget implementations with the same data input as the age-based SS3 model plus length distributions.
- Zúñiga et al 2024 WD: **S1.0_4FLEETS** -Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)
- Zúñiga et al 2024 WD: **S1.0_InitCond_SigmaR** -Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).
- Zúñiga et al 2024 WD: **Scenario S1.0_InitCond_sigmaR_AdjIndexRec**: Assessment for WKBANSP 2024 using age-structured data in SS3: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)
- Zúñiga et al 2024 WD: Reference points and short-term forecast for WKBANSP 2024: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).

Working documents: Anchovy in 27.8 (Bay of Biscay)

- Santos, M., Citores, L. and Ibaibarriaga, L. Anchovy DEPM in the Bay of Biscay: BIOMAN survey 1987-2023.
- Citores, L and Ibaibarriaga, L. 2024 WD. Reference point for anchovy in the Bay of Biscay.
- Citores, L and Ibaibarriaga, L. 2024 WD. Updates on the assessment model for anchovy in the Bay of Biscay.

The Working Documents are attached to this report as annex 3.

1.3 Report structure

The report is structured into sections by stock with anchovy in subarea 8 (section 2), anchovy in 9a (section 3) focusing on stock identity, anchovy in 9a South (section 4), anchovy in 9a West (section 5) and a section with reviewers comments (section 6).

2 Anchovy (*Engraulis encrasicolus*) in Division 8 (Bay of Biscay)

2.1 Issue list

The issue list for the Bay of Biscay anchovy and the progress made during the benchmark are described in Table 2.1.

Table 2.1: Bay of Biscay anchovy Issue list for the Bay of Biscay anchovy and progress made during the benchmark.

ID	Problem/Aim	Work Required	Data Required	Progress Made
354	Total egg production estimates from PEL-GAS survey			Total egg production estimates from PEL-GAS were available, but the same input data as in the previous model were used and these estimates were not included.
355	Review the connectivity among the anchovy populations along the Atlantic coasts (between subareas 7 and 8 and between subareas 8 and 9)	Review latest information from genetics on population connectivity or separations?	Ongoing research projects	There are new publications and working documents on anchovy connectivity (Huret et al., 2020; Garrido et al., 2024; van der Kooij et al., 2024). But further studies are required.
356	In the last years catch data are disaggregated by fleet, landings and discards are separated. This may led to a revision of the catch estimates included in the assessment.	Revise the catch information included in the assessment model.		No revision of the catch estimates was done.
357	Recent advances in target strength estimates on anchovy suggest that current values can be unappropriated and should be replaced, leading to some downward revision of the acoustic survey series estimates.	Revise the biomass time series of the acoustic surveys according to the new target strength values. Assess the impact of a new acoustic survey series input in the stock assessment.	Published papers and reports of ICES WGACEGG meetings concerning acoustic target strength of anchovies."	No revision of the time series of the acoustic surveys was done.

ID	Problem/Aim	Work Required	Data Required	Progress Made
358	There are some recent trends in DEPM residuals which may suggests some trends in catchability in the survey serie, worth exploring.	Assess if the trend in residuals might be due to changes in the Daily Fecundity of the DEPM series, and assess if the changes are well justified.	AZTI biological sample data base from DEPM surveys.	Different configurations were attempted in the stock assessment model. However, these patterns have persisted.
359	There are some large negative residuals in JUVENA recruiment index in last years.	Assess if there is any reason in the implementation of the survey that may justify these negative residuals.		The settings for the JUVENA index in the stock assessment were changed and the residual pattern was improved.
360	Biological Parameters In the past benchmark natural mortality was set at 0.8 for age 1 and 1.2 for ages 2+. Do these values need to be revised according to any potential new information as e.g. the paper (Uriarte et al. 2016)?	Update analysis on Natural Mortality (Uriarte et al. 2016) according to new data series (if any) and to the most recent information from last surveys.	For the natural mortality the same input as for the assessment suffices to review the issue. Continue anaysing if this pattern is recurrent in future years. Ecological models on the trophic webs in the Bay of Biscay may provide information to infer Natural Mortality on anchovy	Due to the change of the stock assessment model, the natural mortality rates for ages 0 and 3+ were revised.
361	In the last year anchovy weight at age has shown a decrease, this may contradict the constant growth assumption in the assessment model.	Review the assumption of constant growth rate parameter along time.		The stock assessment model was changed and the weight at age data are now included in the stock assessment. Sensitivity of the previous CBBM model to potential changes in the growth rates were also studied, but no major impacts were found.

ID	Problem/Aim	Work Required	Data Required	Progress Made
362	There were some (small) retrospective patterns in the series of biomass estimates and fishing mortality in the assessment not fully resolved in the last benchmark which should be revisited. There are some patterns in the residuals of the proportions at age in the catches of the first half of the year which suggest that there might be some shift in the fishing selectivity along the assessment period.	Assess if different settings in the assessment allows diminishing the retrospective patterns or the patterns in residuals (e.g.changes in the natural mortality or allowing a varying fishery selectivity either continuously or for two periods of the fishery - prior and after closure).		The stock assessment model was changed and the model settings were set up to reduce the retrospective pattern as much as possible. However, the retrospective pattern and a systematic degradation along time was consistently found in all the model settings attempted. So, this should be further studied.
363	The relative contribution of different fleets to the international catches at age is changing over time, this may be affecting the constant selectivity assumption.	Explore tuning the catches at age by fleef using different selectivity patterns. Alternatively, if a unique fleet is considered, explore different blocks in time.	Catch at age and weight at age disaggregated by fleet.	The stock assessment model assumed one different fleets by semester. The selectivity of ages 1 and 3+ of each of these fleets was modelled as a random walk along time to account for changes over time.
364	There are some changes in the growth in time.	Explore the benefit of allowing a growth parameter varying in time.		Stock weight-at-age data are now included in the stock assessment.
365	Review the forecast methodology and assumptions depending on the selected assessment model.			The forecast methodology was updated to be consistent with the stock assessment method.
366	Any change in the stock assessment data and model settings could require the revision of the biological reference points. In addition ICES is revising the guidelines for reference points.			Biological reference points were updated based on the new stock assessment results.
367	If the assessment methodology is changed it may imply some new MSE of the HCR of the Management strategy.	Reevaluation of the management plan.		Pending until the benchmark process is finished

2.2 General

The last benchmark for anchovy in Subarea 8 (Bay of Biscay) was conducted in 2013. Since then, the stock assessment has been showing some deterioration in the residuals and in the retrospective pattern. In addition, recent studies have shown changes in some biological parameters (Doray et al., 2018a, Taboada et al., 2023) and in the fisheries (Beckensteiner et al., 2024) that may contradict some of the stock assessment model assumptions. These issues together with the issue list in section 2.1 led to the initiation of the benchmark process.

Available data sources and exploratory data analysis were presented during the Data Workshop in March 2024. Exploratory assessment runs were presented and reviewed during the Benchmark workshop in September 2024 and during additional progress meetings carried out before and after the benchmark workshop. Details of this process and final output are presented here.

2.2.1 Fishery information

Anchovy in the Bay of Biscay is exploited by Spanish and French pelagic fleets (Uriarte et al., 1996). The Spanish fleet is composed by purse-seiners that operate mainly in spring. The French fleet is constituted of purse-seiners (the Basque ones operating mainly in spring and the Breton ones in autumn) and pelagic trawlers (operating mainly during the second half of the year but with decreasing catches along years).

After the fishery collapse in 2005, the anchovy fishery was closed for five years (2005-2009). Since the reopening of the fishery, the number of vessels in both fleets have decreased considerably. The level of adaptability has differed among fleets and their segments (Andres and Prellezo, 2012). While the anchovy stock has recovered, the fishery system has not returned to its pre-collapse status with important socio-economic features having been lost (Beckensteiner et al., 2024). This has been particularly noticeable in the case of the French fleet: since 2020 the French catches have been below 300 tonnes, well below their allocated quota (ICES WGHANSA 2023). The contribution by country to the total catch, both in tonnes and in %, is shown in Figure 2.1.

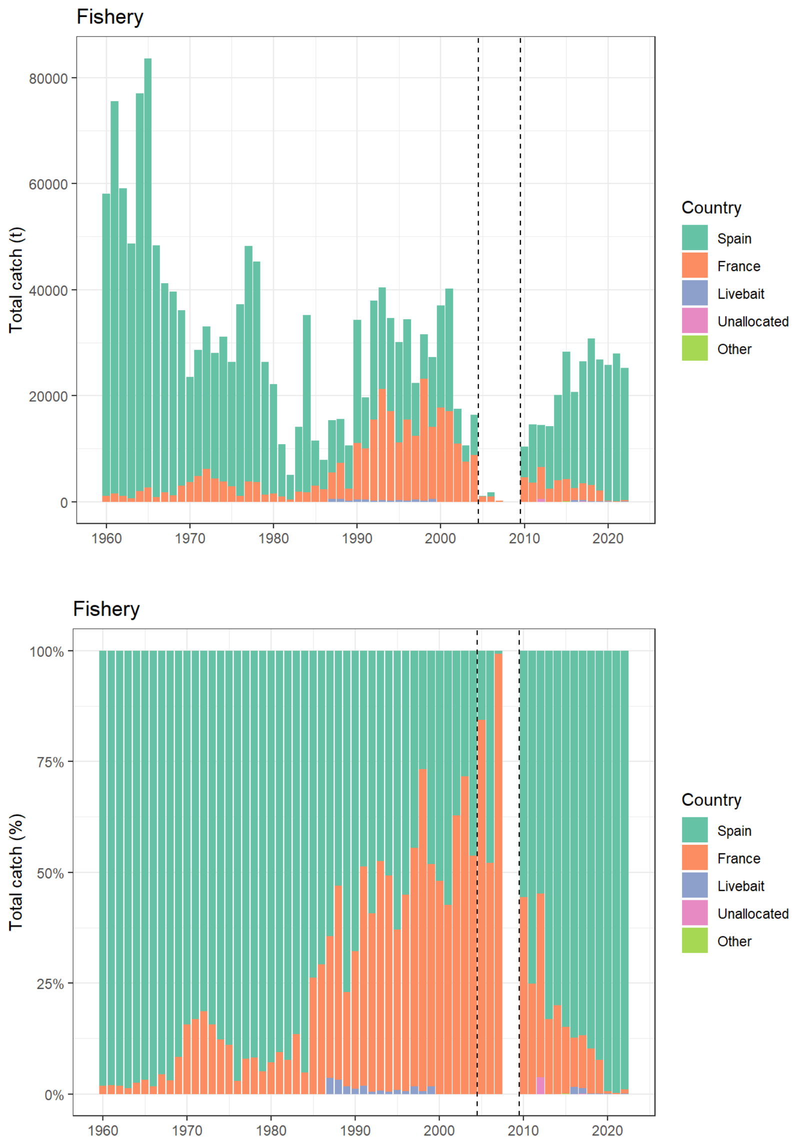

Figure 2.1:Bay of Biscay anchovy. Total catches (in tonnes in the top and in % in the bottom) by Spanish and French fleets as reported in WGHANSA (ICES, 2023). Live-bait corresponds to estimated catches by the Spanish fleet as bait for tuna fishing. The vertical dashed lines indicate the fishery closure period 2005-2009.

2.2.2 Current assessment and advice

The current stock assessment for anchovy in the Bay of Biscay is a Bayesian two-stage biomass-based model (CBBM, Ibaibarriaga et al., 2011). This model is an ad-hoc model specifically developed for this stock. Population dynamics are described in terms of biomass with two distinct age groups: recruits or fish aged 1 year, and fish that are 2 or more years old. The biomass changes exponentially with time according to intrinsic growth, natural mortality and fishing mortality rates. Growth and natural mortality are separated processes that are assumed to be constant along time but distinct across age groups. Fishing is treated as a continuous process in time separated by semester. The observation equations consist of log-normally distributed spawning–stock biomass from the acoustics and DEPM surveys, beta distributed age 1 biomass proportion from the acoustics and DEPM surveys, log-normally distributed juvenile abundance index from the JUVENA surveys, log-normally distributed total catch by semester, beta distributed age 1 biomass proportion in the catch by semester and normally distributed growth rates by ages.

The unknown parameters are the initial biomass, the mean and the precision of the recruitment process in log scale, the acoustic and DEPM surveys catchabilities, the catchability and the power parameters of the JUVENA index, the parameters affecting the precision of the survey and catch observation equations, the year and age components of the fishing mortality by semester, the annual intrinsic growth rates by age and the precision of the observation equations for growth. Inference on the unknowns is made using Markov Chain Monte Carlo (MCMC). The model is implemented in JAGS and the assessment is run from R using the package "rjags".

The short-term forecast is also conducted using an ad-hoc R script based on the same assumptions than the stock assessment model.

The latest stock assessment in 2023 estimated the spawning–stock biomass (SSB) to be well above B_{lim}. Since the re-opening of the fishery, the stock has been managed according to an agreed management plan and its revised versions (Uriarte et al., 2023; Sanchez-Maroño et al. 2018). Since 2016, the management plan is based on the harvest control rule (HCR) named G3 with a harvest rate of 0.4 (STECF, 2013, 2014). This rule was reviewed by ICES in 2016 and was concluded to be precautionary. Therefore, it forms the basis of the current ICES advice. The full formulation of the HCR is as follows:

$$TAC_{Jan_y-Dec_y} = \begin{cases} 0 & if \widehat{SSB}_y \leq 24000 \\ -2600 + 0.4\widehat{SSB}_y & if 24000 < \widehat{SSB}_y \leq 89000 \\ 33000 & if \widehat{SSB}_y > 89000 \end{cases}$$

where $\widehat{SSB}_y$ is the expected spawning–stock biomass in year y.

2.2.3 Main changes and conclusions on stock definition, data, assessment, forecast and reference points

Stock definition

No changes to the stock definition were made during the benchmark process.

Data and Assessment

The time series of the juvenile abundance index from JUVENA was updated. No other changes to the data were made during the benchmark process. Available data sources and exploratory data analysis are presented in section 2.3.

Stock Assessment

The stock assessment model was changed to Stock Synthesis (Methot and Wetzel, 2013). The model settings and the process followed are explained in detail in section 2.4.

The main changes with respect to the previous stock assessment with CBBM are the following:

- Dynamics in terms of mass in CBBM and in terms of numbers in SS.
- Two age groups (1-2+) in CBBM and ages 0-3+ in SS.
- Constant growth rate in CBBM and weight-at-age in the stock included as observations in SS.
- New natural mortality rates for ages 0 and 3+ in SS.
- Power catchability model for JUVENA in CBBM and linear in SS.
- Beta distributions for age 1 proportion in CBBM and multinomial distributions for age structure in numbers in SS.

- Recruitment as random deviations in CBBM and stock-recruitment model included in SS.
- No initial equilibrium status in CBBM and initial equilibrium in SS.
- Flat selectivity in surveys in CBBM and estimated selectivities in SS.
- Constant flat fishery selectivity in CBBM and random walk selectivity in SS.

Furthermore, in terms of estimation, inference in CBBM is based on the Bayesian paradigm and uncertainty estimates are obtained from the posterior distribution samples. On the contrary, SS output is based on maximum likelihood principles and uncertainty estimates have been obtained from the Hessian matrix.

Reference Points

The reference points were updated based on the new stock assessment results and following ICES technical guidelines for fisheries management reference points for category 1 and 2 stocks (ICES, 2021). Details can be found in section 2.6.

Short Term Forecast

During the benchmark the methodology to conduct a stochastic short-term forecast in Stock Synthesis was set up. However, the specific assumptions for the short-term forecast and the range of catch options were not established and were postponed to WGHANSA. See section 2.5.

2.3 Input data for stock assessment

2.3.1 Landings and Discards

Fishery data for anchovy in the Bay of Biscay were not updated during this benchmark.

Available data consists of total catch since 1940. Monthly catches by country are available since 1987 (Figure 2.2). Most of the French catches occur in the second half of the year, while most of the Spanish catches are taken in spring (March-June).

Age structure of the catches by semester are available since 1987 (Figure 2.3 and Figure 2.4). In the first semester most of the catches correspond to ages 1 or 2. In the second semester, age 0 individuals incorporate to the fishery and age 1 increases while older ages (age 2 and 3+ decrease). Regardless interannual variations, the age structure in the catches after the fishery closure seems to have changed with respect to the initial years in the time series.

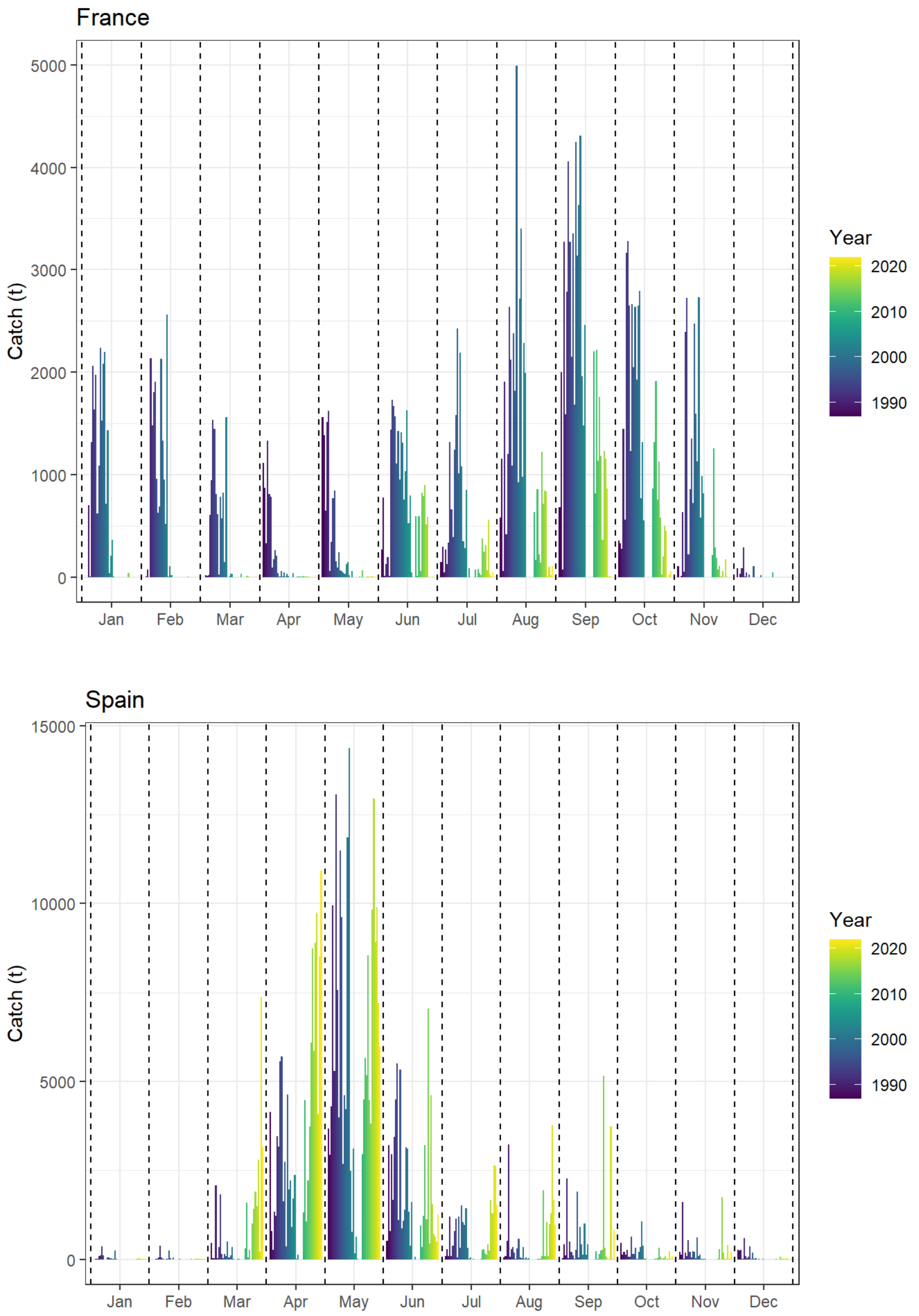

Figure 2.2: Bay of Biscay anchovy. Monthly catches for France (top) and Spain (bottom) since 1987.

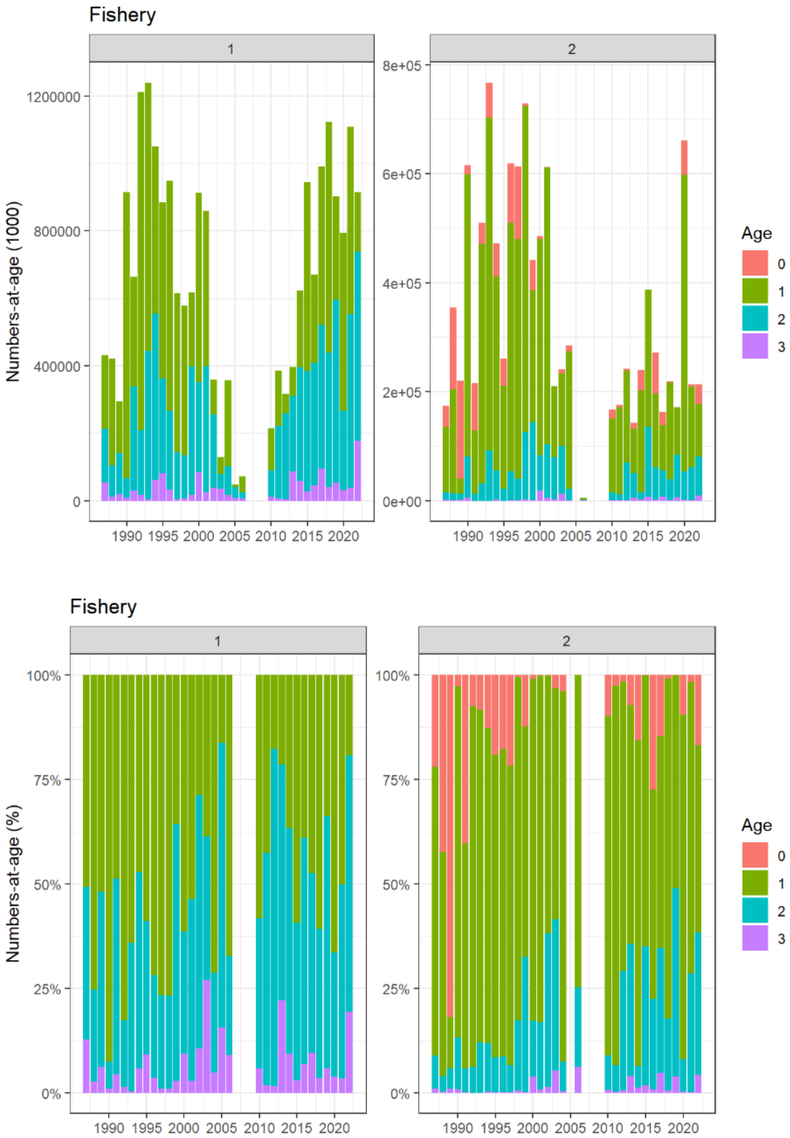

Figure 2.3: Bay of Biscay anchovy. Numbers-at-age by semester in the top and percentage-at-age by semester in the bottom. The age classes are 0, 1, 2 and 3+.

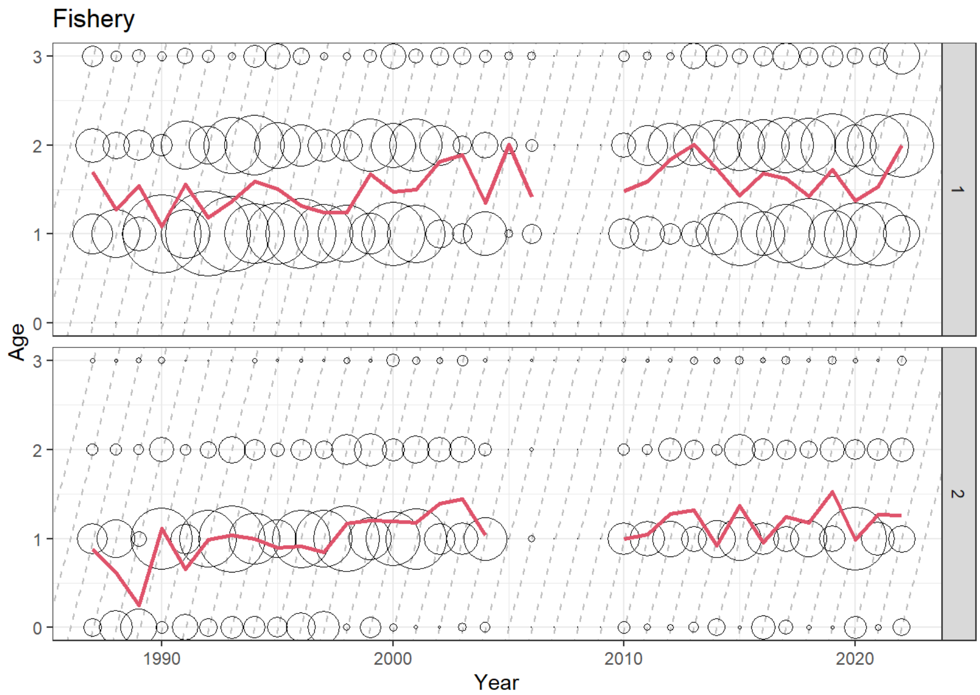

Figure 2.4: Bay of Biscay anchovy. Bubble plot of catch-at-age by semester. The red lines represent the mean age in the catches for each of the semesters.

2.3.2 Weight-at-age in the fishery

The weight-at-age by semester in the fishery is shown in Figure 2.5. Since 2010 there is a decreasing trend in the weight-at-age for all age classes in the first semester and for ages 1 and 2 in the second semester.

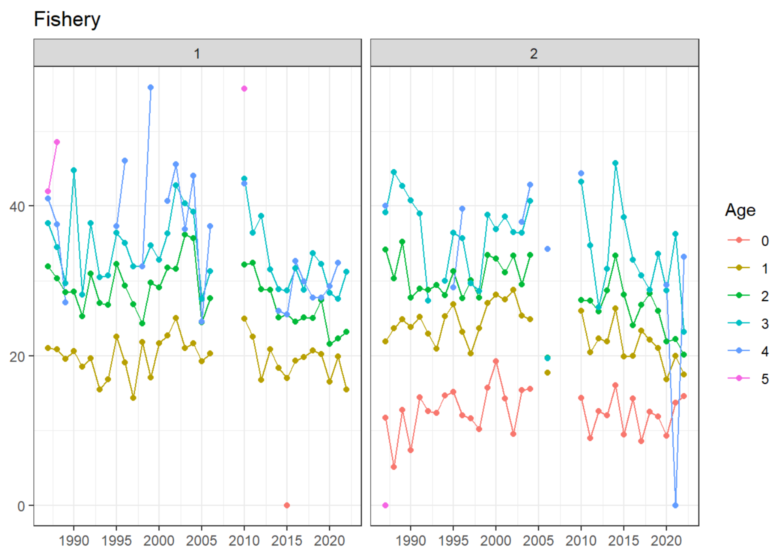

Figure 2.5: Bay of Biscay anchovy. Weight-at-age in the catch since 1987.

2.3.3 Natural mortality

The closure of the fishery from 2005 to 2010 and the close monitoring of the population by the spring surveys (BIOMAN and PELGAS) provided a unique opportunity to investigate natural mortality for this stock (Uriarte et al., 2016). Based on this study, in the CBBM stock assessment natural mortality at age 1 was fixed at 0.8 and natural mortality at ages 2+ was fixed at 1.2.

During this benchmark natural mortality rates for ages 1 and 2 were kept as before. Natural mortality rates for ages 0 and 3+ as required by the SS model were set up as described in section 2.4.1.2.1 and 2.4.1.2.3 respectively.

2.3.4 Maturity

Anchovies are fully mature as soon as they reach their first year of life, in spring the year after the hatch. Therefore, the maturity-at-age vector was set as:

Age	0	1	2	3+
Maturity	0	1	1	1

2.3.5 Surveys

The Bay of Biscay anchovy is monitored by three fishery-independent surveys: BIOMAN, PELGAS and JUVENA. The first two are conducted in spring and the last one in autumn. The three of them are coordinated and discussed in the ICES Working Group on Acoustic and Egg Surveys for small pelagic fish in NE Atlantic (WGACEGG). Details of each survey can be found in the WGACEGG report and references therein. Below a summary of the data used for assessment purposes is provided.

2.3.5.1 BIOMAN

The BIOMAN survey is conducted every year in spring since 1987. Its main objective is to estimate the anchovy spawning stock biomass by means of the Daily Egg Production Method (DEPM). In addition, this survey provides estimates of the age structure and biological parameters at spawning time, among others.

The time series of SSB is shown in Figure 2.6 and the associated coefficients of variation are in Figure 2.7. The age structure is shown in Figure 2.8 and Figure 2.9. Average total mortality at age from these surveys is around 1.16 for age 1 and 2.15 for age 2 (Figure 2.10). The internal consistency across ages from these surveys is quite good with correlations above 0.7 (Figure 2.11). Weight-at-age at spawning time from BIOMAN surveys is shown in Figure 2.12 with a clear decreasing trend already identified in the scientific literature.

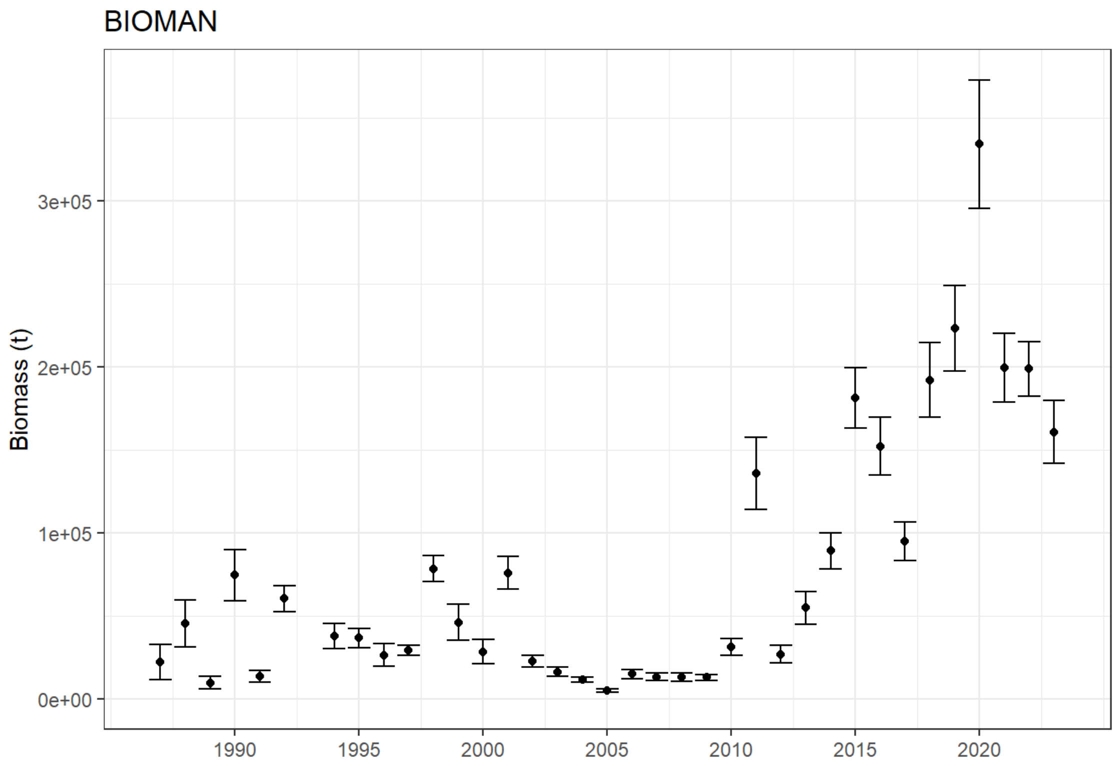

Figure 2.6: Bay of Biscay anchovy. Time-series of SSB from the BIOMAN surveys. The vertical error bars represent the 95% confidence intervals.

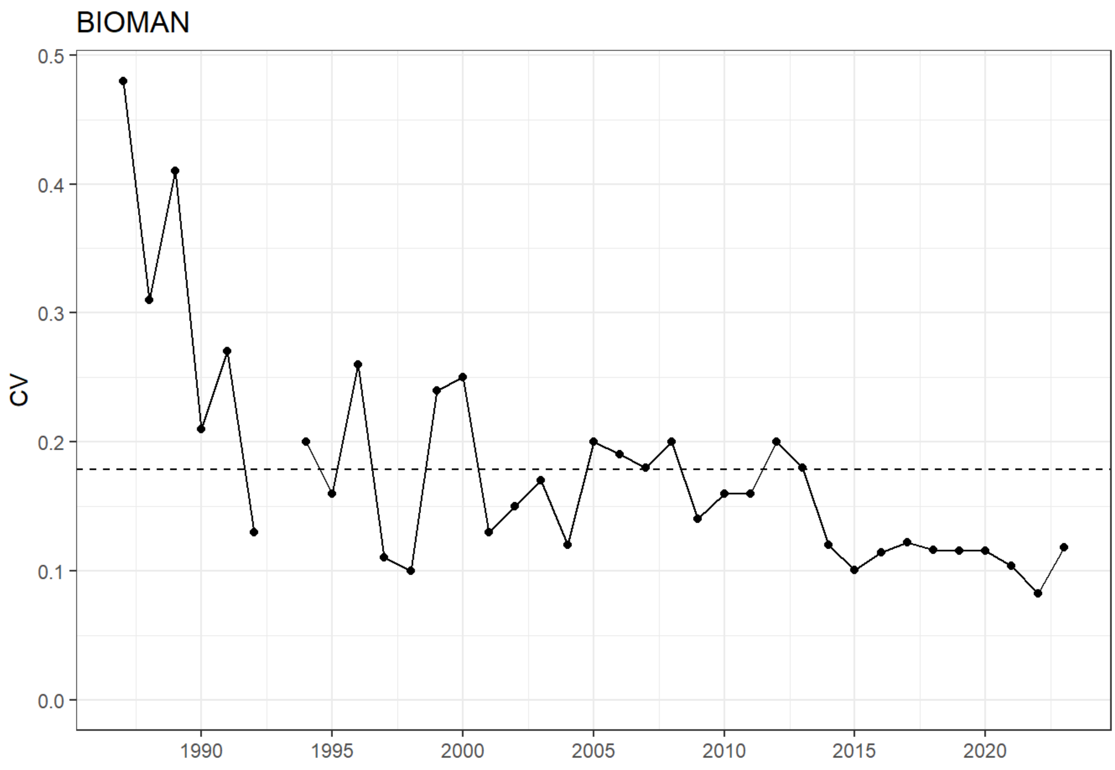

Figure 2.7: Bay of Biscay anchovy. Time series of the coefficient of variation (CV) of the SSB estimates from the BIOMAN surveys.

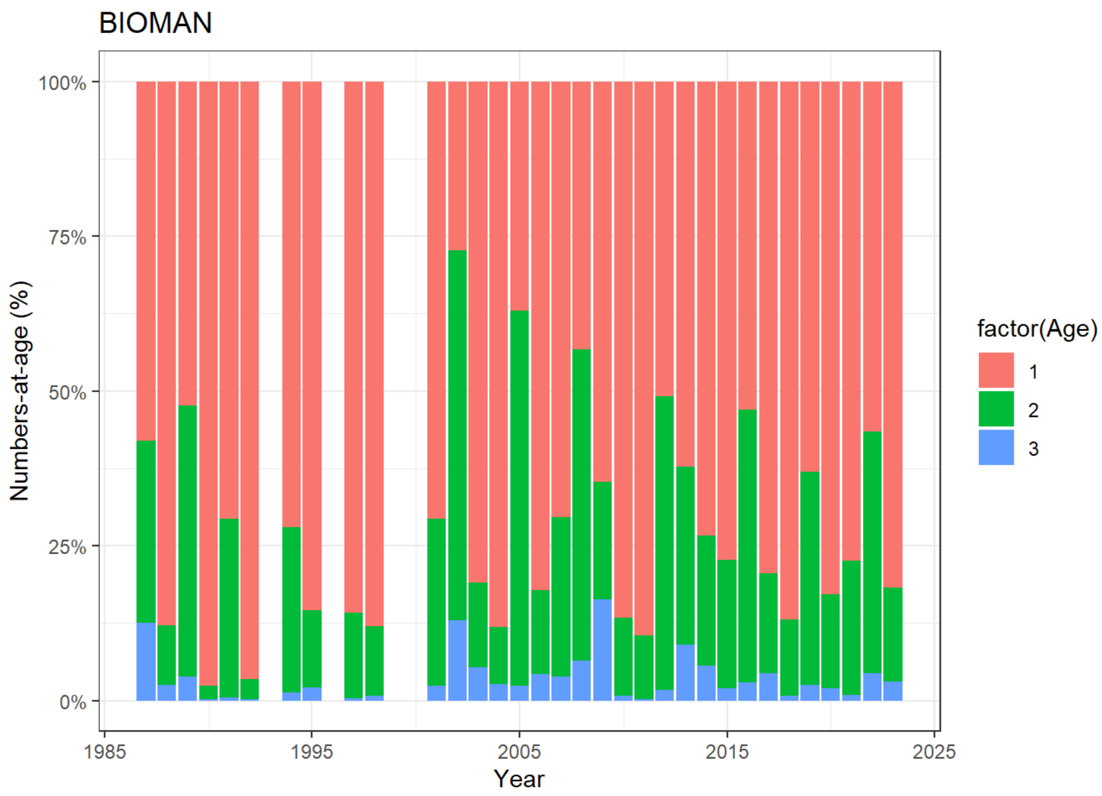

Figure 2.8: Bay of Biscay anchovy. Age structure (in %) from the BIOMAN surveys.

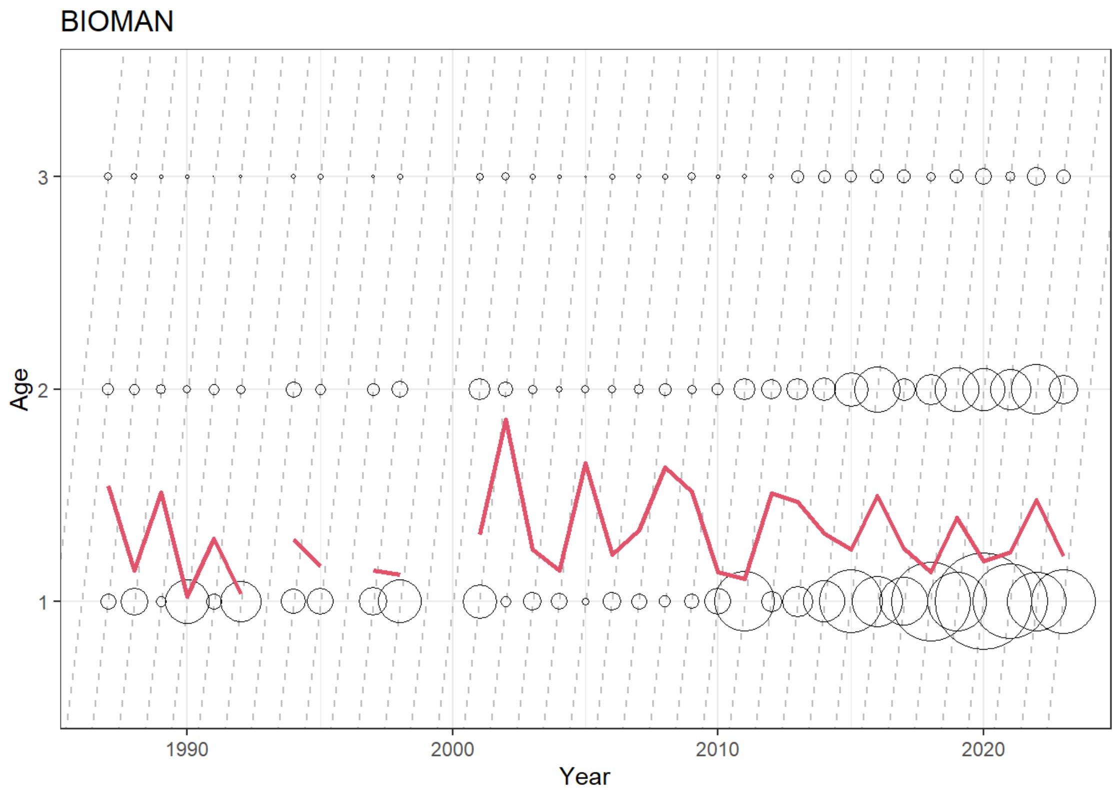

Figure 2.9: Bay of Biscay anchovy. Bubble plots of the numbers-at-age from BIOMAN surveys.

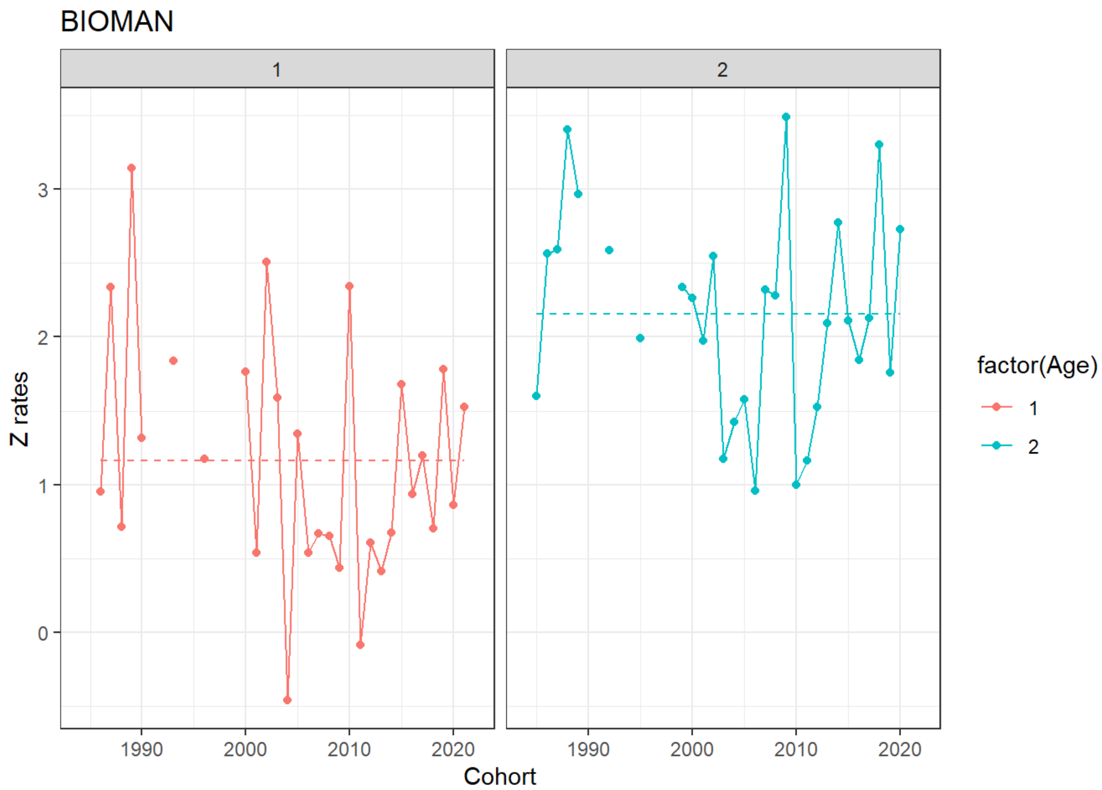

Figure 2.10: Bay of Biscay anchovy. Total mortality rates for ages 1 and 2 as estimated from the BIOMAN surveys.

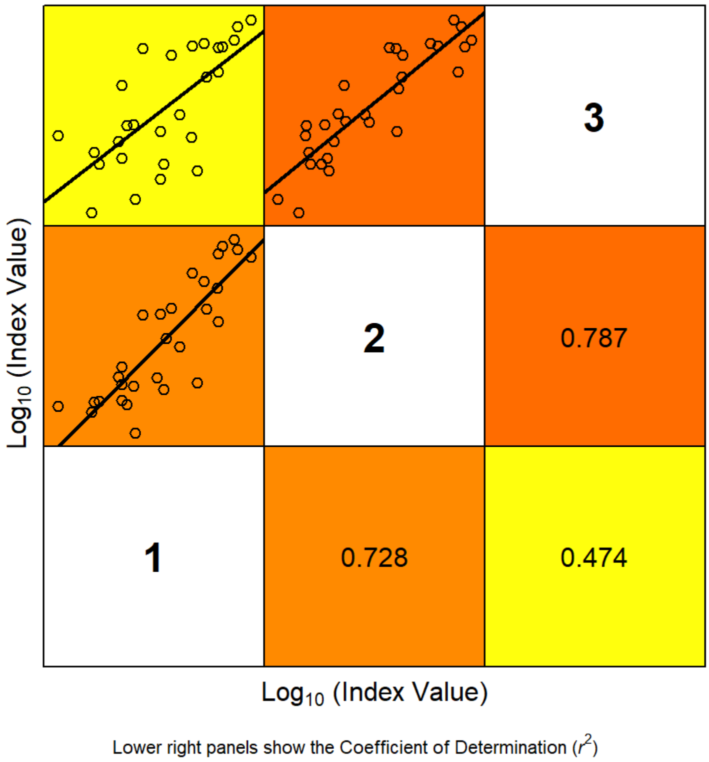

Figure 2.11: Bay of Biscay anchovy. Cross-correlation across cohorts from BIOMAN surveys.

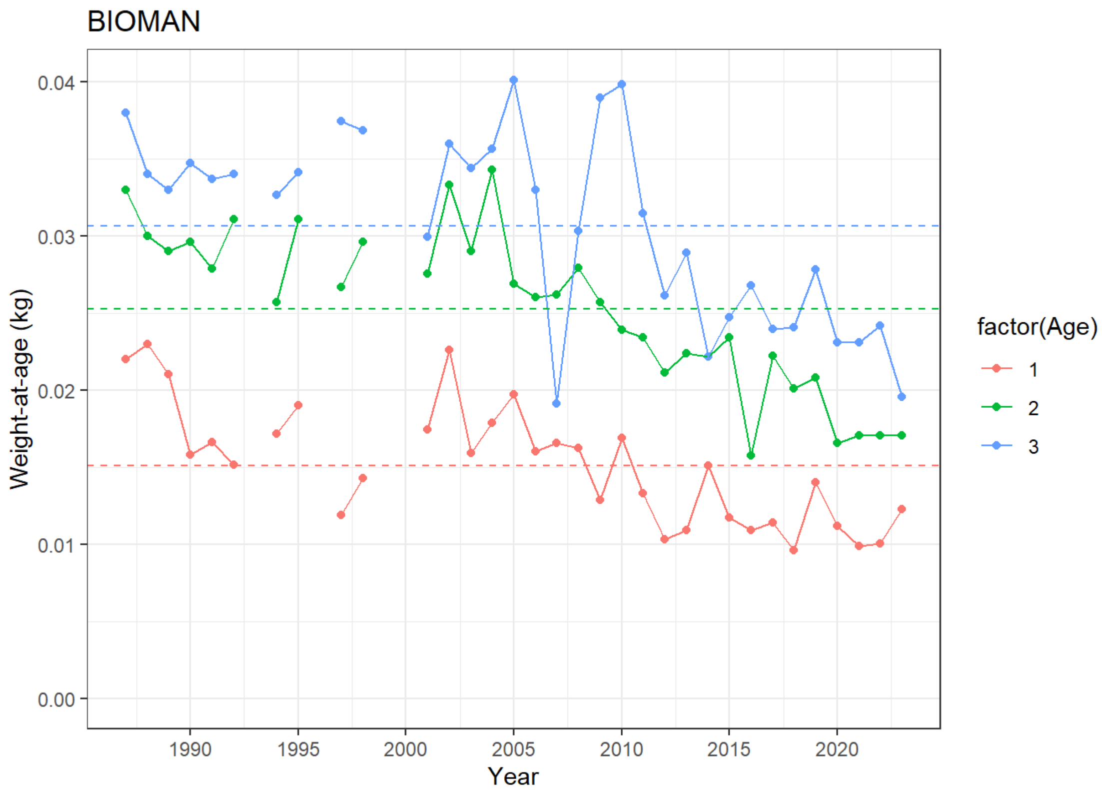

Figure 2.12: Bay of Biscay anchovy. Weight-at-age from BIOMAN surveys.

2.3.5.2 PELGAS

The PELGAS surveys started in 1989 and since 2000 is conducted as an integrated survey (Doray et al., 2018b). Initially it was designed to assess the biomass of anchovy in the Bay of Biscay in spring by acoustics. However, the sampling has been progressively extended to other ecosystem components. For stock assessment, PELGAS provides estimates of the SSB, age structure and biological parameters at spawning time, among others.

The time series of SSB is shown in Figure 2.13 and the associated coefficients of variation are in Figure 2.14. The age structure is shown in Figure 2.15 and Figure 2.16. Average total mortality at age from these surveys is around 1.27 for age 1, 1.88 for age 2 and 3.16 for age 3 (Figure 2.17). The internal consistency across ages from these surveys is quite good between ages 1 and 2 with correlations above 0.6 but decreases to 0.3 between ages 2 and 3+ (Figure 2.18). Weight-at-age at spawning time from PELGAS surveys is shown in Figure 2.19 with a clear decreasing trend already identified in the scientific literature.

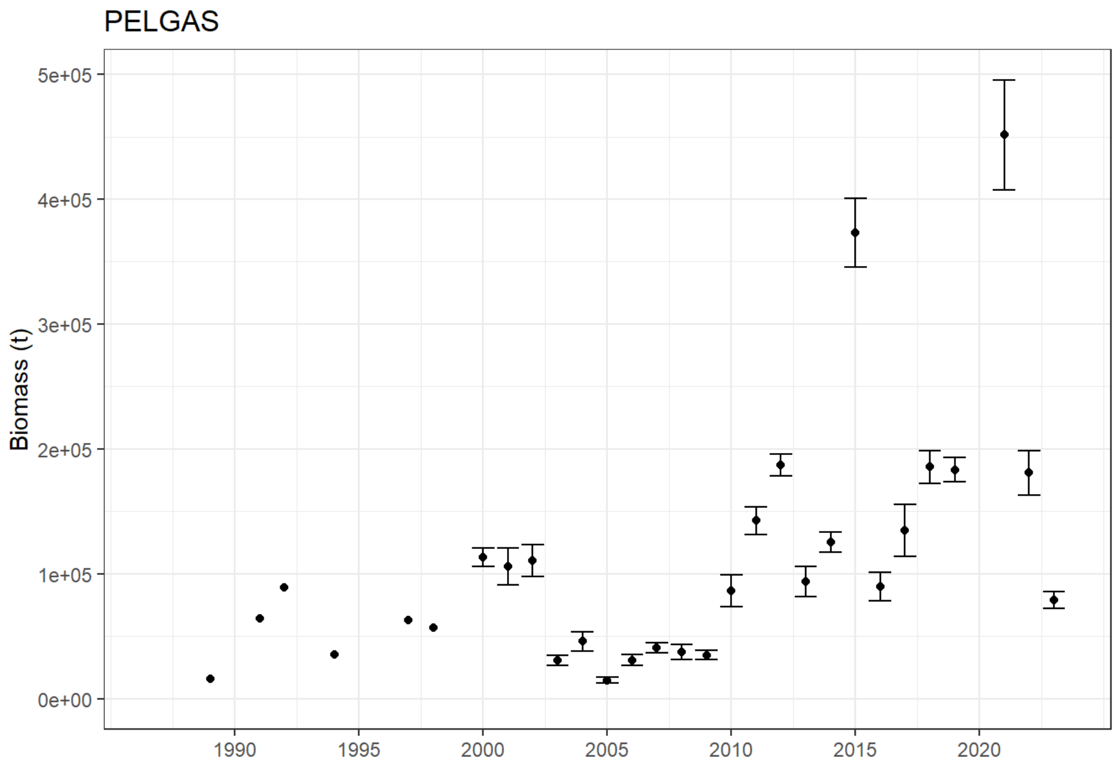

Figure 2.13: Bay of Biscay anchovy. Time-series of SSB from the PELGAS surveys. The vertical error bars represent the 95% confidence intervals.

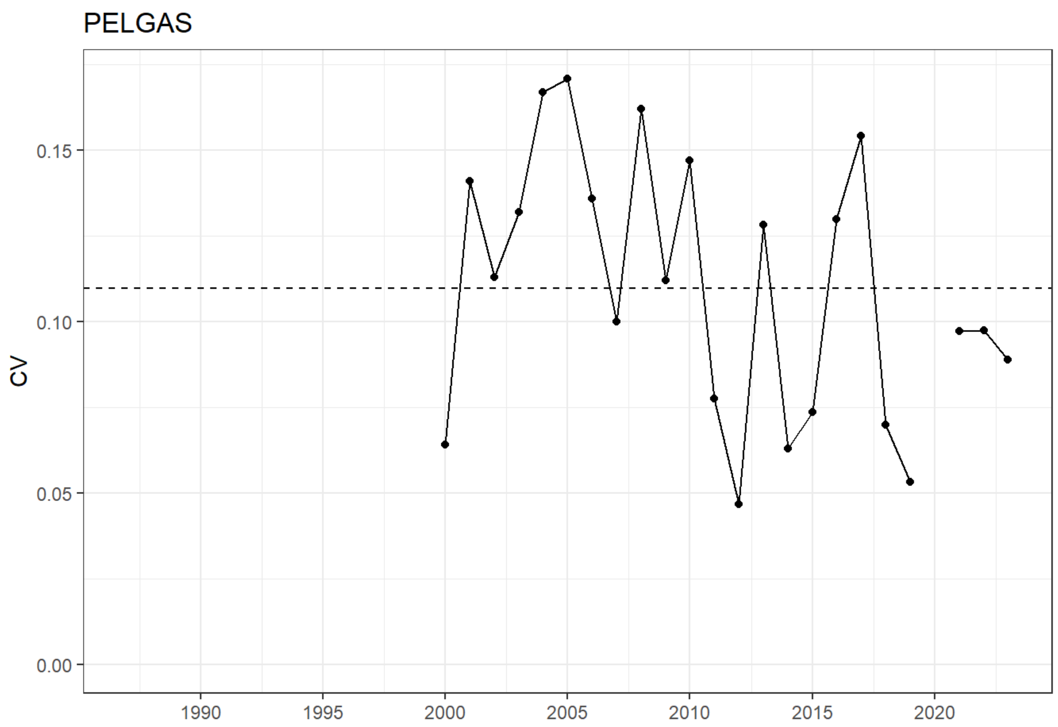

Figure 2.14: Bay of Biscay anchovy. Time series of the coefficient of variation (CV) of the SSB estimates from the PELGAS surveys.

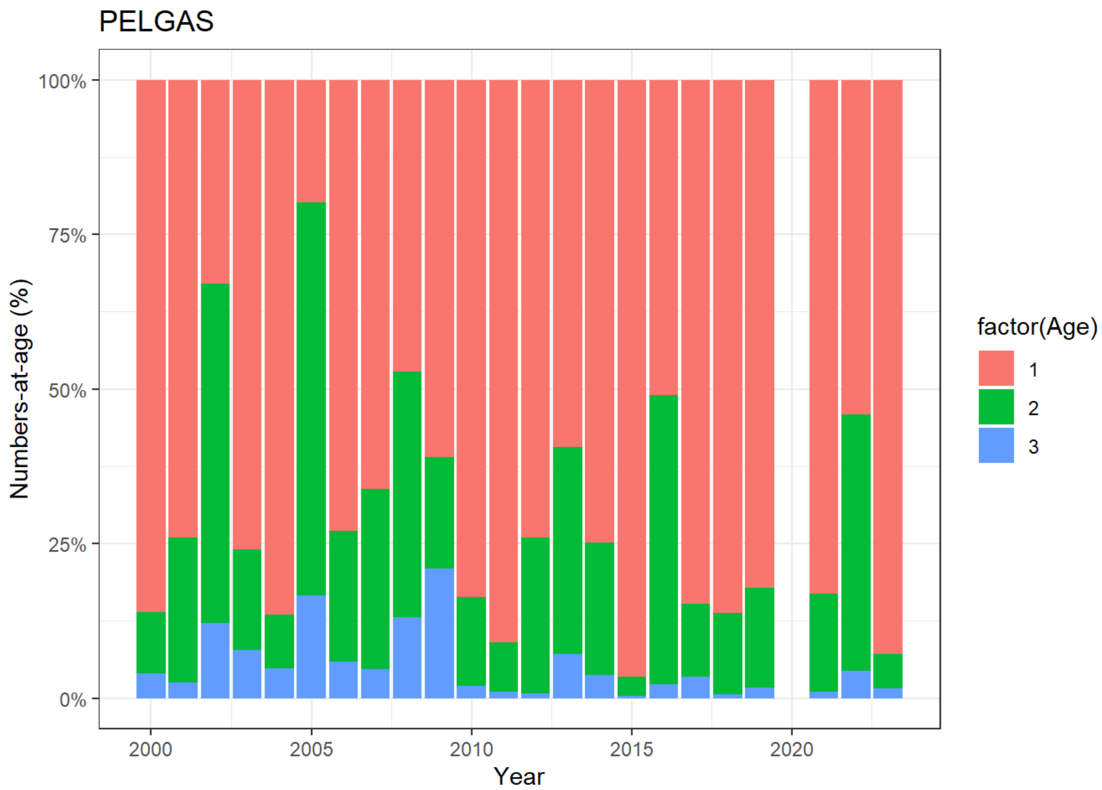

Figure 2.15: Bay of Biscay anchovy. Age structure (in %) from the PELGAS surveys.

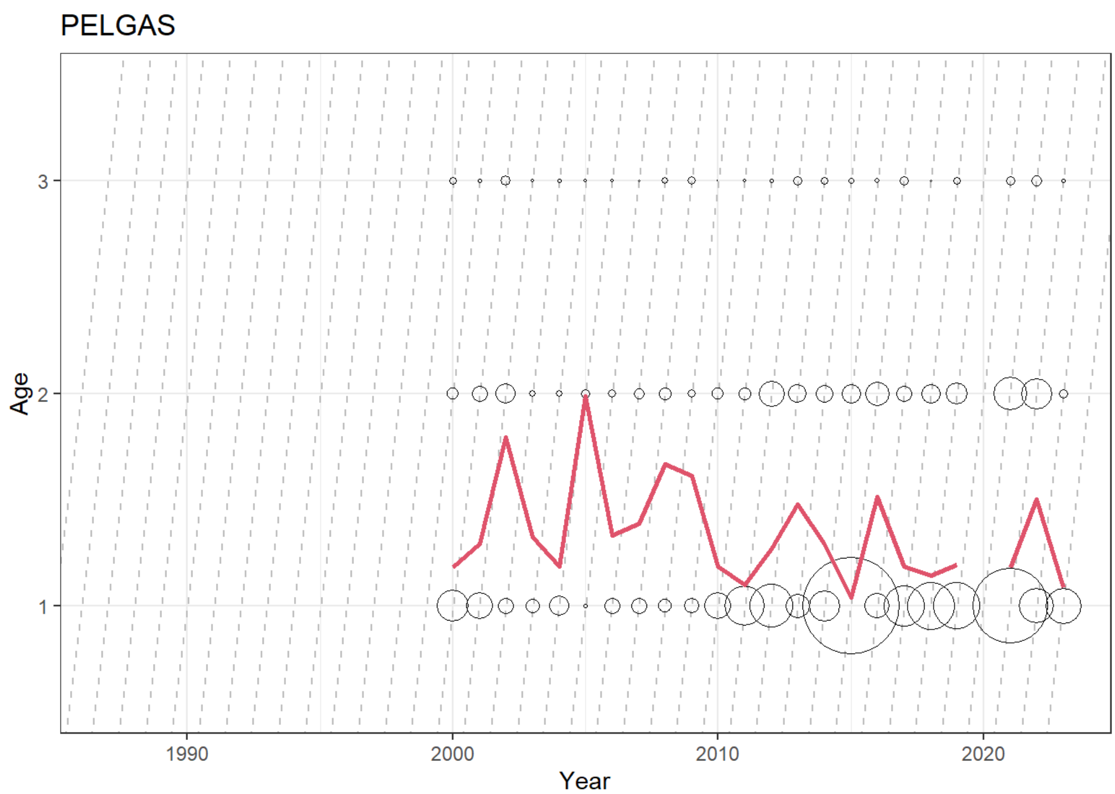

Figure 2.16: Bay of Biscay anchovy. Bubble plots of the numbers-at-age from PELGAS surveys.

Figure 2.17: Bay of Biscay anchovy. Total mortality rates for ages 1 and 2 as estimated from the PELGAS surveys.

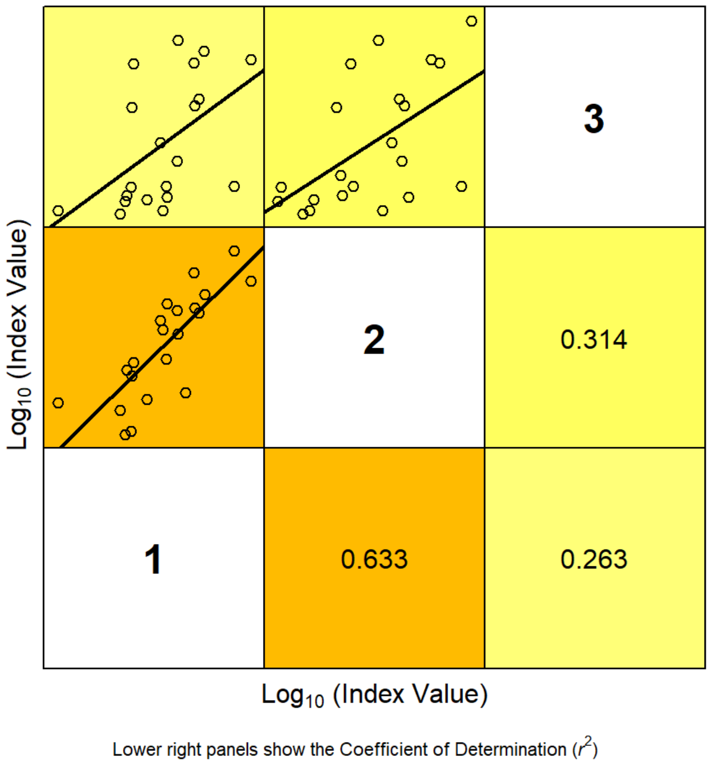

Figure 2.18: Bay of Biscay anchovy. Cross-correlation across cohorts from PELGAS surveys.

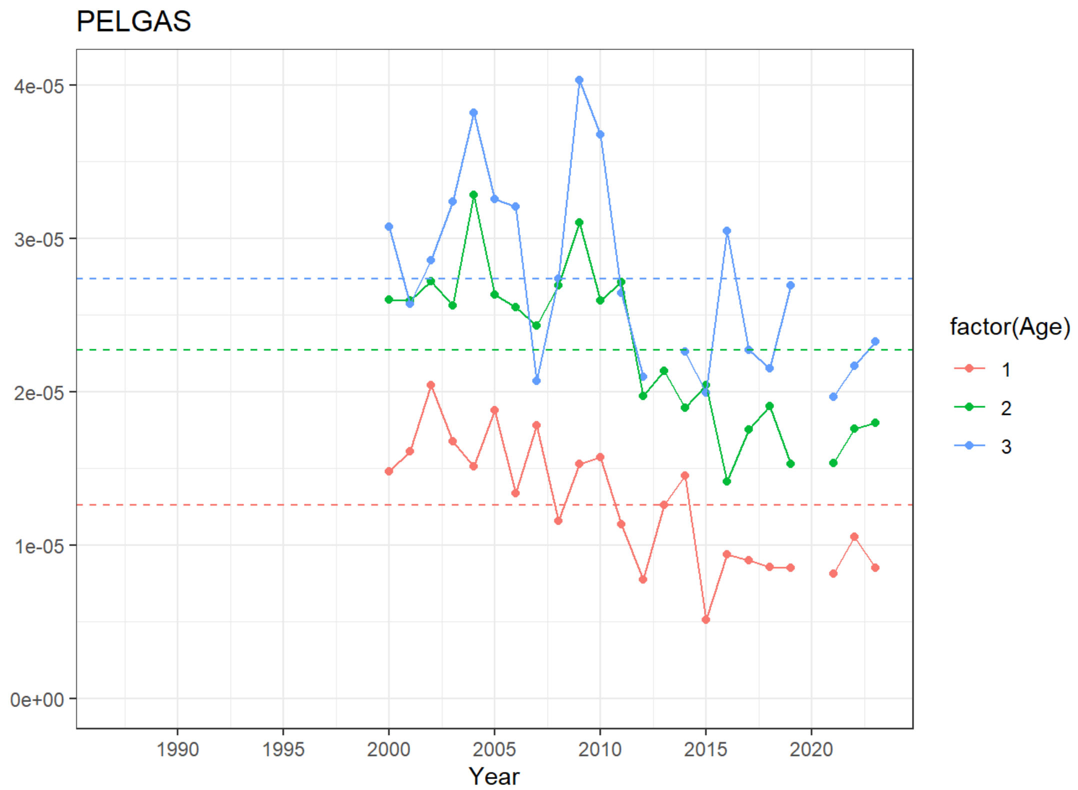

Figure 2.19: Bay of Biscay anchovy. Weight-at-age from PELGAS surveys.

2.3.5.3 JUVENA

The autumn acoustic survey JUVENA started in 2003 and provides estimates of the anchovy juveniles (Boyra et al., 2013). This index gives an early indication of the strength of next year's recruitment.

Before the benchmark, the JUVENA index in biomass was revised. The changes were very minor (Figure 2.20). The final JUVENA index in terms of biomass and numbers is shown in Figure 2.21.

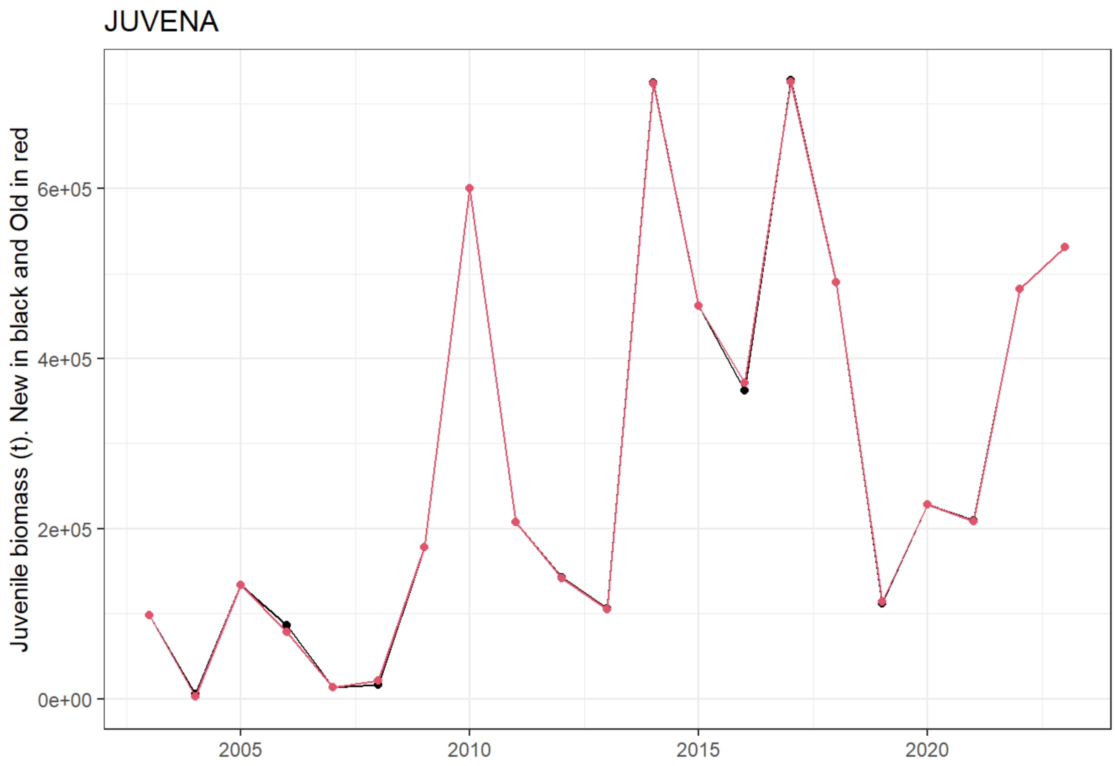

Figure 2.20: Bay of Biscay anchovy. Revision of the JUVENA time-series in biomass (new in black and old in red).

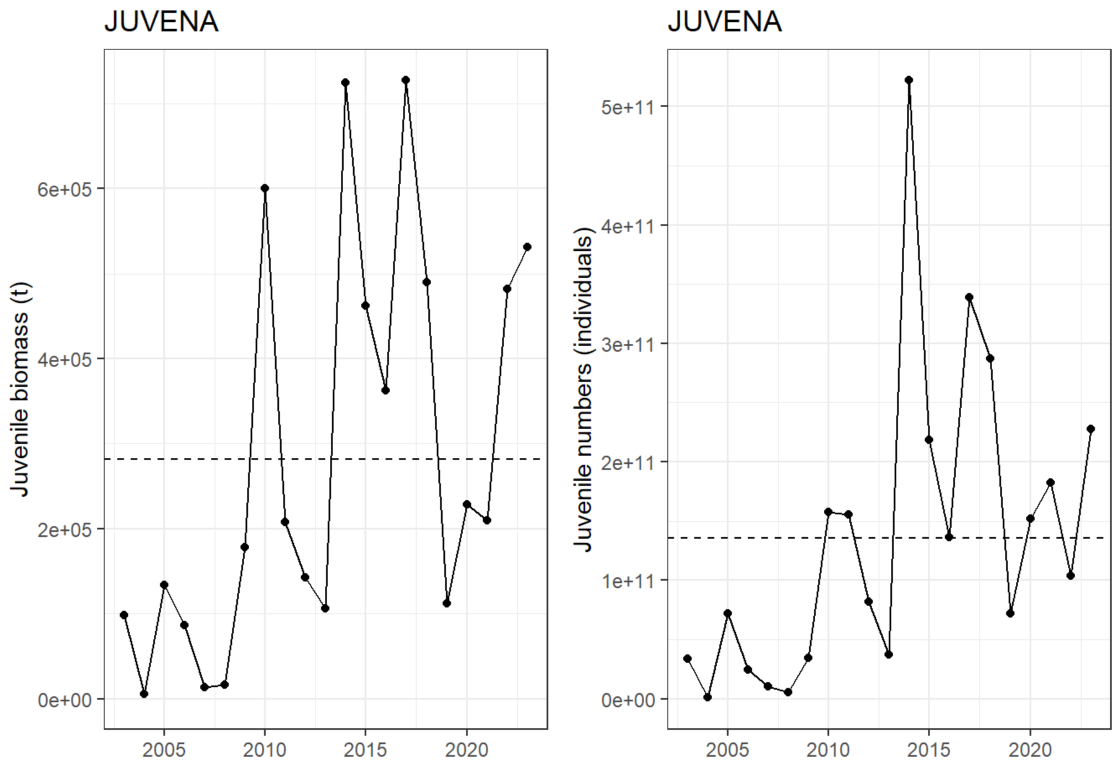

Figure 2.21: Bay of Biscay anchovy. JUVENA index in biomass in the left and in numbers in the right. The horizontal dashed lines represent the corresponding time-series average.

2.4 Stock assessment

The assessment of anchovy in the Bay of Biscay was carried out using Stock Synthesis (SS) (Methot and Wetzel, 2013). SS is a highly flexible length/age-structured population dynamics model that lies within a general class of models termed integrated analysis (Maunder and Punt, 2013). This type of model combines several sources of data into a single analysis. SS is coded in C++ with parameter estimation enabled by automatic differentiation though AD Model Builder ADMB (Fournier et al., 2012). It has been developed over the last 30 years and has been applied in a wide variety of fish stock assessments globally.

All models described here were run under the windows platform with SS version 3.30.22.beta, similar to version 3.30.22.1 (https://github.com/nmfs-ost/ss3-source-code/releases/tag/v3.30.22.1) but with a correction on the reported SSB due to bug that was spotted during the data exploration process before the benchmark. The bug was reported to the SS team and they provided a new corrected executable (version 3.30.22.beta) that was used during the benchmark. This executable is available at WKBANSP ICES SharePoint. All analysis were performed in R version 4.3.2 (R Core Team, 2024) making use of SS related packages r4ss (Taylor et al., 2021) and ss3diags (Winker et al., 2024).

2.4.1 Exploratory assessments

Several model configurations were explored mainly with SS software but also with the previous Bayesian two-stage biomass-based model (CBBM, Ibaibarriaga et al., 2011). SS was chosen as the new stock assessment model due to its high flexibility, its wide application and the available documentation and support from the SS teams in comparison with the ad-hoc CBBM model. Moreover, while the CBBM takes more than 8 hours for a single run, SS showed to be very fast for parameter estimation (less than a minute per run for this case study) which facilitated a wider range of exploratory trials.

All the exploratory runs were fitted using the following available data:

- Total catch and catch at age for the commercial fishery (catch at age 0 is not included),
- SSB and age structure from the acoustic and DEPM surveys,
- The recruitment index from the autumn juvenile acoustic survey,
- Weights at age from the commercial fishery and the surveys,
- Maturity is 0 for age 0 individuals and 1 for age 1 on.

The CBBM model was configured to run using two age classes: 1 and 2+. For the new SS model the age classes were extended to 0, 1, 2 and 3+.

2.4.1.1 Exploratory assessments in CBBM

A full description of the CBBM and its settings is provided in the Stock Annex for Bay of Biscay anchovy (ICES, 2013).

Three exploratory runs were performed with the CBBM:

- Ref: Same run as in WGHANSA 2023 (ICES WGHANSA 2023), but with JUVENA index updated. This run was intended to assess the impact of the JUVENA series update.
- Selblock: Two blocks (1987-2009 and 2010-onwards) for age 1 selectivity in each of the semesters. This run aimed at accounting for changes in the fishery selectivity before and after the fishery closure (2005-2009) and reduce the residual patterns observed in recent years.
- Gblock: Two blocks (1987-2000 and 2001-onwards) for growth rates by age. This run tried to assess if the changes in weight-at-age observed for this stock (Doray et al., 2018a, Taboada et al., 2023) could affect the stock assessment results.

Results for the three runs are compared in Figure 2.22. The update of the JUVENA index did not have an impact on the resulting estimates compared to the most recent assessment (ICES WGHANSA 2023). When two time-blocks were included for age 1 selectivities (Selblock), the age 1 selectivities in the first and second semester were larger in the first period (1987-2009) than in the second one (2010-onwards) after the fishery closure (Table 2.2). As a result, the fishing mortality estimates by semester differed from the reference model (Table 2.2). Alternatively, the model with two time-blocks for growth rates by age did not show any differences on the growth parameters between the two periods nor on the resulting fishing mortalities (Table 2.2). In both cases, the Gblock and Selblock options, the estimated recruitment and SSB were very similar to the reference model (Figure 2.22).

Figure 2.22: Bay of Biscay anchovy. Estimated fishing mortality in semesters 1 and 2, recruitment at age 1 and SSB with the corresponding 95% probability intervals from the three exploratory runs with the CBBM model. In the top the comparison between the results from the 2023 WGHANSA assessment and the same model with the updated Juvena survey (ref). In the middle the comparison between the ref model and the Selblock model, and in the bottom the comparison between the ref model and the Gblock model.

Table 2.2: Bay of Biscay anchovy. Comparison of estimated age 1 selectivity parameters (5, 50 and 95th percentiles) between the ref and Selblock runs (top table) and estimated growth rate parameters (5, 50 and 95th percentiles) between the ref and Gblock runs (bottom table).

		sel1sem1			sel1sem2		
		0.05	0.5	0.95	0.05	0.5	0.95
ref	all	0.396	0.460	0.539	0.849	1.025	1.218
	1987-2009	0.448	0.544	0.664	1.053	1.354	1.712
Selblock	2010-on	0.298	0.377	0.481	0.627	0.807	1.035

		logG1			logG2			psig		
		0.05	0.5	0.95	0.05	0.5	0.95	0.05	0.5	0.95
ref	all	-0.726	-0.621	-0.523	-1.800	-1.528	-1.304	21.527	29.615	40.130
	1987-2000	-0.881	-0.649	-0.459	-2.219	-1.643	-1.233	20.524	28.834	38.708
Gblock	2001-on	-0.740	-0.617	-0.511	-1.738	-1.462	-1.225			

2.4.1.2 Exploratory assessments in Stock Synthesis

2.4.1.2.1 Initial run

The initial configuration for the SS model was set up to be similar to the previous CBBM model with the following assumptions (Model 0):

- The model considered two semesters: January-June and July-December. In order to estimate different selectivities for each semester, the commercial fleet was split into two fleets so that the first fleet operates only in the first semester and the second fleet only in the second semester.
- Spawning time was set at mid-May.
- Settlement was set at first July.
- DEPM aggregated index was modelled as a SSB index at spawning time assuming a simple (linear function) catchability model with extra standard error parameter.
- Acoustic aggregated index was modelled as a biomass index at spawning time assuming a simple catchability model (linear function) with extra standard error parameter.
- Juvenile index was modelled as a recruitment index in numbers in mid-September assuming a nonlinear catchability model (power function) with extra standard error parameter.
- The selectivities for the commercial fleets were fixed to 0 for age 0 and to 1 for ages 2 and 3+. Selectivities for age 1 were estimated by the model.
- Selectivities for the acoustic and DEPM survey were fixed to 0 for age 0 and 1 for ages 1,2, and 3+.
- An initial sample size of 50 was assumed for all age composition data (acoustic and DEPM surveys and fishery).

- Annual recruitments were modelled as deviations from a mean (no stock-recruitment model fitted) with a standard deviation of natural log recruitment (sigmaR) equal to 0.8.
- The initial equilibrium catch provided to the model was the average of total catches in the period 1978-1986 (3 generation times before the first year in the assessment).
- Natural mortalities were the same as in the previous CBBM model: M1=0.8 and M2=M3+=1.2.
- Given that in the previous model the 0 age class was not included, an assumption for natural mortality at age 0 for the new SS model was needed. The Gislason model based on the growth parameters from Uriarte (2015) resulted in natural mortality values for age 0 (M0_gis) and age 1 (M1_gis) of 3.96 and 1.46 respectively. As the natural mortality for age 1, was assumed to be known (M1=0.8), M0 for the new assessment was computed by scaling M1 according to the results from the Gislason model:

$$M0 = M1 * (M0\_gis/M1\_gis) = 2.17.$$

The modelling process started from this initial SS configuration, which is as close as possible to the previous model (CBBM). Then, alternative model configurations (fisheries selectivities, survey catchability, survey selectivies, natural mortality, recruitment modelling, data weighting) were explored. The specific path followed for selecting the final model is explained in detail in the remaining of section 2.4.1.2.

Model selection did not only take into account the obtained diagnostics, but also their interpretation in terms of estimated parameters. In accordance with Annex 3 of ICES (2023), for each of the modelling steps, we examined if the obtained parameter estimates were meaningful and we produced diagnostics for convergence (final gradient, checking estimated parameters did not hit the bounds, standard deviations) and for residuals analysis (patterns, runs tests, RMSE, etc). At some specific steps (e.g. natural mortality analysis) likelihood profiles were analysed. The jittering analysis and the retrospective patterns were included at a later stage for final decision making. All these model diagnostics and some parameter estimates are summarised in Table 2.4 as requested by ACOM during the benchmark revision process. It must be taken into account that the hindcasting diagnostics shown in this table were not calculated during the benchmark workshop, but were added during the benchmark revision process. In addition, not all the model fits in the table can be compared in terms of AIC, given that some components of the likelihood may have different weights (see for instance section 2.4.1.2.5). Estimated SSB and recruitment (at age 0) for the initial run and all exploratory runs are shown in Figure 2.23.

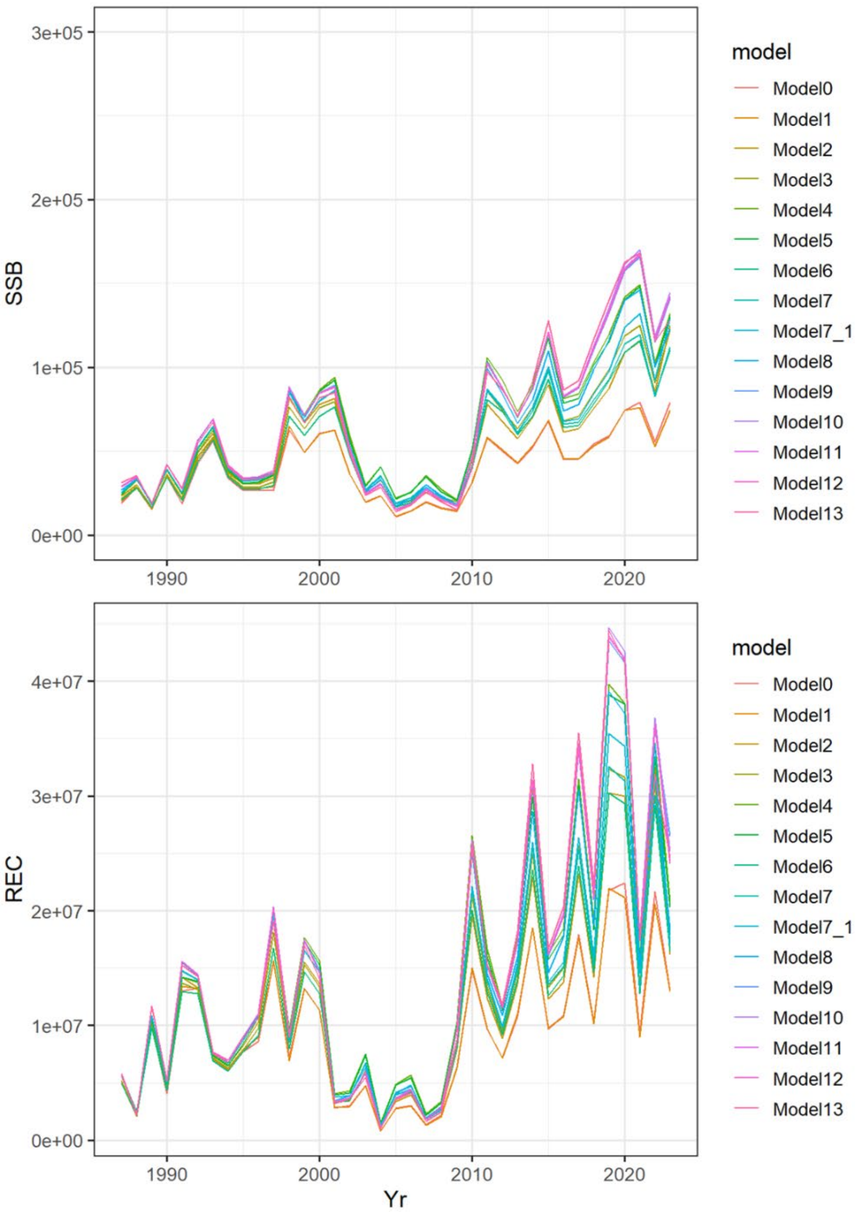

Figure 2.23: Bay of Biscay anchovy. Estimated SSB and recruitment for all SS exploratory models.

Table 2.3: Bay of Biscay anchovy. Description of SS exploratory runs.

Run	Description	Report section
Model0	Initial run mimicking the current CBBM assessment settings	Section 2.4.1.2.1
Model1	Commercial fleet selectivity for age 0 equal to 0 and for age 2 equal to 1, and estimated selectivities for ages 1 and 3+ with two time-blocks (1987-2009 and 2010-onwards) Acoustic survey selectivity for age 0 equal to 0 and for ages 2 and 3+ equal to 1, and estimating selectivity for age 1 with two time-blocks (1987-2006 and 2007-onwards). DEPM survey selectivity for age 0 equal to 0 and for ages 1,2 and 3+ equal to 1 +.	Section 2.4.1.2.2
Model2	Commercial fleet selectivity for age 0 equal to 0 and for age 2 equal to 1, and estimated selectivities for ages 1 and 3+ with two time-blocks (1987-2009 and 2010-onwards) Acoustic and DEPM survey selectivity for age 0 fixed at 0 and for age 2 fixed at 1, and estimated selectivity for ages 1 and 3+. No time-blocks.	Section 2.4.1.2.2
Model3	Commercial fleet selectivity for age 0 equal to 0 and for age 2 equal to 1, and estimated selectivities for ages 1 and 3+. No time-blocks. Acoustic and DEPM survey selectivity for age 0 fixed at 0 and for age 2 fixed at 1, and estimated selectivity for ages 1 and 3+. No time blocks.	Section 2.4.1.2.2
Model4	As Model0 but estimating natural mortality for age 3+ within the SS model.	Section 2.4.1.2.3
Model5	As Model0 but estimating natural mortality for ages 2 and 3+ within the SS model, being M2=M3+.	Section 2.4.1.2.3
Model6	As Model0 but estimating natural mortality for ages 2 and 3+ within the SS model.	Section 2.4.1.2.3
Model7	Combination of selectivity settings in Model 1 and natural mortality settings in Model4. Power function for catchability of JUVENA index.	Section 2.4.1.2.4
Model7_1	Combination of selectivity settings in Model 1 and natural mortality settings in Model4. Linear function for catchability of JUVENA index.	Section 2.4.1.2.4
Model8	As Model7_1 but with data weighting (Francis method with single iteration)	Section 2.4.1.2.5
Model9	As Model 8, but including a Ricker SR model.	Section 2.4.1.2.6.1
Model10	As Model 8, but including a Beverton-Holt SR model.	Section 2.4.1.2.6.1
Model11	As Model 9 but with no bias correction (option 0 in SS).	Section 2.4.1.2.6.1
Model12	As Model9 but with constant bias correction (option -1 in SS).	Section 2.4.1.2.6.1
Model13	As Model12 but including random walks for the commercial fleets selectivities at ages 1 and 3+	Section 2.4.1.2.6.2

Table 2.4: Bay of Biscay anchovy. Negative log likelihood, AIC, total number of parameters, non-deviation number of parameters, maximum gradient, runs test output for all components, RMSE for surveys and age composition, Retro Mohn's rho for SSB, recruitment and F, forecast rho for SSB, MASE for all components and estimated parameters (catchabilities, log(R0), B0, steepness, natural mortality at age 3+, coefficient of variation of terminal year SSB) for all SS exploratory runs. It must be taken into account that not all the models can be compared in terms of AIC as the different elements of the likelihood may have different weights.

run	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model7_1	Model 8	Model 9	Model10	Model11	Model12	Model13
nll	192.262	158.595	147.967	158.058	166.684	178.599	163.469	148.958	150.624	104.457	89.1222	91.3366	97.5984	88.3422	72.9854
AIC	412.5240	367.1900	347.9340	352.1160	359.3680	383.1980	352.9380	349.9160	351.2480	256.9140	226.2444	230.6732	243.1968	224.6844	177.9708
Npars	54	65	66	58	53	53	53	66	65	64	64	64	64	65	205
nodev_Npars	14	25	26	18	13	13	13	26	25	24	24	24	24	24	16
maxgrad	5e-05	0	6e-05	3e-05	5e-05	1e-05	3e-05	4e-05	2e-05	4e-05	4e-05	3e-05	8e-05	2e-05	1e-04
runstest_ac_idx	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
runstest_depm_idx	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed
runstest_juven_inx	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
runstest_age_comm_f1	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
runstest_age_comm_f2	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
runstest_age_ac	Failed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
runstest_age_depm	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Failed
RMSE_idx	63.2	62.3	63.3	61.2	60.9	60.8	61.2	61.9	63.5	60.5	57.4	57.5	57.4	57.4	55.6
RMSE_age	7	6.8	6.7	7	7.1	7.1	7.1	6.8	6.8	7	7.1	7.1	7.1	7.1	6.4
Retro_rho_SSB										0.61	0.47	0.51	0.41	0.47	0.29
Forec_rho_SSB										0.06	0.01	0.05	-0.02	0.02	-0.07
Retro_rho_rec										-0.33	-0.30	-0.27	-0.32	-0.30	-0.30
Retro_rho_F										-0.33	-0.26	-0.28	-0.22	-0.26	-0.17
MASE_ac_idx										0.76	0.85	0.85	0.86	0.86	0.86

run	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model7_1	Model 8	Model 9	Model10	Model11	Model12	Model13
MASE_depm_idx										3.12	2.74	2.60	2.99	2.72	2.88
MASE_juven_idex										1.35	0.54	0.65	0.76	0.55	0.56
MASE_age_comm_f1										0.93	0.90	0.91	0.94	0.90	0.79
MASE_age_comm_f2										0.83	0.81	0.78	0.88	0.81	0.79
MASE_age_ac										1.74	1.58	1.58	1.58	1.58	1.45
MASE_age_depm										1.42	1.27	1.27	1.37	1.27	1.15
SR_par2	-0.902893	-0.869068	-1.00312	-1.05968	0.99	0	0.99	0.99	0.99	0.99	1.39932	0.580652	1.06382	1.4021	1.4021
M3	1.2	1.2	1.2	1.2	2.37064	1.55031	2.6707	2.11478	2.11678	2.24791	2.26185	2.28296	2.26366	2.2619	2.2619
q_ac	2.33	2.61	1.84	1.74	1.42	1.44	1.77	1.79	1.75	1.65	1.6	1.57	1.59	1.59	1.62
q_depm	1.36	1.36	1.26	1.23	0.87	0.88	1.07	0.98	0.96	0.92	0.9	0.88	0.89	0.89	0.91
q_juv	0.02	0.02	0.03	0.02	0.01	0.01	0.02	0.01	6.32	5.91	5.64	5.57	5.64	5.64	5.75
LN_R0	15.77	15.77	15.95	15.97	16.13	16.11	15.93	16.03	16.04	16.09	16.83	16.93	16.62	16.85	16.84
CV_SSB2023	0.32	0.32	0.34	0.29	0.26	0.28	0.28	0.31	0.31	0.29	0.29	0.3	0.29	0.29	0.29
B0	72506	72582.9	87110.8	89021.1	95858.5	95046.2	83036.1	88169.6	89047.4	92394.4	193909	215349	157002	198789	197082

2.4.1.2.2 Alternative selectivity patterns

In addition to the initial selectivity configuration, other alternatives were explored:

- Model 1: Fixing commercial fleets selectivity for age 0 to 0 and for age 2 to 1, and estimating selectivities for age 1 and 3+; fixing acoustic survey selectivity for age 0 to 0 and for age 2 and 3+ to 1, and estimating selectivities for age 1; fixing DEPM survey selectivity for age 0 to 0 and for ages 1,2 and 3+ to 1 with the following time-blocks:
  - Two time-blocks for the commercial fleet selectivity: 1987-2009, 2010-2023 (representing the period before and after the fishery closure)
  - Two time-blocks for the PELGAS acoustic survey selectivity: 1987-2006, 2007-2023 accounting for the start of the participation of commercial vessels in PELGAS from 2007 on (Doray et al. 2018b).

- Model 2: Fixing selectivity for age 0 to 0 and for age 2 to 1 and estimating selectivities for age 1 and 3+ for all fleets (commercial and surveys) + time blocks (only for commercial fleets).
- Model 3: Fixing selectivity for age 0 to 0 and for age 2 to 1 and estimating selectivities for age 1 and 3+ for all fleets (commercial and surveys) with no time blocks.

The first option was the preferred one as it gave more flexibility to the commercial fleets for which the selectivity is less well known, and it assumed that all ages (>0) were fully selected in the spring surveys with the exception of the age 1 for the spring acoustic survey for which age 1 selectivity is estimated in two blocks, due to the improvement on the PELGAS survey since 2007.

The trial runs where the indices' selectivities for age 3 were estimated by the model showed very low values (Figure 2.24) (in contrast to the assumption of age 3 being fully selected in the surveys). This suggested that the natural mortality assumptions may have to be revised (explored in the next section).

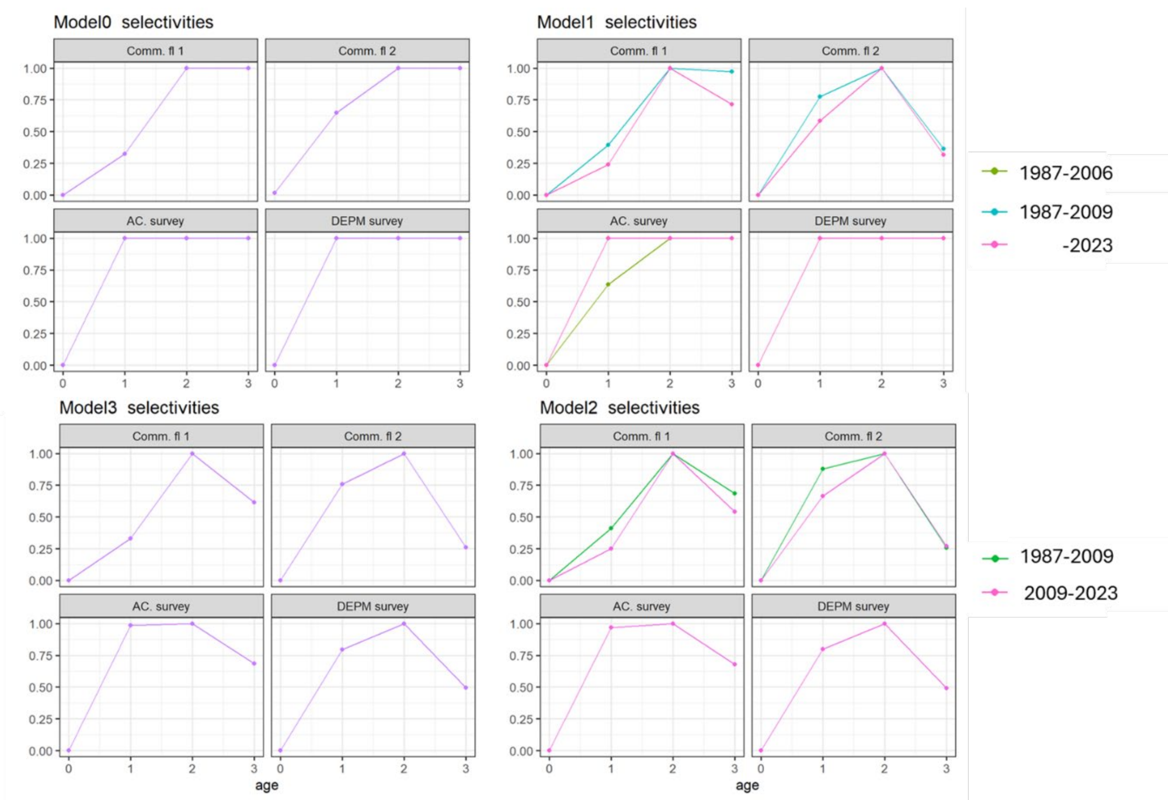

Figure 2.24: Bay of Biscay anchovy. Selectivities for the initial run (Model 0) and the exploratory runs on selectivity configuration (Model 1, 2, and 3)

2.4.1.2.3 Alternative natural mortality

In the initial run (Model0) the natural mortality for ages 1,2 and 3+ was fixed to be the same as used in the CBBM model. However, the new SS model included more age classes than the CBBM, which led the group to consider the exploration of alternative natural mortality vectors. Moreover, the results from the exploratory runs with different selectivity patterns (section 2.4.1.2.2) where the estimated selectivities for age 3+ were very low, suggested that there may be some issues with the assumption taken for natural mortality for age 3+ (M2=M3+=1.2).

The following options were tested (rest of the configuration same as in the initial run):

- Model 4: Estimate natural mortality for age 3+ within the SS model
- Model 5: Estimate natural mortality for ages 2 and 3+ within the SS model, forcing them to take the same value
- Model 6: Estimate natural mortality for ages 2 and 3+ within the SS model as independent parameters. Note that when estimating natural mortality for one or more ages within SS, the model uses natural mortalities by season without the option of fixing the natural mortalities to be the same for the two seasons for a specific age. For Model 6, a model where natural mortality for age 3+ was estimated was configured, and then, a likelihood profiling was performed through values for natural mortality at age 2, using the same values for the two seasons.

The resulting natural mortality vectors from these models (Model0, Model4, Model5 and Model6) are shown in Table 2.5.

Trials on natural mortality estimation within the SS model suggested that the natural mortality for age 3+ is higher than for age 2 (more trials than the ones shown here also confirmed the same pattern). Natural mortality values in the previous model were based on the work presented in the previous benchmark (ICES WKPELA 2013) and the work in Uriarte et al. (2016). It was decided that this evidence should remain. Thus, natural mortality for ages 1 and 2 was kept as in the previous model and natural mortality for age 3+ was estimated within the SS model (Model 4), which resulted in a higher value than the natural mortality for age 2.

Table 2.5: Bay of Biscay anchovy. Natural mortality at age for the initial run (Model 0) and the exploratory runs on natural mortality (Models 4, 5 and 6). Numbers in bold are estimated values within the SS model, while the rest of the numbers are fixed values.

	M0	M1	M2	M3+
Model 0	2.17	0.8	1.2	1.2
Model 4	2.17	0.8	1.2	**2.37**
Model 5	2.17	0.8	**1.55**	**1.55**
Model 6	2.17	0.8	**0.9**	**2.67**

2.4.1.2.4 Linear catchability for the recruitment survey

Based on the above results, a new model run with the preferred options regarding fishery (Section 2.4.1.2.3) and survey selectivities (Section 2.4.1.2.4) was conducted.

- Model 7: Combination of Model 1 and Model 4 (preferred options).

This model had the same configuration for the catchability of the JUVENA recruitment index as the initial run (Model0) and the CBBM, namely. This power function configuration (Model7) was compared to the linear catchability configuration (Model7_1).

- Model 7_1: similar to Model 7 with linear catchability parameter for the recruitment index

These two models showed no significant differences in the model output and performance (difference in AIC < 2, Table 2.3. Thus, the linear catchability configuration was preferred as the most parsimonious option (Model 7_1).

2.4.1.2.5 Data weighting

For the initial run a sample size of 50 was set for all age composition datasets (fisheries by semester, DEPM survey and acoustics survey). However, SS has three different options for age composition data weighting (Methot et al., 2020):

- Francis method (iterative)
- McAllister-Ianelli method (iterative)
- Dirichlet-Multinomial method (non-iterative, extra parameters are estimated to scale sample sizes)

The three methods were tested for this case study. As the initial sample size is an upper bound on weighting for those data, all methods were tested using an arbitrary high starting sample size of 100 and 500, and 10 iterations were performed for the iterative methods.

Looking at the sensitivity to the starting sample size, the Francis method resulted to be the most stable one (Figure 2.25). Performing multiple iterations led to huge differences between datasets' final samples sizes that were not expected and were not considered to be realistic. Following the SS manual suggestion, a single iteration was deemed sufficient in this case. Thus, the Francis method, with a single iteration, was selected as the data weighting method to apply for the final run. As a result, the following run was conducted:

Model 8: Similar to Model 7_1 after data weighting, following these steps:

1) Run the model with the agreed configuration, letting the model estimate natural mortality at age 3+ (M3+).
2) Run one iteration of the Francis reweighting method, starting from a sample size of 100 for all fleets.
3) Final run with fixed natural mortality M3+ and sample sizes resulting from the previous step.

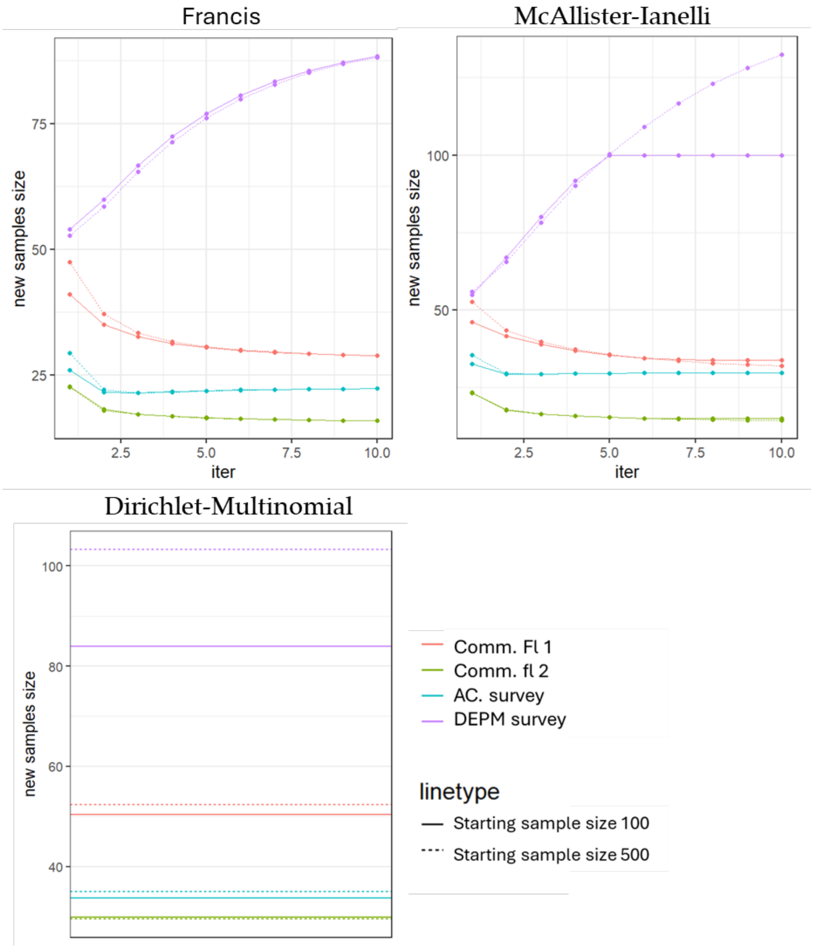

Figure 2.25:Bay of Biscay anchovy. Resulting sample sizes (y axis) after data weighting with three methods: Francis, McAllister-Ianelly and Dirichlet-Multinomial. Solid lines represent results when starting from a sample size of 100, and the dashed line when starting from a sample size of 500. Each colour represents a fleet.

2.4.1.2.6 Alternatives to improve retros

Once the explorations on selectivity, natural mortality and data weighting methods were performed, the preferred options were selected and applied (Model 8) and a retrospective analysis was carried out. This analysis showed high values for Mohn's rho statistic for SSB (>0.6) (Figure 2.26).

To better understand the high Mohn's rho values, a leave one out analysis was performed, leaving a dataset or more out of the model fit in each trial (Table 2.6). Removing the surveys did not improve the retrospective pattern. However, the analysis showed that the catch at age data had a big impact in the retrospective patterns: when removing these datasets the retro patterns improved a lot (Table 2.6).

In order to improve the retrospective patterns, two options were explored: (a) increasing the model stability by fitting a stock-recruitment model within the SS model and (b) giving more flexibility (through random walks) to the selectivity for the commercial fishery.

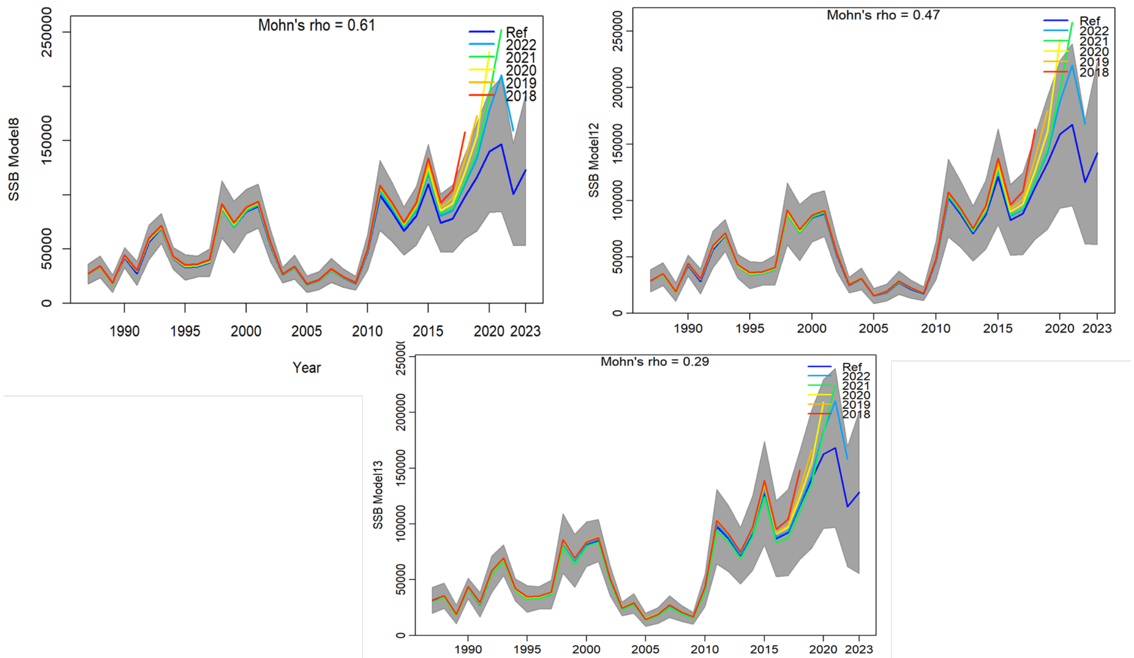

Figure 2.26: Bay of Biscay anchovy. Retrospective SSB estimates for Model 8, Model 12 and Model 13 with their corresponding Mohn's rho values.

Table 2.6: Bay of Biscay anchovy. Mohn's rho values of retrospective analysis performed for each model in the leave one out exercise.

Mohn's rho	SSB	REC	F
Leave out recruitment survey	0.62	-0.63	-0.32
Leave out acoustic survey number at age	0.98	-0.41	-0.44
Leave out acoustic survey number at age and SSB	0.58	-0.48	-0.3
Leave out DEPM survey number at age	0.86	-0.11	-0.42
Leave out DEPM survey number at age and SSB	1	0.04	-0.46
Leave out catch at age	0.32	-0.26	-0.31

Include a stock-recruitment model

Ricker and Beverton-Holt SR models were fitted within the SS model. In both cases, the steepness parameter was estimated within the model and then it was fixed to the estimated value to perform the retrospective analysis. Concerning recruitment deviations, main recruitment deviations were defined from the first to the last data years (1987-2023) and early recruitment deviations were defined a lifespan before the start of the model (1984-1986).

The following trials were run:

- Model 9: similar to Model 8 including a Ricker SR model.
- Model 10: similar to Model 8 including a Beverton-Holt SR model.

As for Model8, the process followed these steps:

1) Run the model with the agreed configuration, letting the model estimate natural mortality at age 3+ (M3+) and the steepness parameter of the Ricker or Beverton-Holt SR function.
2) Run one iteration of the Francis reweighting method, starting from a sample size of 100 for all fleets.
3) Final run with fixed natural mortality M3+, steepness and sample sizes resulting from the previous step.

Results showed that the inclusion of a SR model in the SS assessment model improved the retrospective patterns (Mohn's rho for SSB decreased from 0.61 to 0.47 and 0.51 with Models 9 and 10 respectively, Table 2.4). Both SR models produced very similar results (Figure 2.27). The Ricker model was selected as the preferred model based on some evidence of cannibalism and density dependence for this species (Bachiller et al., 2015).

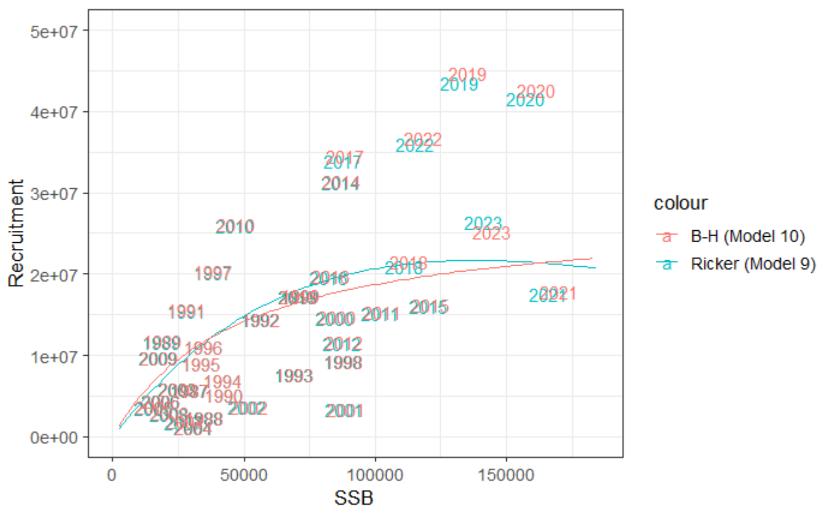

Figure 2.27: Bay of Biscay anchovy. Estimated stock-recruitment curve within SS and annual recruitments for Model 9 and Model 10.

<u>Recruitment bias correction:</u>

When a SR model is included, SS3 suggests applying a time variant bias correction for recruitment in order to deal with data years that can be more or less informative for recruitment (Methot and Taylor, 2011). For the Bay of Biscay anchovy case study, all the years are considered to be informative regarding recruitment, so it was decided not to apply the time variant bias correction. However, to further explore the impact of the bias correction, the following trials were run:

- Model 11: similar to Model 9 with no bias correction (option 0 in SS)
- Model 12: similar to model 9 with constant bias correction (option -1 in SS)

When a bias correction is applied (time variant in Model9 or constant in time in Model12) the expected recruitment after applying the bias correction is very similar to the expected recruitment from Model11 when no bias correction is applied (Figure 2.28). However, if no bias correction is applied for the forecast year, it implies an upwards jump in the expected recruitment between the historical time series and the forecast years. Thus, in order to avoid this jump, a constant bias correction in time including the forecast years was applied (Model 12).

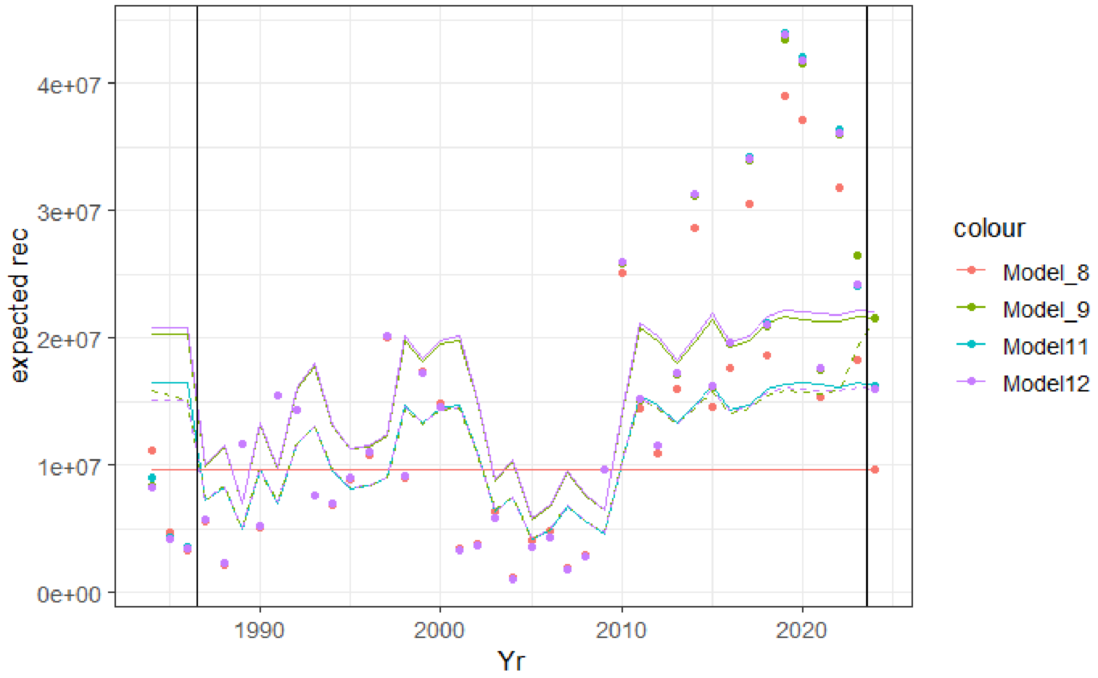

Figure 2.28: Bay of Biscay anchovy. Expected recruitment (Ricker model) estimated by SS model (continuous line), for different bias correction options: time variant bias correction (Model 9), no bias correction (Model 11), constant bias correction (Model 12) and the run with no SR model (Model 8). The dashed line represents the expected recruitment estimated by SS3 after the bias correction is applied. Points represent the predicted annual recruitments. Vertical lines represent the first data year (1987) and the last data year (2023). The last point is the first forecast year (2024).

Include random-walk for commercial fleets selectivities

As described above, giving more flexibility to the selectivity of commercial fleets was identified as an option to improve the model configuration to obtain better retrospective patters. For that, random walks were included for the estimated selectivities of the commercial fleets (selectivities for ages 1 and 3+, age 2 is fixed to 1 as reference).

The steps followed to get to this final run, Model 13, were the following:

1) Run the model with the agreed configuration, letting the model estimate natural mortality at age 3+ (M3+) and the steepness parameter of the Ricker function.
2) Run one iteration of the Francis reweighting method, starting from a sample size of 100 for all fleets.
3) Run with fixed natural mortality M3+, steepness and sample sizes resulting from the previous step.
4) Final run with fixed natural mortality M3+, steepness and sample sizes resulting from step2, and including random walks for the commercial fleets selectivities at ages 1 and 3+.

The combination of including a stock recruitment relationship and then including random walks for the commercial fleets' selectivity led to an improved retrospective pattern (Figure 2.26) with a Mohn's row for SSB below 0.3 (which is the acceptable upper limit for short-lived species according to ICES WKFORBIAS 2020).

The estimated selectivities are shown in Figure 2.29.

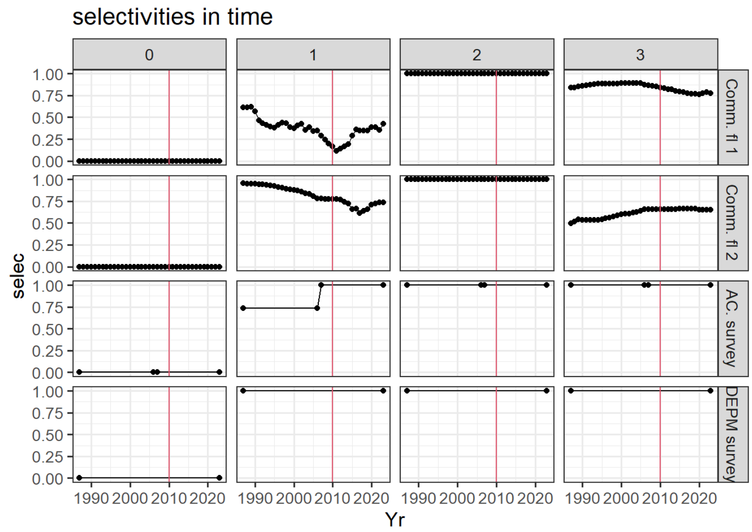

Figure 2.29: Bay of Biscay anchovy. Estimated selectivities for all fleets with age structured data in Model 13.

2.4.1.2.7 Deterioration of the retrospective pattern along time

The retrospective pattern has been consistently found in most of the SS model configurations tried. Furthermore, this was also detected in the last years of the current assessment model (CBBM). The leave-one-out analysis suggested that this was partly explained by changes in selectivity of the commercial fishery. Including a SR model also helped to improve the retrospective pattern. However, the resulting Mohn's rho values of the final model (Model13) are still in the borderline of currently established limits for short-lived species (0.3 for SSB).

To further analyse this, we studied how the retrospective pattern has changed along years. The Mohn's rho was calculated for previous assessment years in order to see how the SSB Mohns' rho has evolved in time, both for the first proposed model (Model8 that was discarded due to the high Mohn's rho) and the final proposed model (Model13 with the time-varying selectivity and the SR model). Overall, there has been a degradation of the retrospective pattern along time in both models (Figure 2.30), as it has been observed also in the CBBM. This suggests that there may be ongoing changes in the population or in the fishery, which may violate some of the model assumptions. So, this retrospective pattern should be further monitored and analysed in the near future.

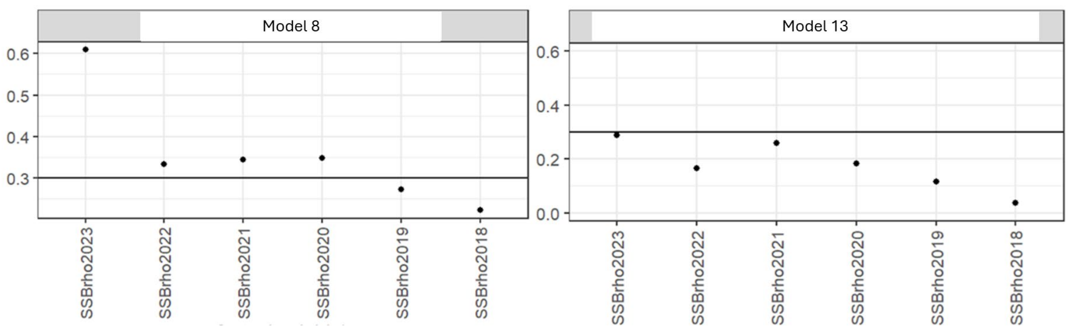

Figure 2.30: Bay of Biscay anchovy. SSB Mohn`s rho values (y axis) for Model 8 (left) and the selected model 13 (right). The x axis represents the year for which the retros were computed, i.e., SSBrho2021 represents the SSB Mohn's rho obtained taking as reference the assessment model with 2021 as the final year and taking into account the retros for the previous 5 years (2020-2016).

2.4.2 Final assessment

2.4.2.1 Model configuration

A summary of the final configuration for the Bay of Biscay anchovy assessment model (Model 13 in the previous section) is given in Table 2.7. The final model is an age-based SS model with 4 age classes (0-3+) and two seasons. Input data include total catch in biomass and catch at age by semester, SSB and numbers at age from two spring surveys, BIOMAN DEPM survey and PELGAS spring acoustic survey, and numbers at age 0 from the JUVENA autumn acoustic survey. The initial equilibrium catch is set to the average catches from the previous 9 years to the first year of the model (three life-cycles). Total catch in biomass is assumed to be known accurately, with an input standard deviation set at 0.05. Coefficients of Variation (CVs) for the aggregated indices of the spring surveys are provided, while a CV of 0.25 is set for JUVENA. An extra standard deviation parameter for each survey is estimated within the model. Concerning age composition data, a different sample size is used for each fleet, coming from a data weighting process following the Francis method with a single iteration (see section 2.4.1.2.5). The sample sizes resulting from this process are the following: 39 for commercial fishery in semester 1, 23 for commercial fishery in semester 2, 24 for the spring acoustic survey and 54 for the DEPM survey.

Considering the current assessment calendar (annual assessment WG in November) all data is included until the assessment year, except for the catch at age data for the second semester of the last year. Figure 2.31 summarizes input data used in the model. Stock weights at age and maturity at age are also input values for the model (i.e. growth is not modelled explicitly). Natural mortality is age specific, with values for age 1 and 2 specified as in the previous CBBM model, age 0 derived from a Gislason model and rescaled to the known M1 value, and natural mortality for age 3+ estimated within the SS model and fixed to the estimated value (Model13 in section 2.4.1.2.6.2). The natural mortality vector is the following: M0=2.17, M1=0.8, M2=1.3 and M3+=2.26.

Annual recruitments are model parameters, defined as lognormal deviations from Ricker stock–recruitment model with input steepness of 1.40 (estimated within the model and then fixed to the estimated value, see section 2.4.1.2.6.2) and penalized by a sigma of 0.8 (following recommended values by SS based on the variance in estimated recruitments post running the model). Bias correction for recruitment is applied as a constant correction over time for the whole time period (option -1 in SS). Main recruitment deviations were defined from 1987 to 2023 and early recruitment deviations from 1984 to 1986. Recruitment settlement is set at 1st July.

Selectivities for all fleets are modelled as independent parameters for each age, having selectivity at age 0 fixed to 0 and selectivity at age 2 fixed to 1 as reference for the fully selected age class. For the commercial fleets, a random walk in time was used to model selectivities at age 1 and 3+. For the PELGAS acoustic survey selectivity at age 1 was modelled in two time blocks, before and after 2007, accounting for the incorporation of commercial vessels to the survey. Ages 2 and 3+ in the PELGAS acoustic survey and ages 1, 2, and 3+ for the BIOMAN DEPM survey, were fixed to 1. All catchability parameters (BIOMAN, PELGAS and JUVENA) were configured as linear models. Spring acoustic and DEPM surveys were modelled as biomass indices at spawning time (15th May) (option 1 in SS) and the autumn juvenile acoustic survey as a recruitment index (option 33 in SS).

Variance estimates for all estimated parameters are calculated from the Hessian matrix.

Estimated parameters and the corresponding standard deviations for the final model are reported in Table 2.8.

Table 2.7: Bay of Biscay anchovy. Final configuration for SS assessment model for the Bay of Biscay anchovy.

Input data	Benchmark 2024 (data until 2023)
Catch	Total catch biomass 1987-2023 by semester (age 0 catch not included) (tonnes)
	Catch-at age (ages 1,2, 3+) 1987-2023 by semester (except for assessment year's second semester that no catch-at-age data are available) (thousands of individuals)
PELGAS spring acoustic survey	Total SSB 1989-2023 (missing years: 1990, 1993-1996, 1999, 2020) (tonnes)
	Numbers-at-age (ages 1,2, 3+) 2000-2023 (missing years: 2020) (thousands of individuals)
BIOMAN DEPM survey	Total SSB 1987-2023 (missing years: 1993) (tonnes)
	Numbers-at-age (ages 1,2, 3+) 1987-2023 (missing years: 1993, 1996, 1999 and 2000) (thousands of individuals)
JUVENA autumn acoustic survey	Numbers-at-age 0 2003-2023 (thousands of individuals)
Weight-at-age in the catch	Averages by year and semester 1987-2023 (except for assessment year's second semester)
Weight-at-age in the stock	From DEPM surveys, linear interpolation for missing years (kg)
Maturity-at-age	All individuals mature at age 1 (maturity at age 0=0)

Model structure and assumptions	Benchmark 2024
Starting year	1987
Ending year	2023
Equilibrium catches	12 246 t in 1st semester and 8164 t in 2nd semester (average 1978-1986, 60% in 1st half-year)
Number of areas	1
Number of seasons	2 (Jan-Jun, Jul-Dec)
Spawning time	15th May
Recruitment settlement time	1st July
Genders	1
Data age bins (for age structured fleets)	0-3+
Natural mortality	M-at-age 0=2.17, M-at-age 1=0.8, M-at-age 2=1.2, M-at-age 3+=2.26

Model structure and assumptions	Benchmark 2024
Recruitment	Density-dependent R model; annual recruitments are parameters, defined as lognormal deviations from Ricker stock–recruitment model, penalized by a sigma of 0.8, and an input steepness (SS parameterization) of 1.4. Constant bias correction for the whole time period (option -1 in SS) Main recruitment deviates: 1987-2023, Early recruitment deviates: 1984-1986
Initial population	N-at-age in the first year are parameters derived from an input initial equilibrium catch, equilibrium recruitment and selectivity in the first year and adjusted by recruitment deviations estimated from the data on the early years of the assessment.
Fishery selectivity-at-age	Selectivity-at-age are independent parameters. Selectivity-at-age 0 fixed to 0, Selectivity-at-age 2 fixed to 1 (as reference) and Selectivity-at-ages 1 and 3+ estimated through random walks for the whole period 1987-2023. A different selectivity is estimated for each commercial fleet (i.e. by semester).
PELGAS spring acoustic survey selectivity-at-age	Selectivity-at-age are independent parameters. Selectivity-at-age 0 fixed to 0, Selectivity-at-age 2 and 3+ fixed to 1 and Selectivity-at-age 1 is estimated in two time blocks: 1987-2006 and 2007-2023.
BIOMAN DEPM survey selectivity-at-age	Selectivity-at-age are independent parameters. Selectivity-at-age 0 fixed to 0, Selectivity-at-ages 1, 2 and 3+ fixed to 1.
PELGAS Spring acoustic survey catchability	Linear catchability parameter with extra standard error parameter
BIOMAN DEPM catchability	Linear catchability parameter with extra standard error parameter
JUVENA autumn acoustic survey catchability	Linear catchability parameter with extra standard error parameter
Log-likelihood function:	
Weights of components	All components have equal weight
Data weights	Sample size of age composition data defined after one iteration of the Francis method: 39 for commercial fishery in semester 1, 23 for commercial fishery in semester 2, 24 for acoustic survey and 54 for DEPM survey. CVs for aggregated indices: inputs from the surveys except for Juvena survey set to 0.25. SD for total catches: 0.05

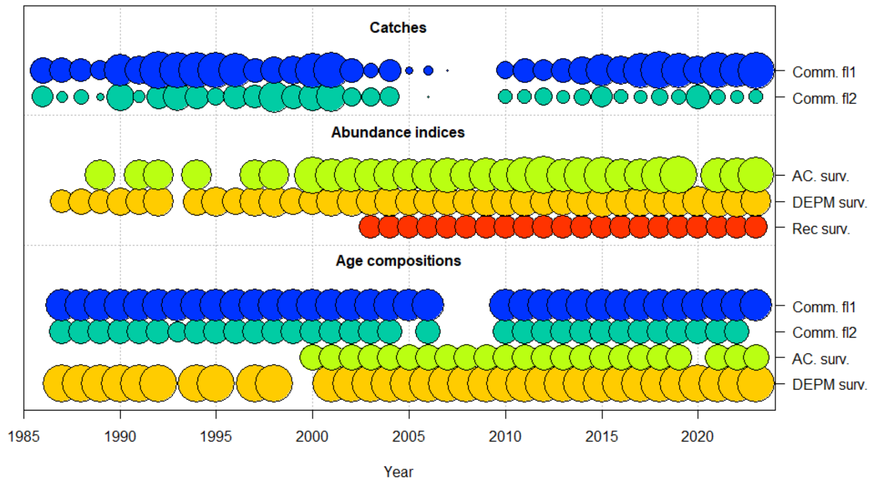

Figure 2.31: Bay of Biscay anchovy. Summary of input data for SS assessment for Bay of Biscay anchovy, where circle area is relative within a data type. Circles are proportional to total catch for catches; to precision for indices; and to total sample size for age compositions observations.

Table 2.8: Bay of Biscay anchovy. Estimated parameters (excluding deviation parameters), minimum and maximum values, initial values, status and standard deviations as reported by SS output for Bay of Biscay anchovy final model configuration.

Estimated parameters	Value	Min	Max	Init	Status	Parm_StDev
SR_LN(R0)	16.8444000	1	20	17.0	OK	0.1123720
InitF_seas_1_flt_1Commercial_vessels1	0.1611880	0	8	0.1	OK	0.0295208
InitF_seas_2_flt_2Commercial_vessels2	0.1456490	0	8	0.1	OK	0.0219036
LnQ_base_Biomass_Pelgas_survey(3)	0.4853560	-7	5	0.0	OK	0.1594070
Q_extraSD_Biomass_Pelgas_survey(3)	0.2490540	0	5	0.0	OK	0.0570622
LnQ_base_Biomass_Bioman_survey(4)	-0.0906839	-7	5	0.0	OK	0.1429760
Q_extraSD_Biomass_Bioman_survey(4)	0.3380860	0	5	0.0	OK	0.0788625
LnQ_base_Juvena_survey(5)	1.7491400	-7	20	0.0	OK	0.2237730
Q_extraSD_Juvena_survey(5)	0.5551310	0	5	0.0	OK	0.1293400
AgeSel_P2_Commercial_vessels1(1)	11.4510000	-5	20	9.0	OK	0.7859830
AgeSel_P4_Commercial_vessels1(1)	12.6455000	-5	20	9.0	OK	2.1810600
AgeSel_P2_Commercial_vessels2(2)	14.0539000	-5	20	9.0	OK	1.4669800
AgeSel_P4_Commercial_vessels2(2)	10.9968000	-5	20	9.0	OK	1.6041300
AgeSel_P2_Biomass_Pelgas_survey(3)	7.5000200	-5	20	20.0	OK	279.5050000
AgeSel_P2_Biomass_Pelgas_survey(3)_BLK2repl_1986	12.0391000	-5	20	20.0	OK	0.6013230
AgeSel_P2_Biomass_Pelgas_survey(3)_BLK2repl_2007	19.4710000	-5	20	20.0	OK	13.5756000

2.4.2.2 Model diagnostics

Model diagnostics for the final assessment run are shown in this section.

The model showed a general good fit to age composition data with no large Pearson residuals or strong patterns (Figure 2.32). Data was accommodated trough a flexible selectivity pattern for the commercial fleets (Figure 2.29). Residuals for mean age passed the run test for the commercial fleets and for the PELGAS spring acoustic survey, indicating no evidence to reject the hypothesis of randomly distributed residuals (Carvalho et al. 2021), while the BIOMAN DEPM survey did not pass the randomly distributed residual test (Figure 2.12). The joint age composition residual plot (Figure 2.34) and the root mean square error (RMSE) of 6.4% indicated a good fit to the data. RMSE values above 30% may indicate data conflicts (Carvalho et al. 2021).

Regarding the fit to aggregated indices, the fits to the data in log scale and the residuals are shown in Figure 2.35 and Figure 2.36. Residuals test was passed for the PELGAS acoustic survey and for the JUVENA recruitment index but not for the BIOMAN DEPM survey. The later index showed a clear residual pattern in time, with positive residuals in the last decade and mainly negative residuals in previous decade. The CBBM model residuals showed the same pattern and none of the exploratory model during this benchmark were able to overcome this residual patterns. Further monitoring of this pattern may be required in the near future.

The final gradient of the model was relatively small (<0.0001), and the Hessian matrix for the parameter estimates was positive definite. None of the parameter were estimated at their bounds and no highly correlated parameters were detected (all correlation coefficients were below 0.9 in absolute value). The 20 iterations of the jittering test resulted in 75% converged runs, at the same exact total likelihood value (Figure 2.37), thus, the jitter test did not provide evidence to reject the hypothesis that the final model parameter optimization converged to the global solution (Carvalho et al. 2021).

The retrospective analysis for the final model was performed for a five-years period (Figure 2.38). Mohn`s rho indicate an overestimation of SSB (Mohn`s rho=0.29) and underestimation of recruitment and F (Mohn`s rho -0.30 and -0.17 respectively). The Mohn's rho for SSB is below the critical value for short-lived species (0.3) and all peels were inside the confidence interval of the reference year. However, as described in the previous section, the retrospective patterns have deteriorated in time and it should be further monitored and analysed in the future.

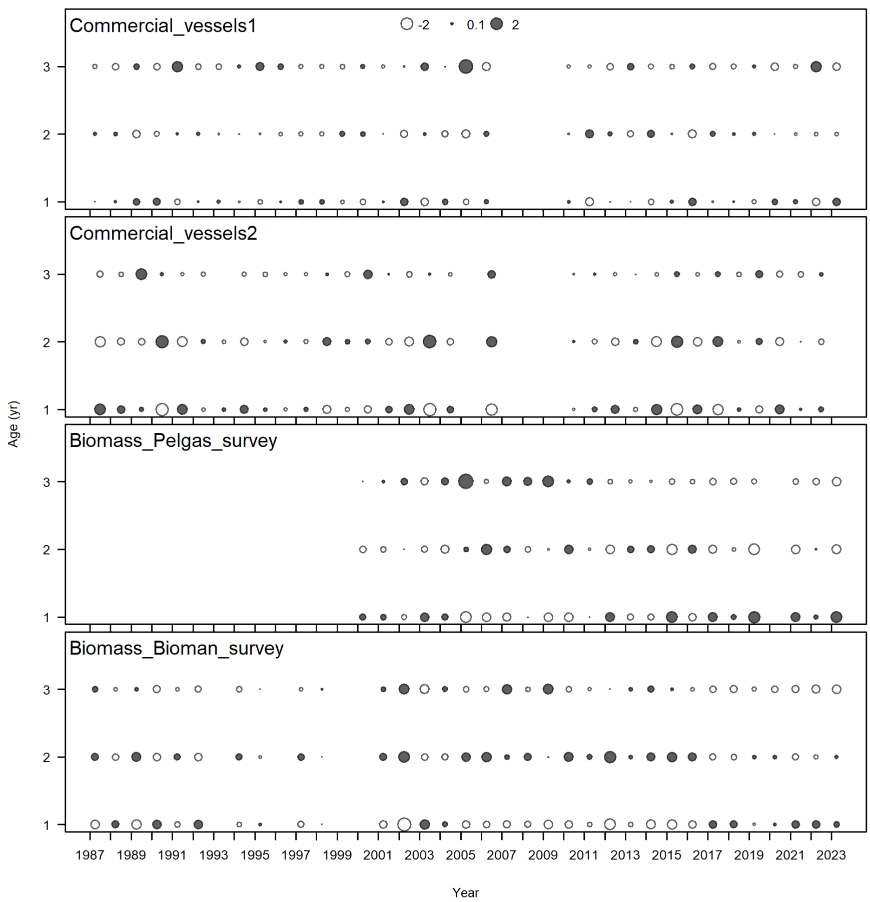

Figure 2.32: Bay of Biscay anchovy. Proportion-at-age residuals (positive residual=black; negative residuals=white) for each fleet with age composition data in the model for Bay of Biscay anchovy.

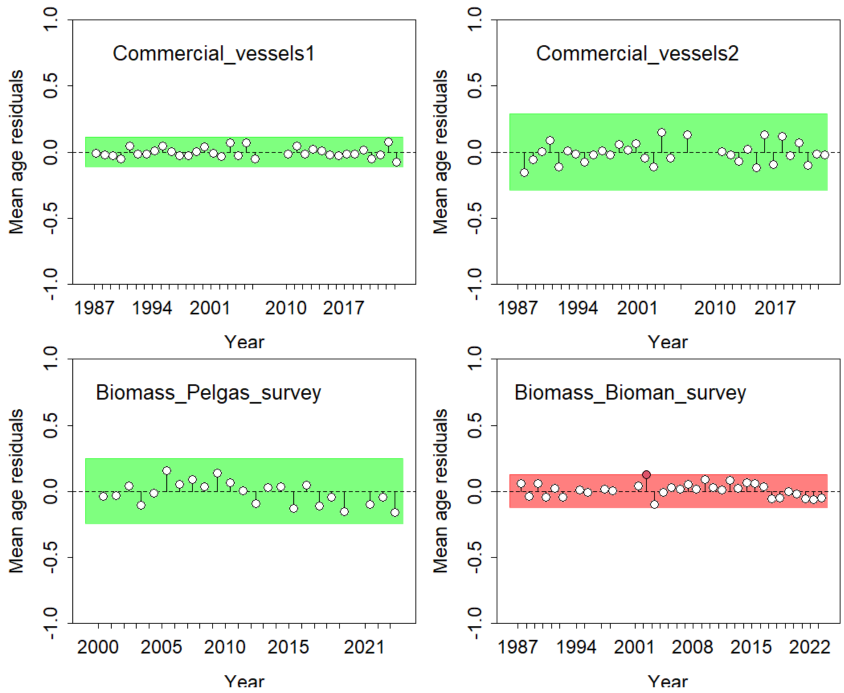

Figure 2.33: Bay of Biscay anchovy. Mean age residuals for each fleet with age composition data in the SS model for Bay of Biscay anchovy. Green shading indicates that the residual test is passes, red indicates the test is not passed.

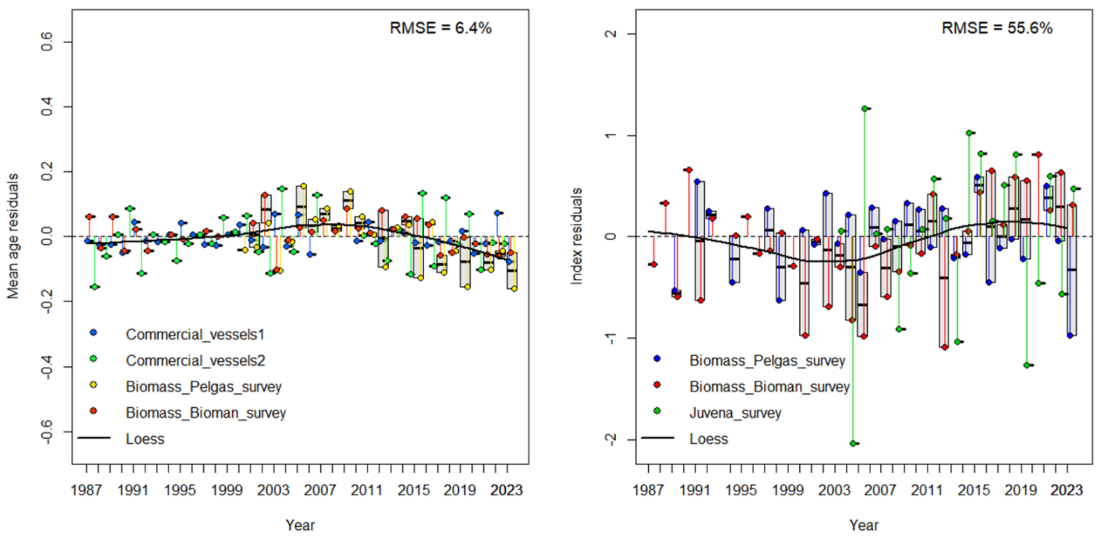

Figure 2.34: Bay of Biscay anchovy. Joint residuals for all fleets and RMSE values for Bay of Biscay anchovy. Age composition residuals on the right and aggregated indices residuals on the left.

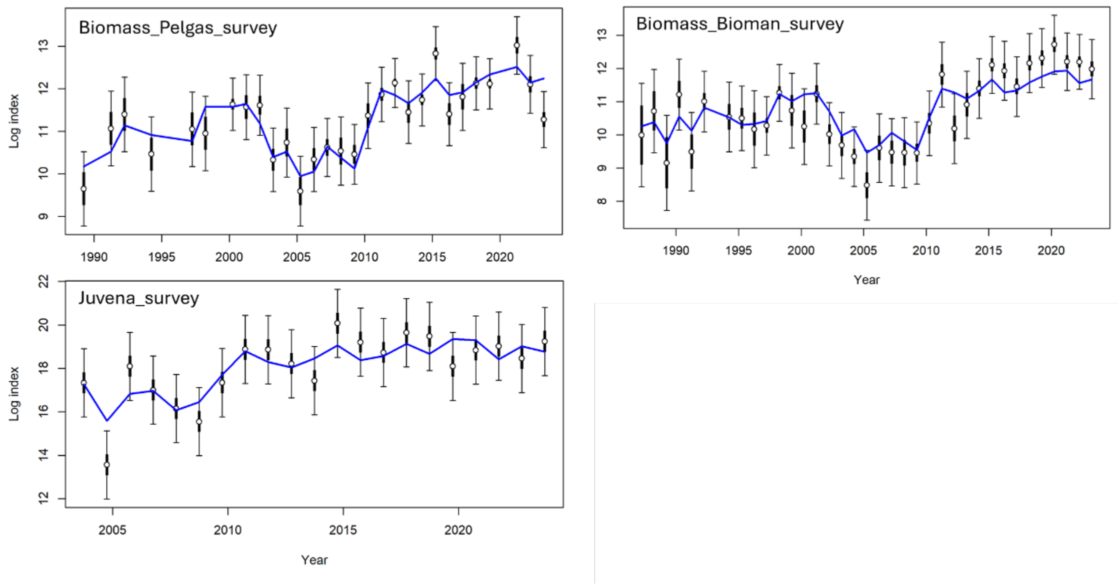

Figure 2.35: Bay of Biscay anchovy. Fits to survey data in log scale (blue line) for Bay of Biscay anchovy. Black point and vertical line represent point estimates and 95% confidence intervals respectively.

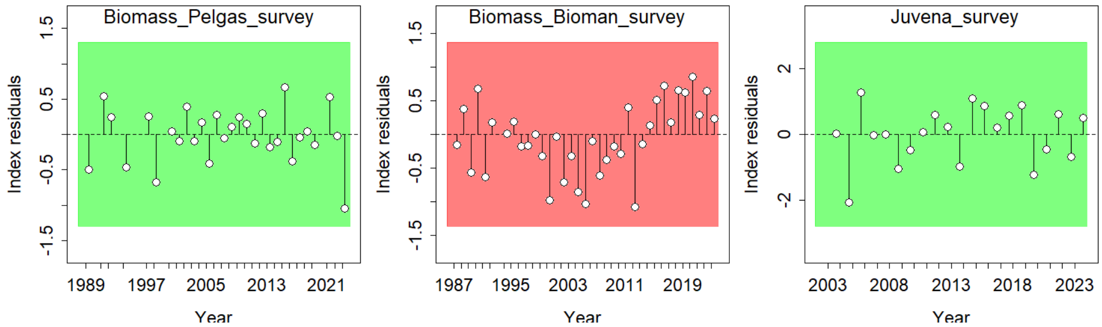

Figure 2.36: Bay of Biscay anchovy. Aggregated indices residuals for Bay of Biscay anchovy. Green shading indicates that the residual test is passes, red indicates the test is not passed.

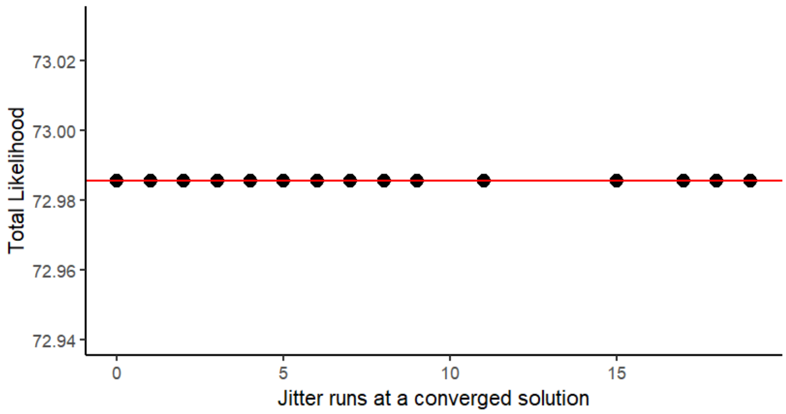

Figure 2.37: Bay of Biscay anchovy. Jittering results for the final SS model for Bay of Biscay anchovy. Solid black circles represent the total likelihood obtained from jittered model runs. The red horizontal dashed line represents the total likelihood value from the base-case model.

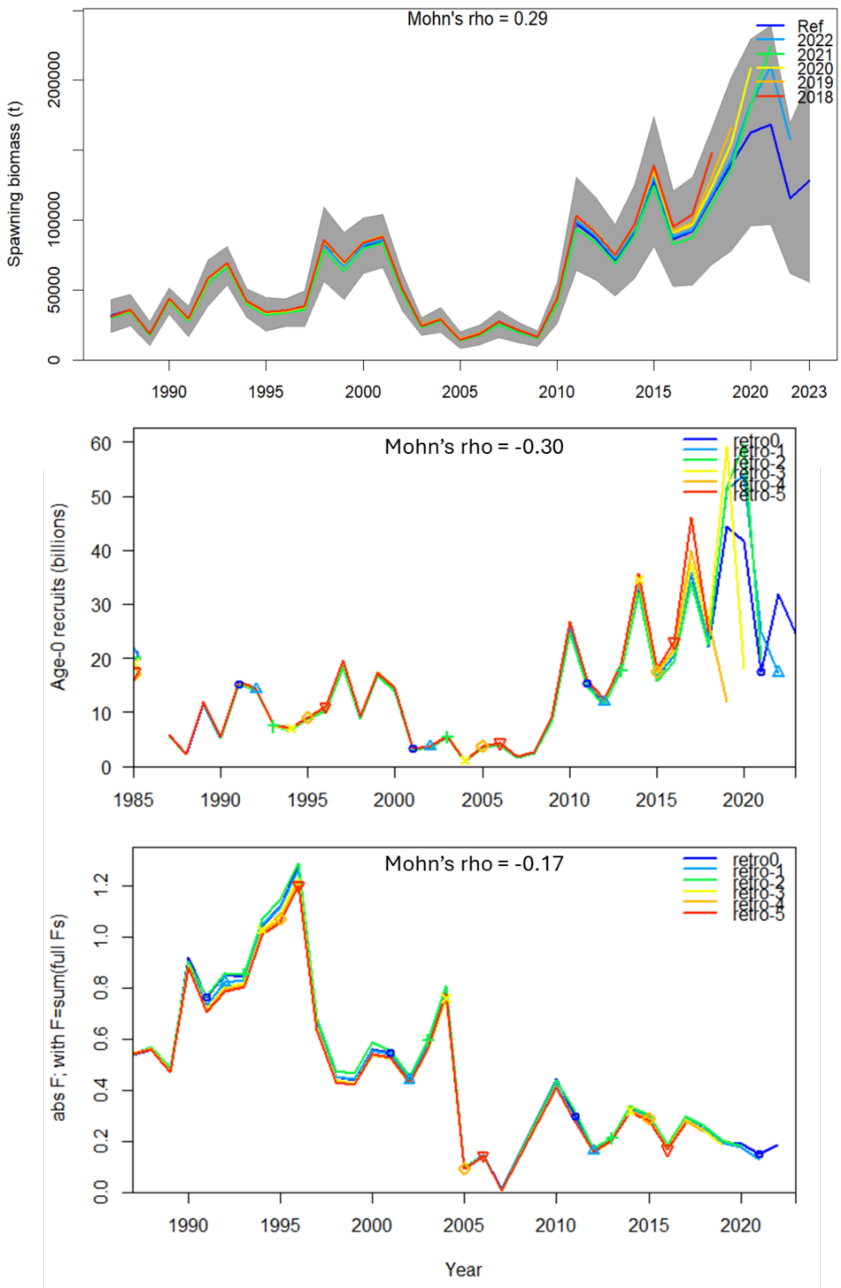

Figure 2.38: Bay of Biscay anchovy. Retrospective patterns for SSB, recruitment and F with their corresponding Mohns rho values. Grey shaded area in the SSB plot represents the 95% confidence interval for the reference run.

2.4.2.3 Comparison with current assessment

The resulting SSB and harvest rate (total annual catch/SSB) from the final SS model was compared to the CBBM model latest output from WGHANSA 2023 (ICES 2023) assessment. Note that recruitments are not comparable as they refer to different age classes, units and time instants in the year: in CBBM recruitment refers to biomass of age 1 individuals at the beginning of the year and in SS recruitment refers to age 0 in numbers at the beginning of July.

Overall, no rescaling of the assessment is perceived when comparing results. SSB is slightly higher in the last period for the new SS model while the harvest rate is slightly lower (Figure 2.39

and Figure 2.40). Confidence intervals for SSB estimates from the two models overlap for the whole time series.

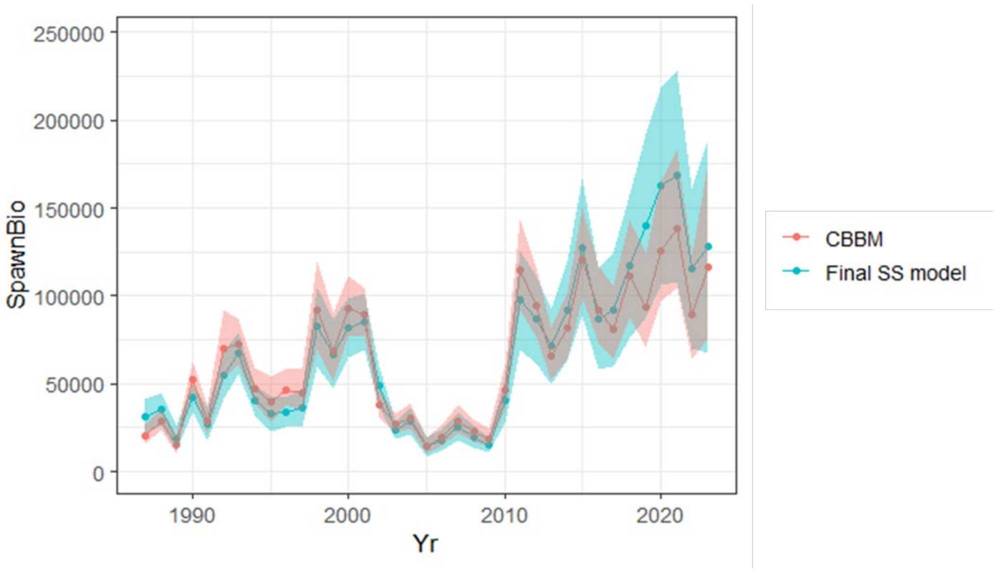

Figure 2.39: Bay of Biscay anchovy. Estimated SSB by the CBBM model in the last WGHANSA 2023 (red) and by the final SS model (blue). Points are medians for the CBBM and point estimated for the SS model. Shaded areas represent the 90% probability interval for the CBBM and the 90% confidence interval for the SS model.

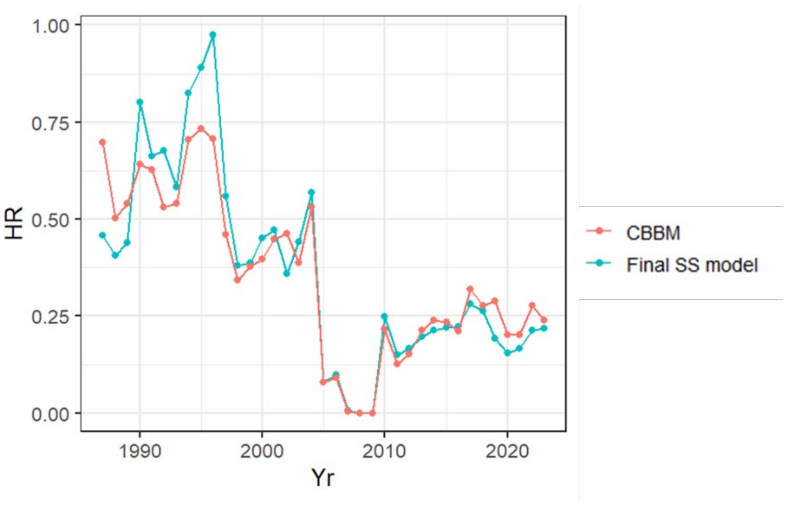

Figure 2.40: Bay of Biscay anchovy. Estimated harvest rate in the CBBM model in the last WGHANSA 2023 (red) and in the final SS model (blue).

2.5 Short term forecast

During the benchmark workshop, the code to run a stochastic short-term forecast in SS was prepared. In contrast to other deterministic alternatives, this allows us to propagate the assessment uncertainty and to account for stochastic recruitment in the projections. However, the specific assumptions for the short-term forecast and the range of catch options were not set up and were postponed to WGHANSA.

2.6 Biological reference points

Anchovy is a short-lived species with a life-span of 3-5 years (Uriarte et al., 2016). This type of species is characterized by high natural mortality rates and highly variable recruitments dependent on the environmental conditions. According to the ICES technical guidelines for fisheries management reference points for category 1 and 2 stocks (ICES, 2021), B_{lim} is calculated in the same manner as for long-lived species. Then, B_{pa} is estimated from B_{lim}, using the same methods as for long-lived stocks, but with a default $\sigma = 0.3$ if the terminal year SSB uncertainty is not available from the assessment. The main difference with respect to long-lived species is that ICES does not utilize F reference points to determine exploitation status of short-lived species. In this section we describe the calculation of reference points for anchovy in the Bay of Biscay.

2.6.1 Stock-recruitment relationship

The stock assessment comprised years from 1987-onwards. All years, including the last assessment year that is informed by the JUVENA recruitment index, were considered reliable and therefore, the full time series of stock and recruitment estimates were considered appropriate for the calculation of reference points.

The stock-recruitment pairs are shown in Figure 2.41. Overall, the stock has shown a wide dynamic range of SSB with evidence of impaired recruitment in the late 2000s when the fishery crashed (Uriarte et al., 2023). After the fishery closure from 2005 to 2009, the fishery was reopened in 2010. Since then, the stock has reached the highest SSB and recruitment levels of the time series, well above the historical averages. The five largest values of recruitment success (R/SSB) corresponded to years 2010, 1989, 1991, 2009 and 1997 (Figure 2.42). Therefore, the stock was classified as Type 2 (stocks with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired).

To assess whether the stock could be a Type 1 spasmodic stock, the method developed by Silvar-Viladomiu et al. (2022) and used also in ICES WKNEWREF (2024) was applied. The results indicated that the stock showed lower variance for both detrended and scaled recruitment, confirming that this stock is not spasmodic (Figure 2.43).

The new stock assessment model includes the fit of a Ricker stock-recruitment relationship within Stock Synthesis (see section 2.4.1.2.6.1). The maximum recruitment value is reached at SSB around 140 600 t, after which recruitment starts to decline smoothly (Figure 2.44). The inclusion of the stock-recruitment relationship provided stability and improved the retrospective pattern of the stock assessment model. Although the differences between Beverton-Holt and Ricker relationships were small, the density dependence pattern of the Ricker model was considered ecologically more appropriate given the cannibalism on eggs observed for this stock (Bachiller et al. 2015).

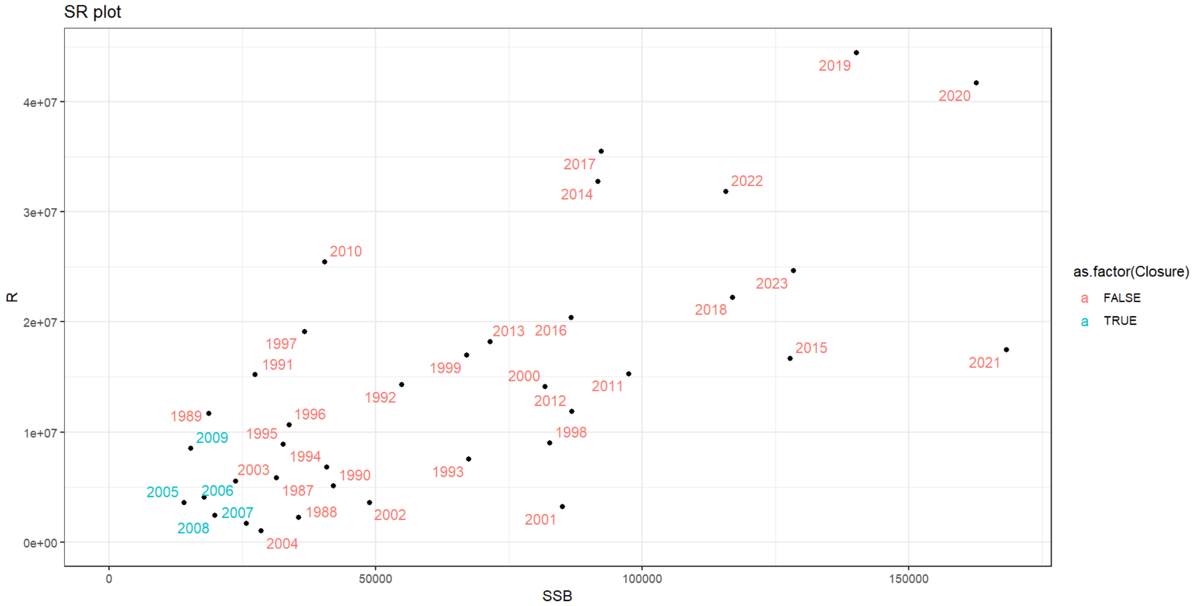

Figure 2.41: Bay of Biscay anchovy. Stock-recruitment plot. Labels in blue indicate the years in which the fishery was closed.

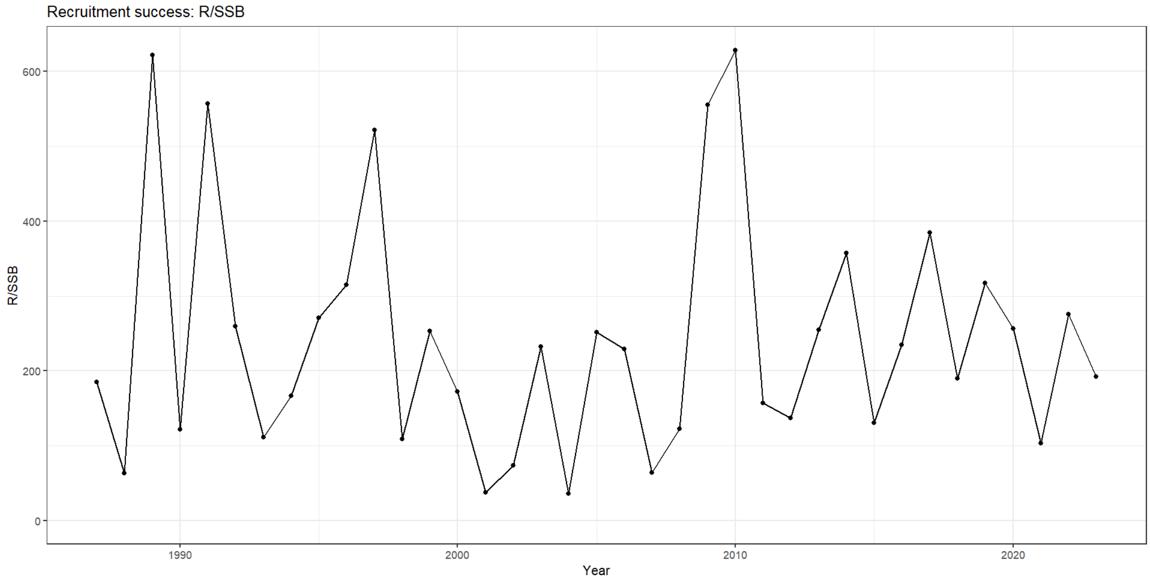

Figure 2.42. Bay of Biscay anchovy. Time series of recruitment success (ratio R/SBB).

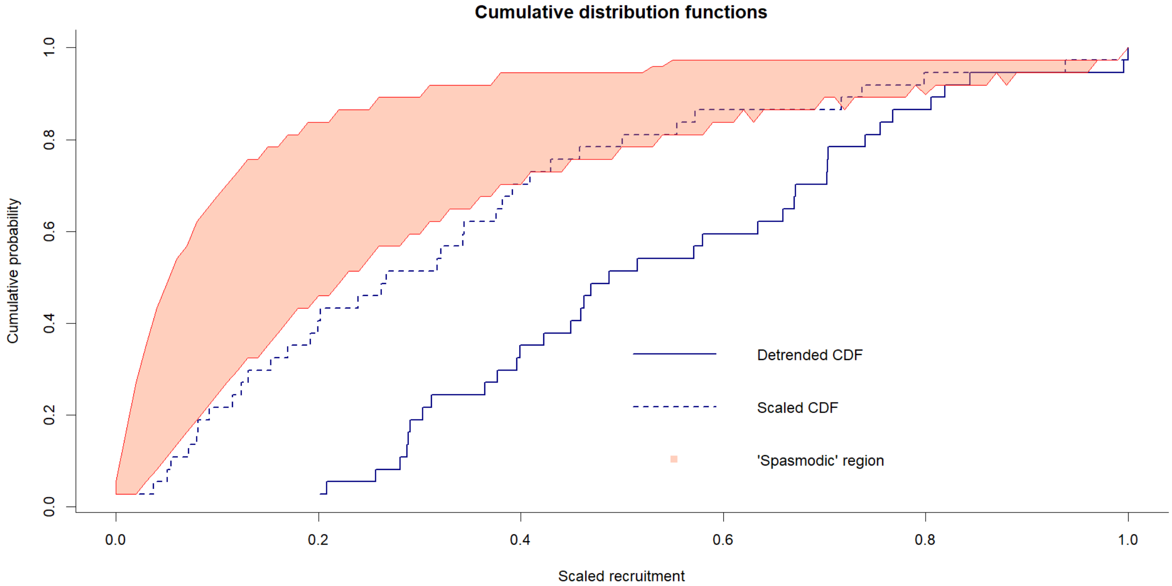

Figure 2.43: Bay of Biscay anchovy. Application to the Bay of Biscay anchovy of the method developed by Silvar-Viladomiu et al (2022) to identify spasmodic stocks.

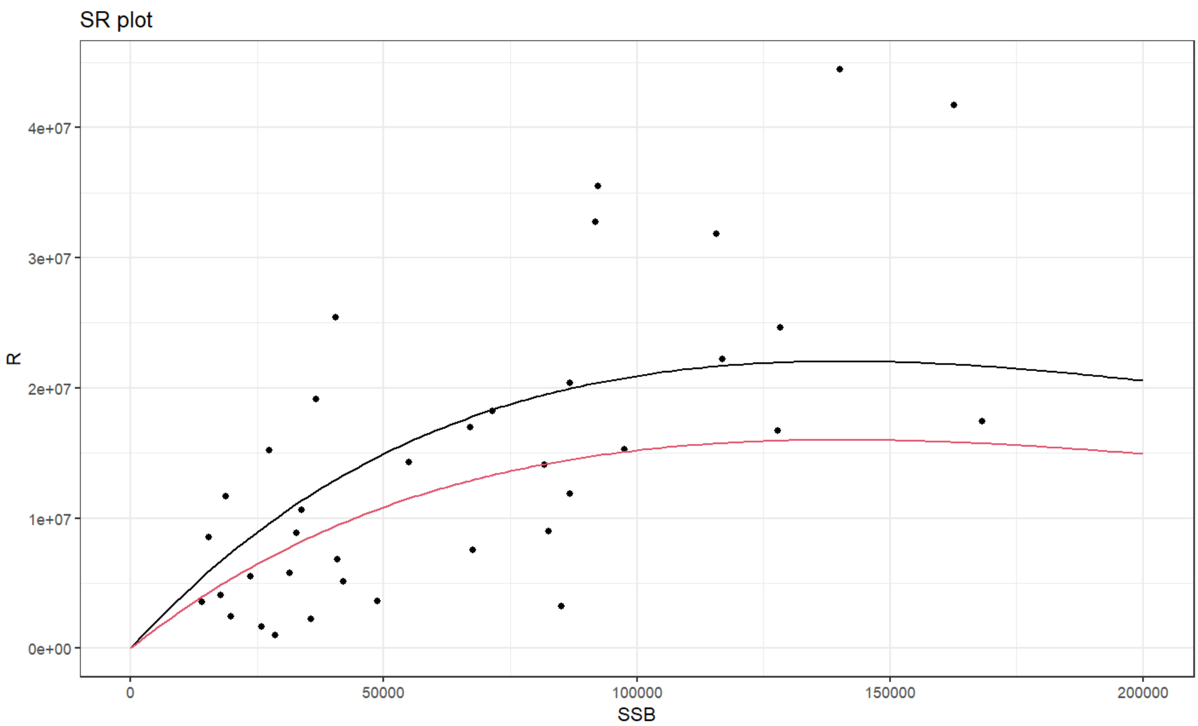

Figure 2.44. Bay of Biscay anchovy. Ricker stock-recruitment model (black line) fitted within the stock assessment model. The red line is the bias-corrected model.

2.6.2 Blim

Several options were explored to estimate B_{lim}:

a) Breakpoint of the segmented regression: The proposed option to estimate B_{lim} for Type 2 stocks is to fit a segmented regression model to the stock-recruitment estimate pairs. In this case, the breakpoint was estimated around 141 100t, which is approximately the 95th percentile of the SSBs (Figure 2.45). This was deemed unrealistically high and this option was not further considered.
b) Empirical B_{lim}: Based on the lowest observed spawning stock biomass producing a "large" recruitment, which is defined as recruitments above the median recruitment (van Deurs et al., 2020). This value corresponded to the SSB in 1991 which was estimated at 27 300 t (Figure 2.46).
c) Empirical B_{lim} (3 points): To avoid the empirical B_{lim} depending on a single point, the empirical B_{lim} was calculated as the average of the three lowest SSB leading to "large" recruitment (recruitments above the median recruitment). This resulted in 34 900 t, which is the average of 1991, 1997 and 2010 (Figure 2.46).
d) Empirical B_{lim} accounting for uncertainty (3 points): To account for the uncertainty of the recruitment estimates, the average of the lowest three SSBs whose confidence intervals at 95% included or were above the median recruitment was calculated. This resulted in 20 500 t, which is the average of 2009, 1989 and 1991 (Figure 2.47).
e) Empirical B_{lim} accounting for uncertainty (2 points after removal of 2009): Similar to option d but removing 2009 in which the fishery was closed and recruitment was assumed to be impaired. This resulted in 23 000 t, which is the average of 1989 and 1991 (Figure 2.47).
f) Empirical B_{lim} accounting for uncertainty (3 points after removal of 2009): Similar to option d and e but up to three points after removing 2009 in which the fishery was closed and recruitment was assumed to be impaired. This resulted in 26 600 t, which is the average of 1989, 1991 and 1996 (Figure 2.47).
g) Cumulative recruitment quantiles: As an alternative to proposed methods, we calculated the cumulative distribution of recruitment for each observed SSB, and we calculated the SSB at which the cumulative recruitment distribution includes the median recruitment (Figure 2.48). This value was 25 900 t (interpolated between the SSBs in 2007 and 1991). In other words, all the SSB levels below 25 900 t resulted in "low" recruitments (recruitment values below the median).
h) Fraction of B0 in integrated models WKREF1 (ICES, 2022) and WKREF2 (ICES, 2022) suggested that B_{lim} could be set as a fraction of B0, where the specific fraction could be within the range of 10-25% B0 depending on the life-history characteristics. In this case B0 is estimated around 197 100 t. Fractions of 10%, 15%, 20% and 25% resulted in values of 19 700, 29 600, 39 400 and 49 300 t respectively.
i) Fraction of Rmax from Ricker stock recruitment relationship. According to the Ricker model fitted within Stock Synthesis, Rmax is around 16007293 (after the bias-correction) and it is reached at SSB around 140 600 t. Myers et al (1994) suggested B_{lim} could be calculated as 50% of Rmax, while van Deurs et al (2021) suggested a value of 83% of Rmax based on an empirical study. The first fraction would lead to B_{lim} around 32 600 t. The second fraction would lead to an unrealistically high value of 71 250 t.

All of these options for calculating B_{lim} are summarized in Table 2.9. Some of these values were considered unrealistically high (e.g. breakpoint of segmented regression) whereas some others were considered that might be too low (e.g. empirical B_{lim} with uncertainty). The options based on fractions of B0 and Rmax were only considered for comparative purposes and sense checking. The remaining empirical options lie between 23 000 and 35 000 tonnes. Specially, the empirical

B_{lim} based on one single point, the empirical B_{lim} with uncertainty based on 3 years without the closure period and the cumulative recruitment quantiles method resulted in very similar estimates (27 300t, 26 600 t and 25 900 t), which increased the reliability of the proposed options.

The robustness of the different empirical options was analysed by conducting a retrospective analysis of B_{lim} (Figure 2.49). The empirical B_{lim} based on a single point was quite stable except in the last two years. Calculating the empirical B_{lim} as the average of three years did not improve the stability of B_{lim}. This could be partly explained by the retrospective pattern of the median recruitment as the number of years in the assessment increases, especially due to the most recent high recruitments (Figure 2.50). The most stable B_{lim} estimates were obtained when the uncertainty of the recruitment estimates was accounted for. Given that during the fishery closure (2005-2009) recruitment was considered to be impaired, the best option for calculating B_{lim} was considered to be based on the average of the three lowest SSBs (except those from the fishery closure period) whose confidence intervals at 95% included or were above the median recruitment (1989, 1991 and 1996). Therefore, B_{lim} was set at 26 600 tonnes.

Table 2.9. Bay of Biscay anchovy. Alternative options for defining Blim for Bay of Biscay anchovy.

Basis	Value (tonnes)
Breakpoint of segmented regression	141 100
Empirical B_{lim} (single value 1991)	27 300
Empirical B_{lim} (average 1991, 1997, 2010)	34 900
Empirical B_{lim} with uncertainty (average 2009, 1989, 1991)	20 500
Empirical B_{lim} with uncertainty (average 1989, 1991, after removing closure year 2009)	23 000
Empirical B_{lim} with uncertainty (average 1989, 1991, 1996, after removing closure year 2009)	26 600
Cumulative recruitment quantiles (interpolated between 2007 and 1991)	25 900
Fraction of B0 (0.1, 0.15, 0.2, 0.25)	19 700, 29 600, 39 400 and 49 300
Fraction of Rmax (bias corrected) from Ricker (0.5, 0.83)	32 600 and 71 250

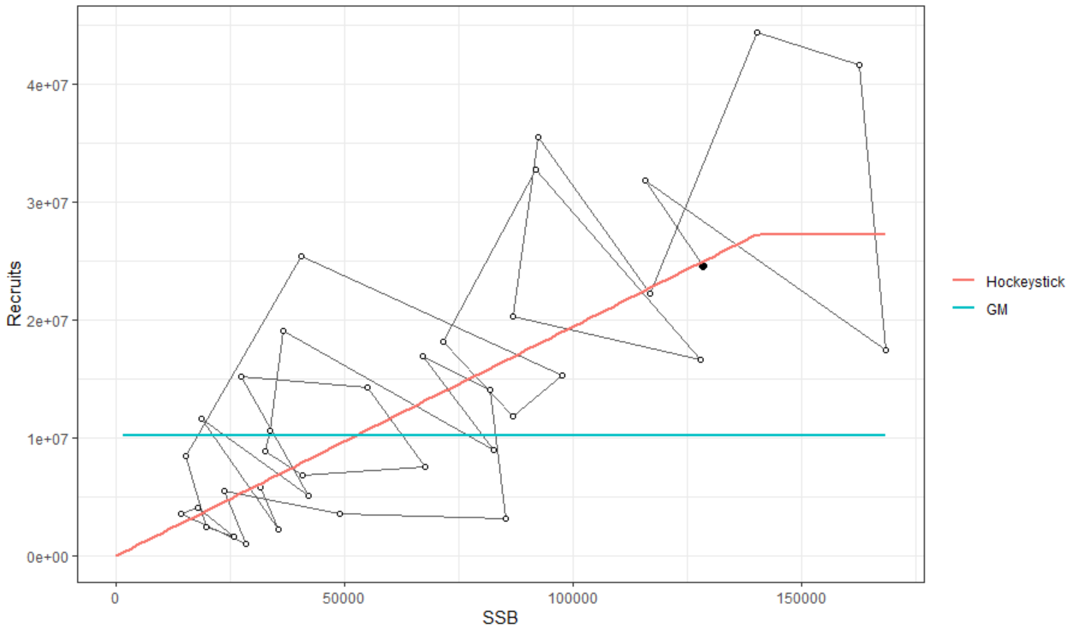

Figure 2.45. Bay of Biscay anchovy. Hockey-stick stock recruitment relationship (in red) for anchovy in the Bay of Biscay. The blue horizontal line represents the geometric mean from 1987 to 2023.

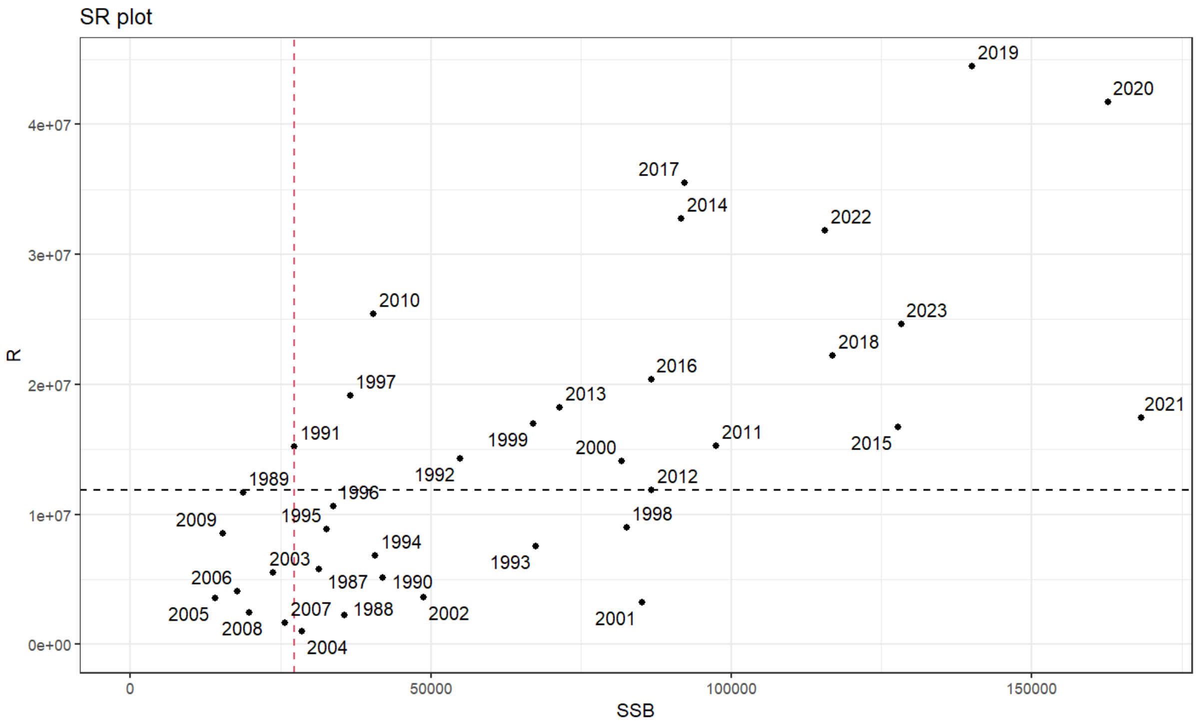

Figure 2.46. Bay of Biscay anchovy. Graphical representation of empirical B_{lim}. The horizontal line represents the median recruitment, while the vertical line is the lowest observed SSB producing a "large" recruitment (above the median recruitment).

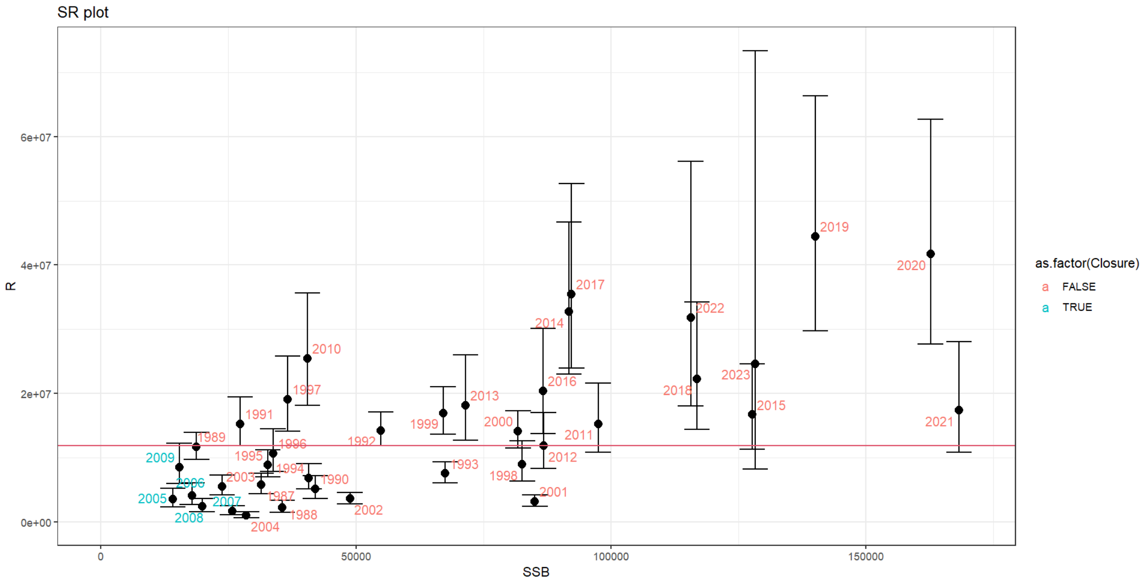

Figure 2.47. Bay of Biscay anchovy. Stock recruitment plot. The vertical error bars represent the uncertainty around the recruitment estimates according to a lognormal distribution. The red horizontal line is the median recruitment.

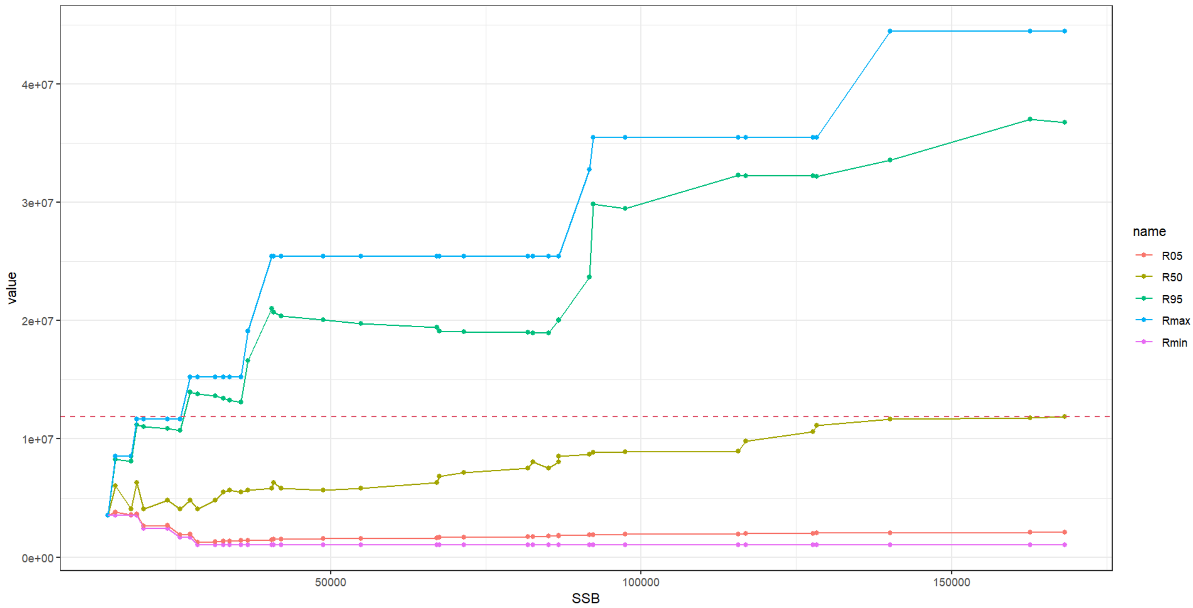

Figure 2.48. Bay of Biscay anchovy. Cumulative recruitment distribution (i.e. percentiles 0, 5, 50, 95 and 100 of recruitment for SSB values at or below each observed SSB). The recruitment percentiles for the highest biomass correspond to the whole time series. The horizontal red dashed line is the median recruitment of the whole time series.

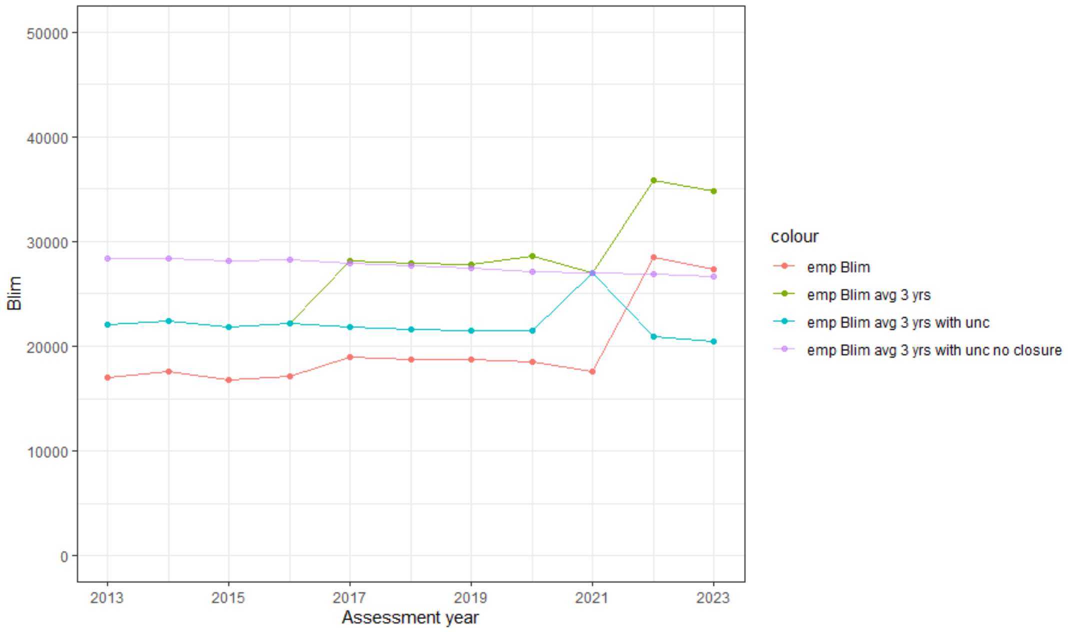

Figure 2.49. Bay of Biscay anchovy. Retrospective analysis of the calculation of B_{lim} for Bay of Biscay anchovy according to several options: empirical B_{lim} based on 1 point, empirical B_{lim} based on 3 points, empirical B_{lim} based on 3 points accounting for uncertainty, empirical B_{lim} based on 3 points accounting for uncertainty after removal of fishery closure years.

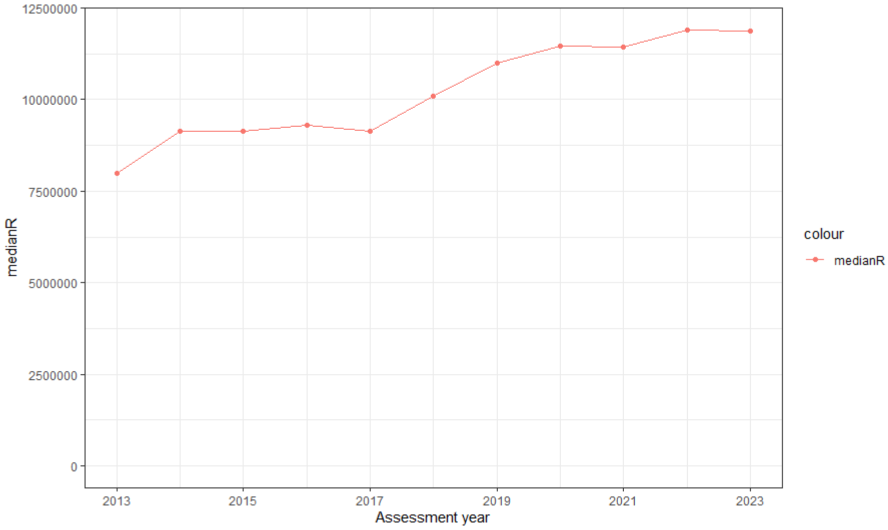

Figure 2.50. Bay of Biscay anchovy. Retrospective analysis of the median recruitment.

2.6.3 Bpa

Following the ICES guidelines, B_{pa} is calculated as:

$$B_{pa} = B_{lim} \exp\{1.645\ \sigma\},$$

where σ is estimated from the assessment uncertainty in SSB in the terminal year (σ is the estimated standard deviation of ln(SSB) in the final assessment year). In this case the coefficient of variation of SSB in the terminal year is 0.29 (Figure 2.51). This value is very close to the default value of 0.3 set for short-lived species. Therefore, based on $\sigma = 0.3$, Bpa was set at 43 600 t.

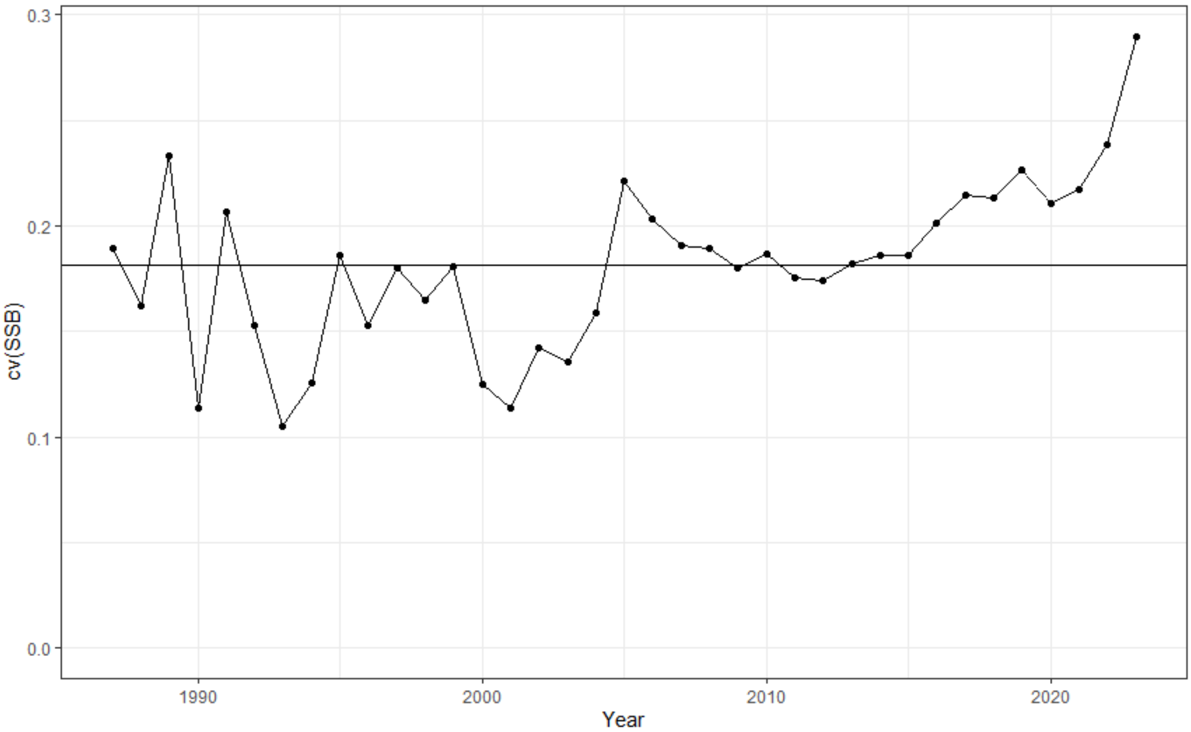

Figure 2.51. Bay of Biscay anchovy. The coefficients of variation of SSB estimated from the stock assessment.

2.6.4 Summary table of reference points

The reference points for Bay of Biscay anchovy are summarised in Table 2.10.

Table 2.10. Bay of Biscay anchovy. Summary table of reference points.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	Not defined		
	F_{MSY}	Not defined		

Framework	Reference point	Value	Technical basis	Source
Precautionary approach	B_{lim}	26 600 t	Mean of the SSB estimates in the three years 1989, 1991 and 1996, which have the lowest SSB estimates resulting in recruitments with 95% confidence intervals including or being above the median recruitment (excluding 2009 within the closure period)	ICES WKBANSP (2024)
	B_{pa}	43 600 t	$B_{pa} = B_{lim} * \exp(1.645 * \sigma), \sigma = 0.3$	ICES WKBANSP (2024)
	F_{lim}	Not defined		
	F_{pa}	Not defined		
Management plan	SSB_{mgt}	24000 t (lower trigger) 89000 t (upper trigger)	TAC set to zero if SSB below the lower trigger, and to 33000 t if SSB is above the upper trigger. The harvest control rule results in 5% probability of SSB < B_{lim} in the long term (being Blim=21 000t).	STECF (2014)
	F_{mgt}	Not defined		

When comparing the estimated SSB with respect to the biological reference points, SSB was found to be below B_{lim} in 1989, 2003 and 2005-2009 (Figure 2.52). Since 2011, the stock has been well above B_{pa}.

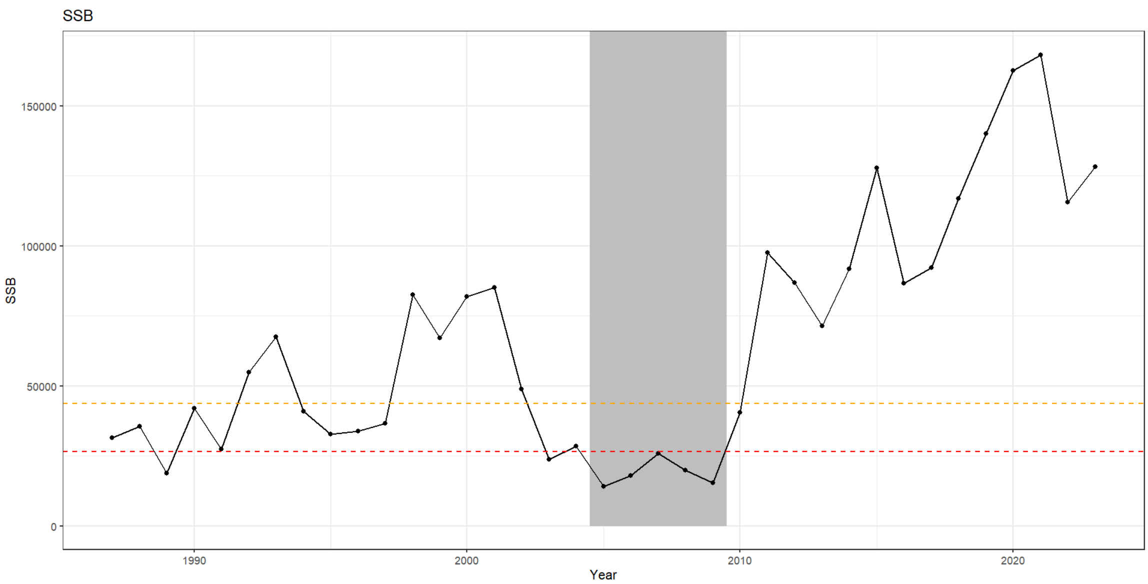

Figure 2.52. Bay of Biscay anchovy. Time series of SSB. The shaded area represents the fishery closure from 2005 to 2009. The horizontal dashed red and orange lines are the proposed B_{lim} and B_{pa} respectively.

2.7 Management considerations

Since the reopening of the fishery in 2010, the Bay of Biscay anchovy has been managed under an agreed management plan subject to several updates (Uriarte et al., 2023; Sanchez-Maroño et al., 2019). This management plan was scientifically assessed by the Scientific, Technical and Economic Committee for Fisheries (STECF 2013, 2014). ICES has also assessed that the harvest control rule in the management plan is precautionary (i.e. complies with the probability of risk of 5%) and conforms to the ICES criteria for management plans.

The methodological changes proposed during the benchmark workshop do not imply big changes in the historical perception of the stock (see section 2.4.2.3). Therefore, until a proper management strategy evaluation is conducted, the current management plan seems to be potentially applicable to set initial catch options for 2025. However, a full analysis to study the performance of the management plan conditioned on the new population dynamics and including the new stock assessment and short term forecast in the management procedure should be conducted as soon as possible.

2.8 Future considerations/recommendations

Future considerations/recommendations are as follows:

- Stock ID: Recent studies on anchovy stock identity (WD Garrido et al., 2024) suggest potential connectivity between anchovy in the Bay of Biscay (Subarea 8) and the Western Iberian waters (Subdivision 9a west). This should be further explored in the future.
- Input data: Although the bulk of the population is assumed to be well covered by the current surveys, it may be of interest to study the information provided by other surveys like e.g. the PELACUS acoustic survey covering the division 8c in spring.
- Retrospective pattern: A retrospective pattern was consistently found in all the SS models attempted during the benchmark and in the previous CBBM model. Furthermore, the retrospective pattern was found to have deteriorated in the last years regardless the model used. Although the retrospective pattern was alleviated by including a random walk for the fishery selectivity and a stock-recruitment relationship in the SS model, the resulting Mohn's rho for SSB is on the borderline of the limits established in ICES for short-lived species. This retrospective pattern needs to continue to be monitored.
- Residual pattern DEPM: As in the previous CBBM model, there is still a pattern in the residuals of the aggregated DEPM index. None of the model settings improved this pattern, so this should be further investigated in the near future.
- Management strategy evaluation: The historical population status with the new SS model is similar to the previous stock assessment with CBBM, therefore the current management plan seems to be potentially applicable to set the catch options for 2025. However, the methodological changes made during the benchmark could imply changes in the performance of the current management plan in terms of biological risks and expected catches. A proper re-evaluation of the current management plan according to the most recent changes should be undertaken as soon as possible.

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2.10 Stock-specific working documents

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- Citores, L and Ibaibarriaga, L. 2024 WD. Reference point for anchovy in the Bay of Biscay.
- Citores, L and Ibaibarriaga, L. 2024 WD. Updates on the assessment model for anchovy in the Bay of Biscay.

3 Anchovy (*Engraulis encrasicolus*) in Division 9a (Atlantic Iberian waters)

3.1 Issue list

The issue list for anchovy 27.9a is described in Table 3.1. It includes a clarification of the stock structure of the 9a stock, given the evidence of sub-stock structure within Division 27.9a and improvements to data input and assessment of the southern component of the stock. The work on stock identification will be presented in the current section 3, whereas the remaining rolling issues, related anchovy in 9a South (Gulf of Cadiz), will be presented in section 4 and anchovy in 9a West (Western Iberian waters) in section 5.

Table 3.1 - Issue list of the anchovy 27.9a stock

ID	Type	Priority	Problem/Aim	Work Required	Data Required
277	Assessment method	High priority	The biomass indicator index rule used for both components leads to a decrease in catches in the long term and needs to be replaced by another method. Particularly for the western component, is not sufficiently dynamic to follow the abrupt changes in biomass of the stock component, leading to very high HR in years of low biomass and very low HR in years of high biomass. For the Southern component, model updates the population trend every year and the harvest rule applied is not consistent with these changes.	For the Western component a new rule should be explored; a MSE should be carried out to evaluate other rules namely constant HR (possibly within WKDLSSLS). For the Southern component a MSE should be carried out to evaluate other harvest control rules with the current model but also a new combination of models and harvest control rules.	Data available for the assessment.
278	Stock identity	High priority	Stock structure must be properly defined, two components with different dynamics and a single TAC can lead to overexploitation of one of the components.	National and international projects focusing on the connectivity of anchovy populations with genomics are underway and can provide useful insights into the stock structure off Atlanto-Iberian waters. A new report summarizing existing information on population dynamics and distribution can also be produced to help with this issue. Analysis regarding stock identity using morphometrics, genetics, parasites, fisheries, surveys and modelling.	Published and unpublished data of morphometrics, genetics, parasites, fisheries,surveys and modelling.

ID	Type	Priority	Problem/Aim	Work Required	Data Required
279	Assessment method	High priority	There are two additional surveys series that are now available for the southern component, ECOCADIZ-RECLUTAS (acoustic) and BOCADEVA (anchovy DEPM), with at least six years of data that should be included as model input.	Incorporation of these two surveys series into the Gadget model should be explored.	Surveys data.
280	Other issues	High priority	The Gadget model for the southern component estimates very high survey catchabilities.	Explore the sources of these high values, including analysis of data input consistency and model calculation.	Data available for the assessment.

3.2 General

3.2.1 Current assessment and advice regarding stock definition

The stock status of anchovy in the Division 27.9.a (Atlantic Iberian waters) was first assessed after its first benchmark in February 2018 (ICES, 2018). Recognizing the different fisheries and populations dynamics of the west and south Iberian populations, WKPELA 2018 supported the separation of the stock into two different stock components for management purposes (Fig. 1): The Western component – in ICES Subdivisions 9a.N, 9a.CN and 9a.CS, and the Southern component – in ICES Sub-division 9a.S, for which the advice is given separately. During the benchmark, it was advised that more information should be collected regarding the population structure of Iberian populations of the anchovy, namely genetic information, to ascertain if the two components should be managed as independent stocks. During 2022 an updated version of the Stock structure Working Document was submitted to SIMWG (Garrido et al. 2022). The group considered that the results of the genomic analysis that was ongoing at that time should be completed in order for the group to evaluate the results and make a decision.

Figure 3.2.1.1. Map showing the two stock components of the anchovy stock of Division 9a: 9a South (blue) and 9a West (yellow). Note that the stock component 9a South is further divided into Portuguese and Spanish waters, whereas stock component 9a West is divided into subdivisions 9a North, 9a Central–North, and 9a Central–South.

Currently, advice for the western and southern components of the 9a stock is given separately using constant harvest rate rules for both components (ICES, 2023). Although catch options are set separately, a single TAC is set for Division 9a, resulting from the sum of the advice for each component. Given the independent dynamics of the two components and the short time series over which the stock is being assessed (2018-2024), it is frequently observed opposite trends of biomass for the two components. This results in very different advice for fishing opportunities, which can lead to overexploitation of the component with lower advised catch.

3.2.2 Summary of information regarding stock definition

Multidisciplinary work on the stock structure of anchovy off Iberian waters was carried out by members of WGHANSA, WGACEGG and others, and presented to the benchmark WKBANSP and to SIMWG (WD Garrido et al. 2024). The WD presents the state-of-the-art and new information on the stock structure of anchovy in Division 27.9.a (Atlantic Iberian waters). It includes analysis of;

1) spatial distribution assessed in surveys and catches
2) variability of life-history traits
3) synopsis of works published using morphometric and genetic analysis
4) new data on genomics of anchovy in the area of distribution and contiguous areas
5) new data of modelling of larval dispersal in Iberian waters
6) new data of stable isotopic analysis of eye lenses.

Data of the spatial structure of anchovy in division 9a (surveys and landings) shows a persistent discontinuity of the western and southern components of the stock (around 9aCS), for all the life stages (eggs, juveniles and adults) and seasons of the year covered by the surveys (spring, summer, fall). No significant correlation was found of anchovy abundance at age between the western and southern stock components, suggesting independent cohort dynamics and low or absent connectivity. Morphometric studies point to a separation of the Gulf of Cadiz anchovy population from that in western Iberia, although samples from the Algarve were absent. Genetic studies conducted in the past were not conclusive as they might be confounded by the presence of a coastal and a marine ecotype. However, new genomic results taking these ecotypes into consideration show that the southern anchovy component is clearly differentiated from the western component and that the populations belong to two different genetic lineages. New larval dispersal results suggest it is unlikely that the eggs being spawned in the Gulf of Cadiz can disperse and survive to the northwestern coast in any relevant numbers for all years tested (2013-2020), suggesting low to absent connectivity during the early life stages. New analyses on isotopic composition of the eye lenses of juvenile and adult anchovy collected during different years show a clear isolation of the western and southern populations.

The working document also included analysis of the potential connectivity of the western Iberian anchovy populations with the neighbouring anchovy stock in Division 8, in the Bay of Biscay. The spatial distribution of the anchovy in the Cantabrian Sea (division 8c) varies from year to year. During some years with high anchovy abundance, there is a continuous distribution of eggs (SAREVA, PELACUS survey series) and adults (PELACUS survey series) and occasionally high abundances in the westernmost tip of the Cantabrian Sea, contiguous to sub-division 9aN, particularly during the most recent years when anchovy peaked in western Iberia. To accommodate this expansion to the west of the Biscay stock the western limit of the BIOMAN and JUVENA surveys was extended. There is a significant correlation of anchovy abundance-at-age between western Iberia and the Cantabrian Sea for all ages groups (1 to 3), either of fish of the same age and with a 1 year lag (assuming migration of recruits from the Cantabrian Sea to the western Iberian coast). It seems to indicate movement from the north to the west but it can also indicate a response of both populations to the same environmental queue. New results on larval dispersal modelling suggest high connectivity between the Biscay anchovy populations and the Western Iberian populations, particularly during years with strong and persistent westward currents, which can disperse eggs to the NW Iberian coast in relevant numbers (Teles-Machado et al., 2024). These westward currents occurred in higher prevalence during the years matching the recent increase in abundance of anchovy in western Iberia. Morphometric studies point to contrasting results, revealing either an intermediate population on western Iberia or similarity between 9a west and the Bay of Biscay. New isotopic analysis shows an overlap of isotopic values between the juveniles and adult anchovy of western and northern Iberia which suggests either a strong connectivity of these populations or low baseline contrast between the two areas. Finally, recent genomic results show that the Bay of Biscay anchovy is genetically connected to the western populations.

WGHANSA requested SIMWG to review the information provided in the WD Garrido et al. 2024 in preparation of the current Benchmark Workshop (WKBANSP), particularly with the proposal to separate the two components within the 9.a stock. The SIMWG recognized that the analyses indicate that there is likely a population structure within the Division 9.a anchovy stock area, that aligns with the current components (western and southern) of the two assessments conducted on the 9a anchovy stock. However, there was no agreement within SIMWG (ICES, 2024) regarding the support to separate both components. According to the report, one group believes more survey and catch data should be explored before recommending the separation while another group support the separation of both components of the anchovy stock, mostly based on the clear signal of the genomic study showing a strong differentiation of the populations of the western and southern. SIMWG also suggests that a more comprehensive and holistic stock identification programme is introduced, addressing the issues identified in the review, including the connectivity to anchovy in Subarea 8, followed by a specific workshop with all relevant stakeholders to review the data and to consider the implications for management.

3.2.3 Main changes and conclusions on stock definition

The results of the extensive array of techniques that were used to explore the stock structure of anchovy pointed systematically to the separation of the components. The genomic results point to a clear differentiation of the southern and western populations. The current management is not aligned with the current advice provided by ICES, which can risk the sustainability of the stocks. The benchmark group believes that there is compelling evidence to separate the two components of anchovy in 9a into two different stocks for which management options should be provided separately.

The group also acknowledges that there are also several results that show that the western and northern Iberian anchovy populations might be strongly connected. The group agrees with the SIMWG that a holistic stock identification programme followed by a workshop should be carried out. This will address the potential connectivity of the western populations with the anchovy in Subarea 8 in the next benchmark. However, WKBANSP agrees that the further exploration needed to ascertain the potential connectivity to the north should not delay the decision to separate the western and southern components of the Division 9a stock, for which there is already compelling evidence of strong population structure.

3.3 Future considerations/recommendations

It is recommended to implement a comprehensive and holistic stock identification programme to address the stock structure of anchovy across the area of distribution, particularly addressing the connectivity of the western Iberian populations and the anchovy in Subarea 8. This should be followed by a specific workshop with all relevant stakeholders to review the data and to consider the implications for management.

3.4 References

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3.5 Stock-specific working documents

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4 Anchovy (*Engraulis encrasicolus*) in Subdivision 9.a South (Gulf of Cádiz)

4.1 Issue list

The issue list for the anchovy stock in 27.9.a includes the 9.a south and 9.a west components (Table 4.1.1). A primary issue focused on analysing the stock structure of anchovy in 9.a, given the evidence of sub-stock structure within this Division and is explained in detail in section 3 of this report. Assessment model explorations were carried out including testing the performance of the Gadget model (previously used to provide advice) and other alternative models (i.e., SS3). The incorporation of additional survey time series not considered before and an exploratory analysis of the potential causes of the (high) survey catchabilities were also investigated. During this benchmark, a modification of the current assessment method (Gadget based) for the Gulf of Cádiz (GoC) anchovy stock was conducted which relies on the provision of advice based on the outputs of a newly configured SS3 age-based model.

Table 4.1.1. Anchovy in Subdivision 9.a South (Gulf of Cádiz). Issue list of the anchovy 27.9.a stock related to the 9.a south component and considered in WKBANSP 2024.

ID	Type	Priority	Status	Problem/Aim	Work Required	Data Required
278	Stock identity	High priority	Open	Stock structure must be properly defined; two components with different dynamics and a single TAC can lead to overexploitation of one of the components.	National and international research focusing on the connectivity of anchovy populations with genomics are underway and can provide useful insights into the stock structure of Atlanto-Iberian waters. A new report summarising existing information on population dynamics and distribution can also be produced to help inform this issue along with analysis regarding stock identity using morphometrics, genetics, parasites, fisheries, surveys and modelling.	Published and unpublished data of morphometrics, genetics, parasites, fisheries, surveys and modelling.
279	Assessment method	High priority	Open	There are two additional survey series that are now available for the southern component, *ECOCADIZ-RECLUTAS* (acoustic) and *BOCADEVA* (anchovy DEPM), with at least six years of data that should be included as model input.	Incorporation of these two survey series into the Gadget model should be explored.	Surveys data.
280	Other issues	High priority	Open	The Gadget model for the southern component estimates very high survey catchabilities.	Explore the sources of these high values, including analysis of data input consistency and model calculation.	Data available for the assessment.

4.2 General

4.2.1 Fishery information

The anchovy fishery in subdivision 9.a South (Gulf of Cádiz, GoC) is harvested by Portugal and Spain (in Portuguese and Spanish waters of the GoC, respectively). The Spanish purse seine fleet (métier PS_SPF_0_0_0) is the main fleet responsible for the GoC anchovy fishery, accounting for an average of 95% of the total anchovy landings (Ramos *et al*., 2018, WD 2024). The Spanish bottom-trawl fleet (OTB_MCD_> = 55_0_0) follows in importance with approximately 3% of the total anchovy landings, however, such contribution was mainly restricted to the second half of the nineties, when this fleet fished anchovy as bycatch. The Portuguese purse seine fleet only contributes an average of 2% of total catches in the GoC. Incidental catches are also landed by Portuguese bottom trawl (OTB_DEF_> = 55_0_0) and artisanal fleets using artisanal purse seines (also termed in their national statistics as "polyvalent" vessels; MIS_MIS_0_0_0_HC). Discards are considered negligible.

Traditionally, anchovy and sardine are the main target species for the Spanish and Portuguese purse seine fleets, respectively. Silva *et al*. (2007) identified a clear seasonality in the Spanish purse seine fishery, characterised by a sequential occurrence of anchovy and sardine fishing trips through the year, with trips targeting anchovy being dominant during spring–summer and those ones targeting sardine being more frequent from late summer to late winter, seasons coincident with the spawning seasons of these target species in the area.

4.2.2 Current assessment and advice

The ICES framework for category 3 stocks has been applied to the southern component of anchovy in 9.a (Method 3.2: Constant harvest rate [chr] rule for short-lived stocks [ICES, 2022]) to provide advice. The Spawning Stock Biomass (SSB) estimated by the Gadget assessment model was used as an indicator of stock development (see WGHANSA-1 2024 report for details on the modelling framework and outputs). The last advice (969 t) was based on the stock indicator for 2024 (1938 t), multiplied by a constant harvest rate (0.50) and a biomass safeguard, as tested in the management strategy evaluation (MSE) for the stock (ICES, 2023).

4.2.3 Main changes and conclusions on stock definition, data, assessment, forecast and reference points

Stock definition

Major changes to the stock definition were made during the last benchmark process (ICES, 2024). See Section 3 for details. A summary of the evidence presented to the Benchmark meeting on the stock definition of anchovy in Division 9.a, the comments of the ICES SIMWG that reviewed that information and the decisions taken during the Benchmark are described in Section 3. A full description of the evidence on anchovy stock structure is found in Garrido *et al*. (WD 2024).

Based on the extensive work on stock identification, the benchmark decided to split the former anchovy stock in Division 9.a into two stocks, corresponding to the former western and southern components. Therefore, the current anchovy (*Engraulis encrasicolus*) stock in Subdivision 9.a West (Western Iberian waters, ane.27.9.aW) corresponds to the former western component, comprising Sub-Divisions 9.a N, 9.a C-N, 9.a C-S, whereas the anchovy stock in Subdivision 9.a South (GoC, ane.27.9.aS) corresponds to the former southern component. Given that the advice on fishing opportunities was already given separately for the two components, such a change does not affect the current assessments or the provision of separate advice and catch opportunities.

Data and time of the advice

Main differences compared to the previous assessment framework, in terms of data are:

- Only age-based data compared to the length and age data used before
- The incorporation of *BOCADEVA* and *ECOCADIZ-RECLUTAS age 0*, as abundance index and recruitment index, respectively.
- The incorporation of the age 0 of *ECOCADIZ-RECLUTAS survey*

The timing of the advice is proposed to change to the end of the year compared to the previous advice that was given in the middle of the year.

Stock Assessment model

The main difference is regarding the model used, which is now an SS3 model and replaces the Gadget model used previously

Reference Points

New reference points were calculated. B_{lim} is now defined as B_{lim}=B_{pa} * exp(-1.645 * SigmaB), with B_{pa}=B_{loss} and SigmaB=0.2 (as used in other fisheries).

Reference points were calculated following ICES guidelines for calculation of reference points for category 1 and 2 stocks. In those guidelines, the S-R plot characteristics classify this stock as a "stock type 5" (i.e. stocks showing no evidence of impaired recruitment or with no clear relation between stock and recruitment (no apparent S-R signal)). According to this classification, B_{loss} estimation is possible according to the standard method and it corresponds to the estimated SSB in 2010. The fact that the methodology adopted B_{loss} as B_{pa} instead of as B_{lim}, corresponds more with the guidelines for Type 6 stocks (stocks with a narrow dynamic range of SSB and showing no evidence of past or present impaired recruitment).

This new methodology compared to the previous is justified by the fact that assuming B_{lim} equal to B_{loss}, as previously, will imply B_{lim}=0.4*B0 which is a very big proportion, thus suggesting the range of biomasses being covered by the assessment was rather narrow yet.

Short Term Forecast

In the previous framework there was no short-term forecast. This is the first year that a Stochastic short-term forecast is estimated.

4.3 Input data for stock assessment

Input data include total catch (in biomass) and age composition of the catch (in proportion) for the commercial fleet (*SEINE*); abundance (in biomass) and age composition from three annual surveys: *PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS*; and spawning-stock biomass (SSB) estimates from a triennial DEPM *BOCADEVA* survey. To account for catch seasonality, the *SEINE* fleet has been divided into four fleets, one per quarter.

More details on data and data consistency can be found in *Ramos et al 2024. WD: Ane.27.9a stock (Anchovy in ICES Division 9a). Southern component (Anchovy in ICES Subdivision 9a South): Fishery, Biological and Surveys data. Data availability and trends* and *Zúñiga et al 2024 WD: Data consistency analysis of survey age-length data available for the Southern component of anchovy 9a stock.*

Figure 4.3.1 provides a visual representation of the input data used in the model, categorised into three main types: catches, abundance indices, and age compositions. These data are displayed over time (years) and are represented by circles, with the size of each circle reflecting the magnitude of the data.

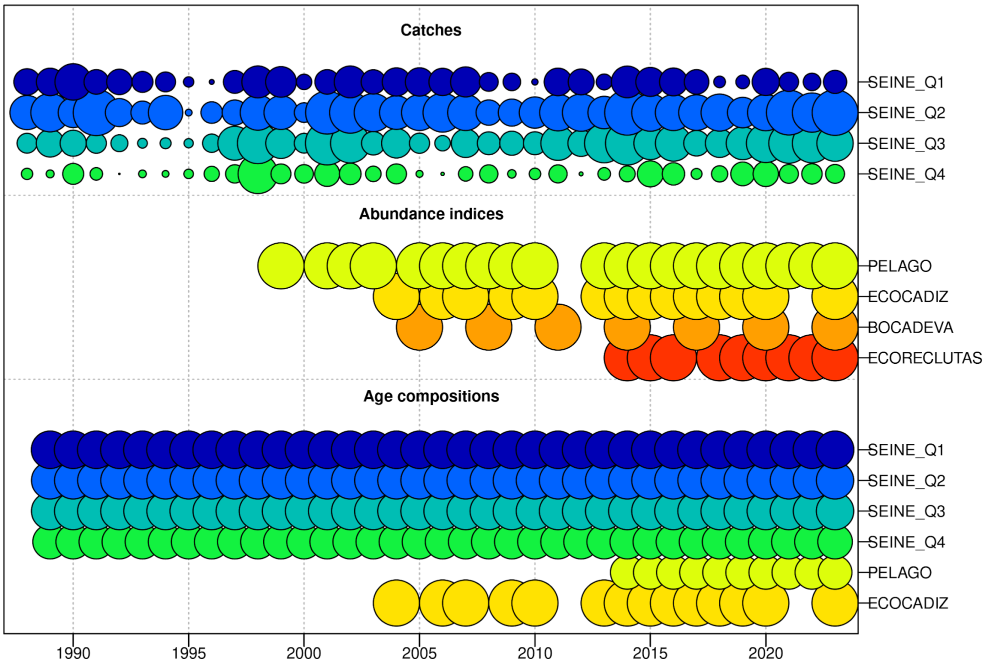


Figure 4.3.1: ane.27.9a Southern stock. Summary of model data input by year, where circle area is relative within a data type. Circles are proportional to total catch for catches, to precision for indices and to total sample size for age compositions.

4.3.1 Catches

Anchovy catches in the GoC exhibit seasonality, with 40.61% concentrated in the second quarter (Q2), averaging 2,120.26 tons historically, followed by the third quarter (Q3) with 29.60% (1,545.23 tons), the first quarter (Q1) with 19.39% (1,012.42 tons), and the fourth quarter (Q4) with 10.39% (542.61 tons). In 2023, first-quarter catches were 7.84% lower than the historical average, while second, third, and fourth-quarter catches increased by 71.03%, 48.06%, and 14.70%, respectively (Figures 4.3.2 and 4.3.3).

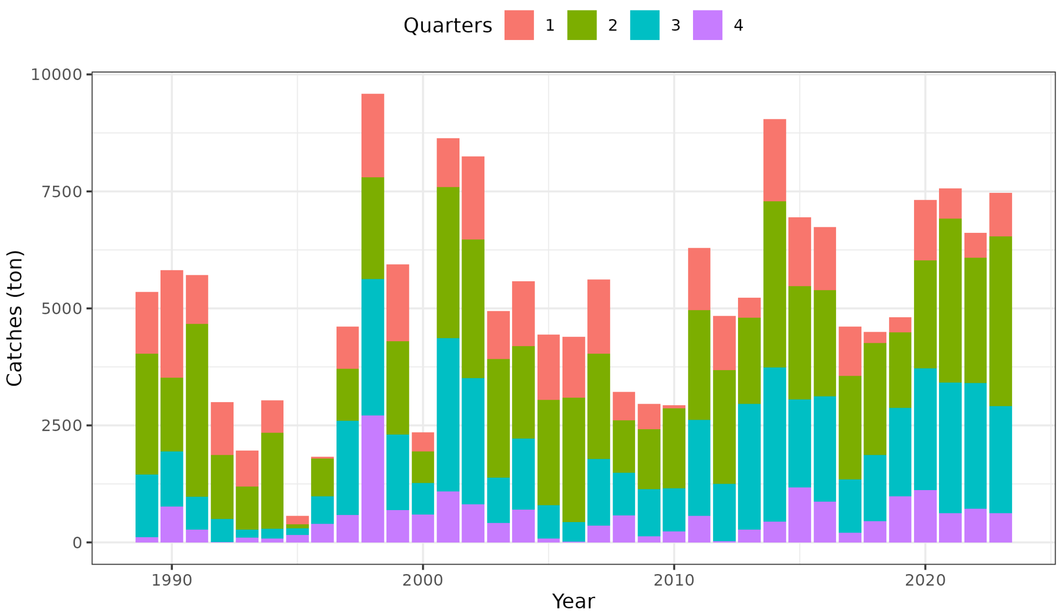


Figure 4.3.2: ane.27.9a Southern stock. Time series of quarterly catches.

	Catches (ton)				
Year	Q1	Q2	Q3	Q4	Total
1989	1318	2589	1336	111	5354
1990	2300	1571	1182	765	5818
1991	1049	3693	702	274	5718
1992	1125	1368	500	4	2997
1993	767	921	167	105	1960
1994	690	2055	210	80	3035
1995	185	80	148	157	570
1996	41	807	586	398	1832
1997	908	1110	2007	588	4613
1998	1781	2176	2909	2716	9582
1999	1638	1995	1616	691	5940
2000	412	668	673	600	2353
2001	1046	3227	3275	1089	8637
2002	1772	2957	2699	816	8244
2003	1027	2539	965	416	4947
2004	1384	1976	1522	699	5581
2005	1398	2252	706	85	4441
2006	1297	2657	416	19	4389
2007	1581	2251	1423	361	5616
2008	613	1121	910	576	3220
2009	533	1280	1016	126	2955
2010	67	1709	920	232	2928
2011	1326	2343	2051	571	6291
2012	1159	2433	1220	26	4838
2013	434	1837	2683	277	5231
2014	1754	3553	3300	439	9046
2015	1471	2425	1880	1174	6950
2016	1352	2267	2254	869	6742
2017	1051	2213	1140	206	4610
2018	236	2391	1414	458	4499
2019	322	1621	1889	982	4814
2020	1286	2315	2603	1113	7317
2021	644	3500	2794	623	7561
2022	532	2682	2679	722	6615
2023	933	3626	2288	622	7469

Figure 4.3.3: ane.27.9a Southern stock. Time series data of quarterly catches.

4.3.2 Abundance indices

The abundance indices *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS* exhibit interannual variability over time (Figure 4.3.4). *PELAGO*, with data from 1999 to 2023, shows fluctuations with a peak in 2016 at 65,345 tons, followed by a decline, but with a slight recovery in 2023 to 26,786 tons. *ECOCADIZ*, covering the period from 2004 to 2023, reaches its maximum in 2019 at 57,700 tons, followed by a significant decrease to 9,714 tons in 2023. *BOCADEVA*, with data from 2005 to 2023, shows a steady increase to its peak in 2020 at 81,466 tons, followed by a reduction to 15,138 tons in 2023. *ECOCADIZ-RECLUTAS*, recorded from 2014 to 2023, shows a sustained increase until 2019 at 48,398 tons, followed by a decrease to 8,300 tons in 2023.

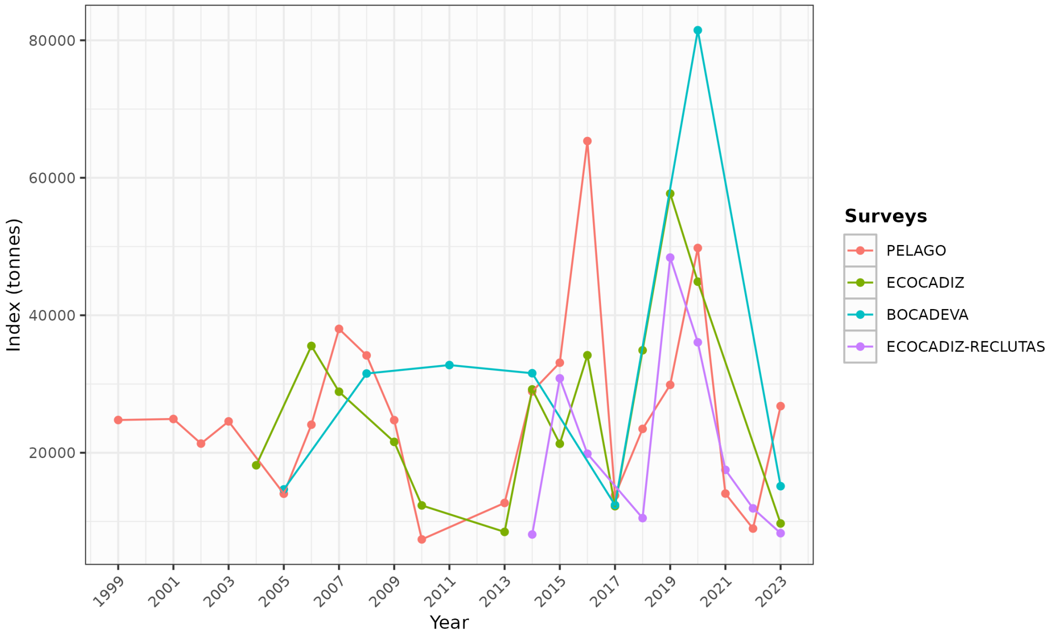


Figure 4.3.4: ane.27.9a Southern stock. Biomass estimates from *PELAGO, ECOCADIZ, BOCADEVA* and *ECOCADIZ-RECLUTAS* surveys.

As it can be observed also in the raw data (Table 4.3.5), these patterns reflect a high variability in abundance over time with periods of increase followed by declines in the later years of each series.

Table 4.3.5: ane.27.9a Southern stock. Biomass estimates data from *PELAGO, ECOCADIZ, BOCADEVA* and *ECOCADIZ-RECLUTAS* surveys.

Acoustic Biomass (ton) by surveys				
year	PELAGO	ECOCADIZ	BOCADEVA	ECOCADIZ-RECLUTAS
1999	24763			
2001	24913			
2002	21335			
2003	24565			
2004		18177		
2005	14041		14673	
2006	24082	35539		
2007	38020	28882		
2008	34162		31527	
2009	24745	21580		
2010	7395	12339		
2011			32757	
2013	12700	8487		
2014	28917	29219	31569	8113
2015	33100	21305		30827
2016	65345	34184		19861
2017	13797	12229	12392	
2018	23473	34908		10493
2019	29876	57700		48398
2020	49787	44887	81466	36070
2021	14065			17512
2022	8972			11912
2023	26786	9714	15138	8300

4.3.3 Age composition

In the model, the age proportions from the commercial fleet (*SEINE*) by quarter from 1989 to 2023, are used (Figure 4.3.6). It can be observed that the proportion of age-0 in Q4 compared to other ages has been increasing in the last years while age-1 predominates in Q1 and Q2, with a constant proportion over time. Age-0 is not recorded in Q1 and Q2 by convention. In Q3 and Q4, the proportion of age-1 individuals decreases as the proportion of age-0 increases. Additionally, ages 2 and 3 exhibit lower and variable proportions across all quarters over the years, without a defined pattern of change.

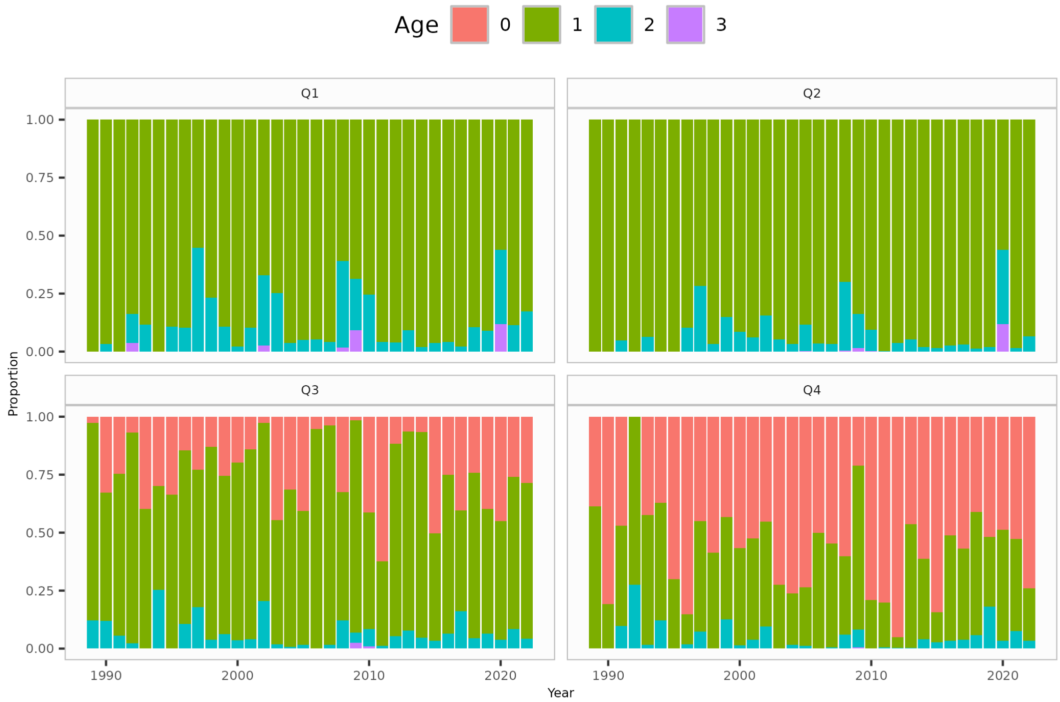


Figure 4.3.6: ane.27.9a Southern stock. Age proportion in the commercial fleet catches by quarter (1989 to 2023).

Figure 4.3.7 shows the yearly age proportions from surveys *PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS* that were used as input for the model. It can be observed that in the *PELAGO* survey, conducted in the second quarter (Q2), age 1 represents the highest proportion over time, with a presence of ages 2 and 3, and no records of age 0 individuals. The *ECOCADIZ* survey, primarily conducted in the third quarter (Q3), shows a predominance of age 1, with an increase in the proportion of age 0 from 2010 onwards; in 2004 and 2006, when the survey was conducted in the second quarter (Q2), no age 0 individuals were recorded by convention. The *ECOCADIZ-RECLUTAS* survey, conducted since 2014 in October (fourth quarter, Q4), shows a higher proportion of age 0, followed by age 1, with lower representation of ages 2 and 3.

In the SS3 model, age-based data from the *PELAGO* survey were included only for the period 2014-2023, when age-length keys from the surveys were available, as per WKPELA 2018. The *ECOCADIZ-RECLUTAS* index relies exclusively on the biomass of age-0 individuals, allowing it to serve as a direct measure of recruitment.

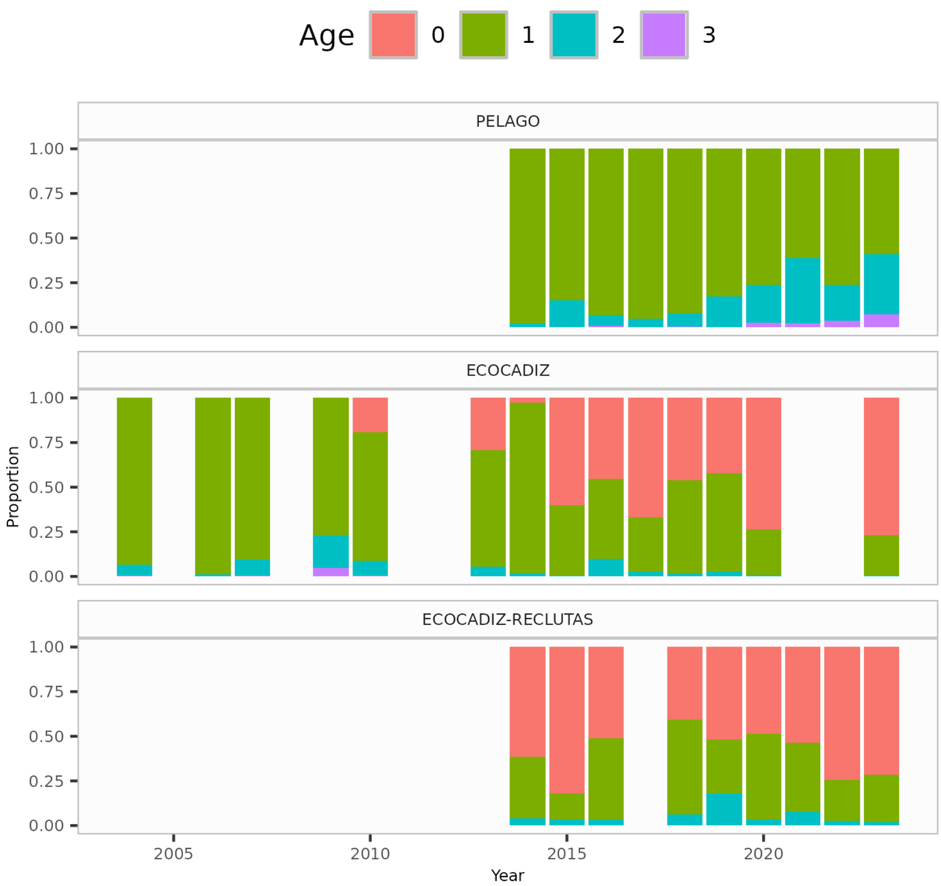


Figure 4.3.7: ane.27.9a Southern stock. Age proportion in acoustic surveys estimates from *PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys.

4.3.4 Weight-at-age

Fish body weight is crucial for converting modelled numbers-at-age into metrics like total catch biomass or abundance indices. For GoC anchovy, weight-at-age data from the SEINE commercial fleet and acoustic surveys (*PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS*) were processed to remove out-of-range and missing values, followed by natural log transformation. Linear mixed-effects models, using the nlme R package, were fitted with log-transformed weight as the dependent variable, age as a fixed effect, and year as a random effect to capture interannual variability. These models generated estimates for 1989–2024 (ages 0–3), which were used to populate the "wtatage.ss" file for Stock Synthesis, specifying mean weights at the beginning and midpoint of each quarter for 1989–2023, ensuring consistency across datasets.

Figure 4.3.8 demonstrates that mean weight differences between age groups have remained relatively stable over time, although some variability is observed across quarters. Individuals aged 3 exhibit greater variability in mean weight compared to younger age groups, which is attributed to the low representation of age-3 fish in all data sources used. For further details, refer to the working document by *Zuñiga et al. (2024 WD): Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).*

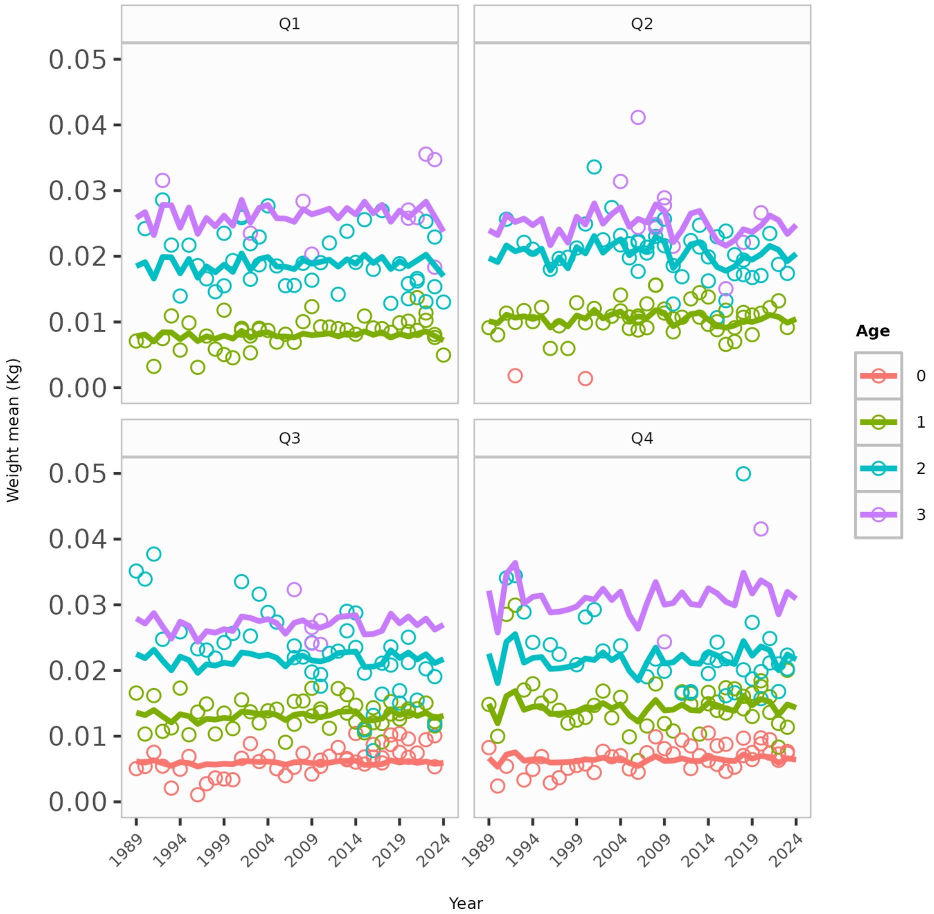


Figure 4.3.8 ane.27.9a Southern stock. Observed and estimated mean weights (in kilograms) by age group (0 to 3 years) for the four quarters over the period 1989 to 2024. Circles represent observed data points, while solid lines indicate the linear mixed-effects model estimates. Each panel corresponds to a specific quarter.

4.3.5 Growth parameters

The description of the estimation of the growth parameters given below is a summary of the work presented in a manuscript that was already submitted (Rincón et al. submitted).

The parameters Linf , k, and t0 were estimated by fitting the Von Bertallanfy Growth Function (VBGF) to the observed length-age data using nonlinear regression and nonlinear mixed-effects techniques. Initially, a nonlinear regression technique was implemented. Two scenarios were explored: in the first, the parameters were estimated independently, while in the second, the parameter t0 was fixed at zero. Subsequently, a nonlinear mixed-effects (mixed-effects hereafter) model was fitted to the data. Six different scenarios were evaluated, varying the combinations of random effects among the parameters Linf , k, and t0 .

The estimated parameters and Akaike Information Criterion (AIC) values were used to select the most suitable method framework and scenario for anchovy growth data.

The comparison of parameter estimates and model fit for nonlinear and mixed-effects models is presented in Table 4.3.6. That comparison shows that allowing t0 to be estimated freely by nonlinear models results in a higher estimate of Linf. In contrast, fixing t0 results in lower estimates of Linf and higher estimates for k.

Among these approaches, the mixed-effects model assuming random effects for t0 and k provides the best fit to the data, as indicated by the lowest AIC value. This suggests that incorporating random effects may effectively capture the variability in the data. The final parameters selected were: Linf = 19.95, k = 0.46, t0 = −0.74.

Table 4.3.6: ane.27.9a Southern stock. Comparison of growth parameter estimates and model fit between nonlinear and nonlinear mixed-effects models. Additionally, the AIC (Akaike Information Criterion) values are provided for each model.

method	Random effect	Linf (mm)	k (1/year)	t0 (years)	AIC
Nonlinear free t0	-	427.17	0.10	-1.99	781165
Nonlinear fixed t0	-	149.65	1.34	0	795342
Mixed-effects	t0	226.62	0.31	-1.15	776750
Mixed-effects	k	251.55	0.24	-1.40	777271
Mixed-effects	Linf	274.37	0.20	-1.55	777465
Mixed-effects	t0 and k	199.58	0.46	-0.74	775272
Mixed-effects	t0 and Linf	208.93	0.40	-0.86	775424
Mixed-effects	Linf and k	243.11	0.30	-1.13	775817

4.3.6 Natural mortality

The Gislason *et al*. (2010) method for modelling natural mortality, M, at age as a function of the growth parameters was applied. For that, the length-at-age vector for ages 0-3 years derived from the von Bertalanffy growth function (VBGF) was used. The value of the parameters for this function (Linf = 19.95, k = 0.46, t0 = −0.74), as explained before, were obtained from Rincón et al. (submitted).

As anchovy is a short-lived species, Gislason *et al*. (2010) methodology estimates (M0 = 2.97, M1 =1.13, M2 = 0.759 and M3 = 0.618) were not very accurate for ages 1+ , if we assume that M in older ages may be similar to the one of the Bay of Biscay anchovy. Results from Uriarte *et al*. (2016) suggest that mortality at these older ages should be higher because senescence might be occurring, in accordance with the expectation of observable senescent mortality affecting short-lived cupleoids (Beverton 1963).

To estimate M1+, 13 estimators were calculated based on the VBGF parameters (Rincón *et al*., submitted) and the maximum observed age for anchovy in 9a South. While maximum ages of 3 and 4 years were considered, age 3 was deemed more appropriate since the few age-4 individuals observed were considered outliers (3 and 4 individuals in the *ECOCADIZ* 2009 and *ECOCADIZ-RECLUTAS* 2017 surveys, respectively). The resulting mean value, M = 1.33, is recommended as the best estimate.

As in the 2018 benchmark (ICES 2018), overall likelihood scores were compared across different model implementations, varying the value of natural mortality (M) while maintaining the same pattern: M0 = M + 0.9, M1 = M, and M2+ = M. Preliminary results from the SS3 model showed consistency within the range of 1.2 < M < 2.3. In summary, the following M-at-age values are recommended for 9a South anchovy: (M0 = 2.97, M1 = 1.33, M2 = 1.33 and M3 = 1.33). For further details, refer to the working document by *Rincón et al. (2024 WD): Growth and natural Mortality parameters estimation for anchovy 9a South.*

However, these values will be adjusted in subsequent model runs to determine the final configuration (see Section 4.4.1.3.1.4).

4.3.7 Maturity

Due to some inconsistencies in the maturity ogives not noticed during WKPELA 2018, that still remain, it was assumed that all individuals with age 1 or higher (B1+), are mature, *i.e.* these abundance estimates result equivalent to spawning stock biomass (SSB) estimates.

Parameter	Age_0	Age_1	Age_2	Age_3
Maturity	0	1	1	1

4.4 Stock assessment

The assessment of the anchovy in ICES subdivision 9a South was performed in Stock Synthesis (SS3) (Methot and Wetzel, 2013). SS3 is a generalised age and/or length-based model that is very flexible with regard to the types of data that may be included, the functional forms that are used for various biological processes, the level of complexity and number of parameters that may be estimated. The model is coded in C++ with parameter estimation enabled by automatic differentiation (www.admb-project.org) and available at the NOAA Fisheries integrated toolbox: https://noaa-fisheries-integrated-toolbox.github.io/SS3. A description and discussion of the model can be found in Methot and Wetzel (2013).

All models described here were executed on a Linux platform using SS version 3.30.22.beta. This version is similar to 3.30.22.1 (https://github.com/nmfs-ost/ss3-source-code/releases/tag/v3.30.22.1) but includes a correction for a bug affecting the reported SSB, identified during the data exploration process for the Ane.27.8 stock before the benchmark. The bug was reported to the SS development team, who provided a corrected executable (version 3.30.22.beta) used throughout the benchmark. This executable is available on the WKBANSP ICES SharePoint. The R packages r4ss (version 1.50.0; Taylor et al., 2021) and ss3diags (version 1.10.3; Carvalho et al., 2021) were employed to process and visualise the model outputs. All analyses were conducted in R version 4.4.1 (2024-06-14).

4.4.1 Exploratory assessments

Several model configurations were tested, primarily using SS software, with additional exploration of the previous Gadget model (WKPELA 2018, ICES 2018) and SPICT. Gadget and SPICT were used exclusively for comparative purposes, as the SS3 age-based model provided robust results. The Gadget model does not provide estimates of parameter uncertainty, producing deterministic values for key variables such as SSB, numbers-at-age, and biomass-at-age. Moreover, the computation time for Gadget2 (3 to 4 hours per run) makes it unsuitable for stock assessment or Management Strategy Evaluation (MSE) in scenarios requiring additional analyses. Although Gadget3 offers faster computation, its limited documentation restricts its applicability.

SS3 was selected as the primary stock assessment model because it provides estimates of parameter uncertainty, along with its flexibility, broad application, available documentation, and support from the SS development team. Additionally, SS completed parameter estimation runs in less than a minute for this case study, allowing for a wider range of exploratory analyses.

The initial exploratory runs were fitted using the following available data:

- Total catch by quarters (Gadget, SPICT and SS3)
- Catch-at-age for the commercial fishery by quarters (Gadget and SS3)
- Catch-at-length for the commercial fishery by quarters (Gadget)
- Total biomass acoustic surveys (*PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS*) (Gadget, SPICT, SS3)
- Age structure from the acoustic surveys (*PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS*) (Gadget and SS3)
- Length structure from the acoustic surveys (*PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS*) (Gadget)
- SSB biomass from de DEPM survey (*BOCADEVA*) (Gadget, SPICT and SS3)

4.4.1.1 Exploratory assessment in Gadget

A full description of the Gadget and its settings is provided in the Stock Annex of the anchovy in ICES division 9a, southern component.

The Gadget model was run using data up to 2023, including acoustic surveys (*PELAGO*, *ECOCADIZ*, *ECOCADIZ-RECLUTAS*) and DEPM (*BOCADEVA*), to evaluate sensitivity to growth parameters and natural mortality (*Rincón, 2024 WD: Comparison of Gadget implementations with the same data input as the age-based SS3 model plus length distributions*.) :

- Model 1: Fixed growth parameters (Linf = 19.95, k = 0.46) and natural mortality from WKPELA 2018 (M0 = 2.21, M1 = 1.3, M2 = 1.3, and M3 = 1.3).
- Model 2: Fixed growth parameters (Linf = 19.95, k = 0.46) and updated natural mortality (M0 = 2.97, M1 =1.33, M2 = 1.33 and M3 = 1.33).
- Model 3: Growth parameters estimated by the model (Linf = 40.258, k = 0.034) and natural mortality from WKPELA 2018 (M0 = 2.21, M1 = 1.3, M2 = 1.3, and M3 = 1.3).
- Model 4: Growth parameters estimated by the model (Linf = 25.6, k = 0.04) and updated natural mortality (M0 = 2.97, M1 =1.33, M2 = 1.33 and M3 = 1.33).

The evaluated scenarios indicate that growth parameters estimated internally by the Gadget model (Model 3 and 4) produce lower k values and higher Linf estimates compared to externally estimated parameters (see Section 4.3.5). These internally estimated parameters do not accurately represent the species' biology.

Figure 4.3.9 shows the fits to the *BOCADEVA*, *ECOCADIZ*, and *PELAGO* survey indices across different model runs. The *ECOCADIZ-RECLUTAS* index shows difficulty in fitting the highest values in the series when growth parameters are estimated within the Gadget model (Models 3 and 4).

Catchability estimates for all surveys in the Gadget model vary depending on the treatment of growth parameters, ranging from 5 to 6.8 when parameters are fixed (externally estimated) and from 1 to 2.5 when parameters are estimated internally (Figure 4.3.10). These differences in parameter estimation also affect biomass and fishing mortality, with increases in B1+ biomass levels and reductions in fishing mortality (Figure 4.3.11). These results highlight the importance of carefully selecting how growth parameters are incorporated into the modelling process to ensure reliable and interpretable outcomes.

The Gadget model was used exclusively for comparative purposes; the impact of estimating parameters within the model on other estimated parameters was not assessed, nor were additional diagnostic analyses conducted. Exploring additional sensitivity scenarios during the benchmark was not possible due to the extensive computational time required for each model run (over three hours). Therefore, the decision was made to rely on the age-based SS3 model (growth is not modelled explicitly), due to its flexibility, broad application, available documentation, and support from the SS3 development team. Additionally, SS3 completed parameter estimation runs in less than a minute for this case study, allowing for a wider range of exploratory analyses.

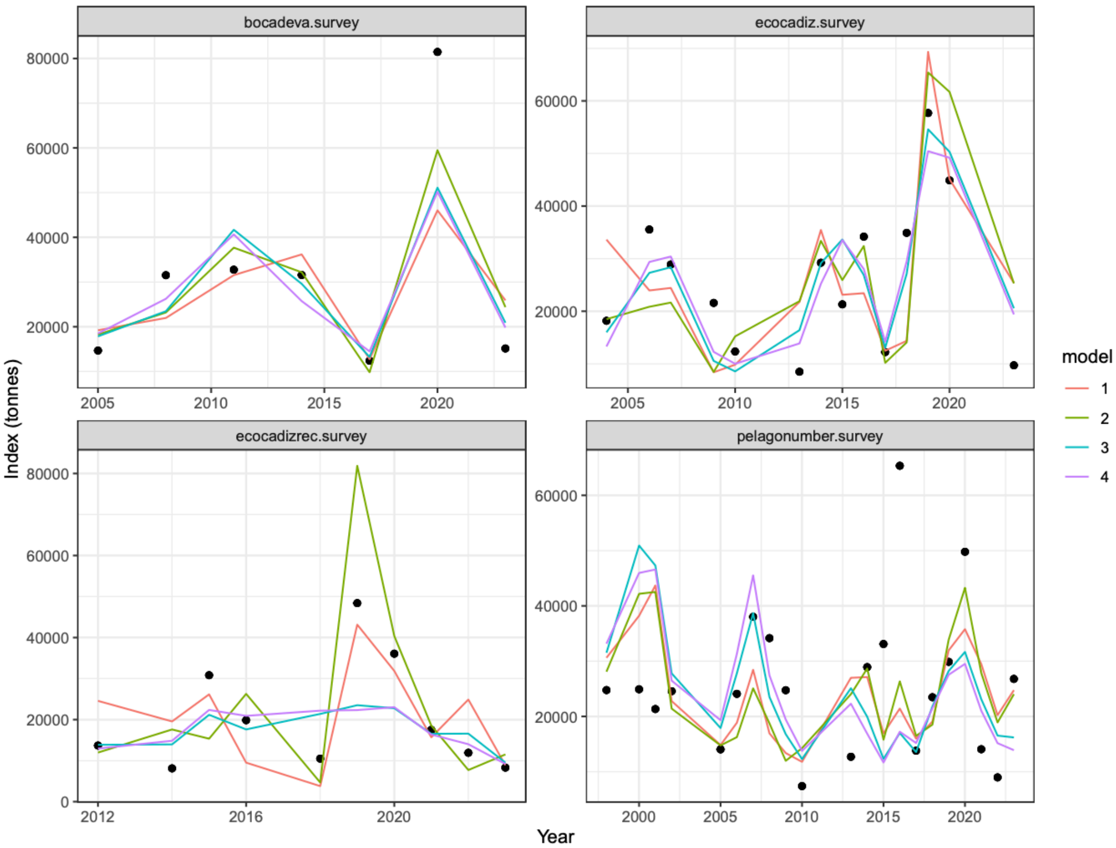


Figure 4.3.9. ane.27.9a Southern stock. Survey fit for each of the Gadget model runs.

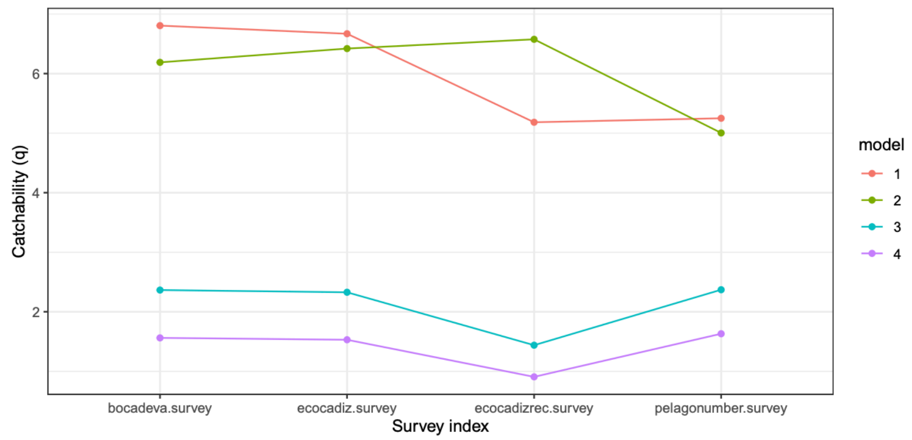


Figure 4.3.10. ane.27.9a Southern stock. Estimated catchability for all surveys across the model runs in Gadget.

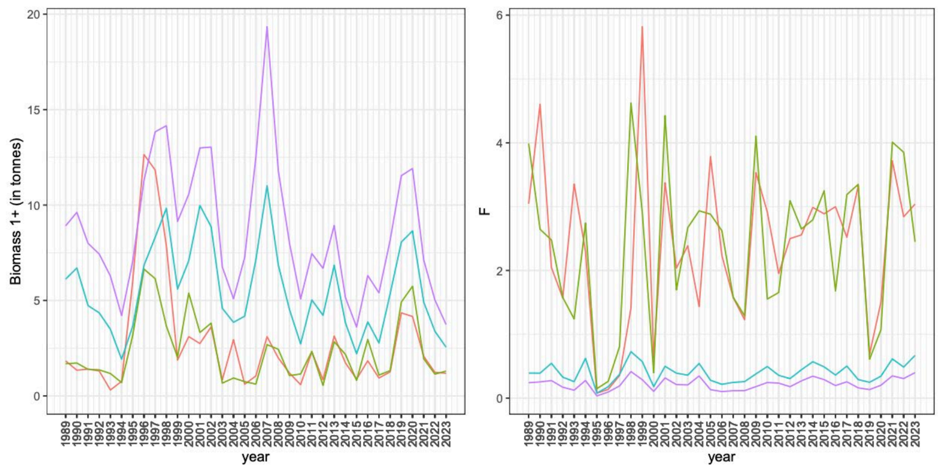


Figure 4.3.11. ane.27.9a Southern stock. Absolute values of B_1+ estimates at the end of the year and the absolute values for the mean quarterly fishing mortality (F) at age 3 for each year.

4.4.1.2 Exploratory assessment in SPICT

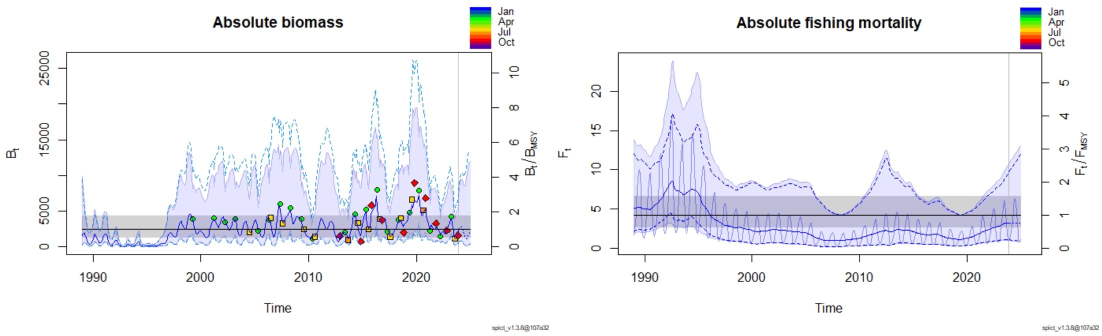
Two scenarios were evaluated using the SPICT model. Model 1 included quarterly landings for the period 1989-2023 and annual abundance indices from the *PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS* surveys. Model 2 added the *BOCADEVA* index to the data used in Model 1.

- Model 1: Quarterly Landings: 1989-2023 and yearly Abundance Indices: *PELAGO* (1999-2023) , *ECOCADIZ* (2004-2023) and *ECOCADIZ-RECLUTAS* (2012-2023).
- Model 2: Quarterly Landings: 1989-2023 and yearly Abundance Indices: *PELAGO* (1999-2023), *ECOCADIZ* (2004-2023), *ECOCADIZ-RECLUTAS* (2012-2023) and *BOCADEVA* (2005-2023).

The results indicated a biomass in 2023 of 2,219.43 and a fishing mortality of 3.25 for Model 1, while Model 2 estimated a biomass of 2,513.80 and a fishing mortality of 2.75. Both scenarios exhibited similar orders of magnitude compared to estimates from the Gadget model (see, Figure 4.3.11 Gadget and Figure 4.3.12 SPICT) and high catchabilities ranging between 4.4 and 8.9 (Table

4.3.6). No further explorations were conducted, and the decision was made to proceed with the SS3 model.

Model 1



Model 2

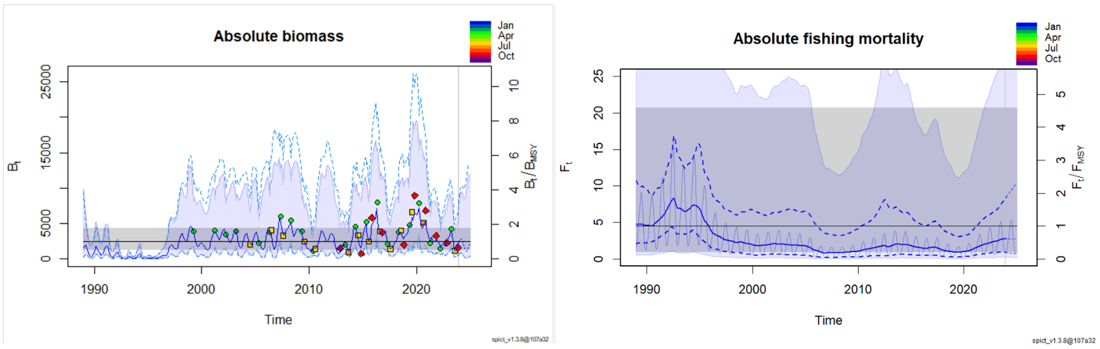


Figure 4.3.12. ane.27.9a Southern stock. Top panel: Biomass and fishing mortality estimates from Model 1. Bottom panel: Biomass and fishing mortality estimates from Model 2.

Table 4.3.6. ane.27.9a Southern stock. Estimated catchability for all surveys across the model runs in SPICT.

	PELAGO	*ECOCADIZ*	*ECOCADIZ-RECLUTAS*	*BOCADEVA*
model 1	6.29	8.75	5.31	-
model 2	5.52	7.33	4.45	8.86

4.4.1.3 Exploratory assessment in Stock Synthesis

Initial run

The first modification to the initial model was to split the SEINE fleet into four, one per quarter, to account for the different seasonal selectivity patterns; that model was referred to as S1.0_4FLEETS and hereafter is going to be considered as the initial run.

The initial configuration for the **S1.0_4FLEETS** model is as follows:

The model incorporated four quarters (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Nov). To estimate different selectivity patterns for each quarter, the commercial fleet was divided into four separate fleets: the first fleet operates exclusively during the first quarter, the second during the second quarter, the third during the third quarter, and the fourth during the fourth quarter. This approach assumed different selectivities per quarter to account for the seasonal age patterns.

Spawning and Settlement:

- Spawning time was set at the beginning of April.
- Settlement was set at the beginning of July.

Weight-at-age:

- Mean weight estimates by quarter and year (1989–2023) were obtained using a linear mixed-effects model that incorporated the entire dataset.

Maturity-at-Age:

- All individuals are mature at age-1 (maturity at age-0 = 0).

Biomass and Age Compositions:

- Biomass (in tonnes) and age compositions (as proportions) from the surveys were considered annually.

Survey Details:

- *PELAGO* Spring Survey: Conducted primarily in April from 1999 to 2023.
- *ECOCADIZ* Summer Survey: Conducted in July from 2004 to 2023.
- *BOCADEVA* (DEPM) Summer Survey: Conducted triennially in July from 2005 to 2023 (without age composition; fixed at 0 for age-0 and at 1 for all other ages over time).
- *ECOCADIZ-RECLUTAS* Fall Survey: Conducted in October from 2014 to 2023.
- All acoustic surveys were modeled as total biomass, assumed to be relative indices of abundance. Catchability was modeled with a simple q linear model.
- Standard errors of 0.3 assumed for all surveys.
- Selectivity-at-age was assumed to follow logistic functions fixed over time (except for *BOCADEVA,* fixed at 0 for age-0 and at 1 for all other ages over time).
- No time blocks for the estimation of catchability or selectivity were adopted for the initial runs.

Equilibrium Catches:

Equilibrium catches were set to 0 tonnes for all quarters in 1988.

Recruitment:

- Annual recruitments were modelled as lognormal deviations from the Beverton-Holt recruitment curve.
- Equilibrium recruitment (R0) was estimated, while steepness (h) was fixed at 0.8, and sigmaR was set at 0.6.
- Main recruitment deviations were estimated for the period 1991–2023, while early recruitment deviations were estimated starting from 1985.

Natural Mortality:

- Age-specific natural mortality values were estimated using the Gislason et al. (2010) method, which models mortality as a function of growth parameters derived from a nonlinear mixed-effects model. The resulting values were: M-at-age-0 = 2.97, M-at-age-1 = 1.33, M-at-age-2 = 1.33, and M-at-age-3 = 1.33 (see Section 4.3.6).

All model specifications and results can be found in *Zúñiga et al. (2024 WD): S1.0_4FLEETS - Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)*.

Table 4.3.7. and Table 4.3.8. show the scenarios tested during the benchmark and their main diagnostics.

Table 4.3.7. ane.27.9a Southern stock. List and description of the scenarios tested during the benchmark

Scenario	Description
Initial implementing model	
S0	One fleet for four season (1 fleet, 4 season)
S1.0 4FLEETS	One fleet per season (4 fleet, 4 season)
Fixed weight at age exercise	
S1.0_4FLEETS_WatageFix	Empirical Weight-at-age fixed years
Fixing catchabilities exercise	
S1.0 4FLEETS q1PEL	S1.0 4FLEETS + Catchability fixed q=1 PELAGO
S1.0 4FLEETS q1ECO	S1.0 4FLEETS + Catchability fixed q=1 ECOCADIZ
S1.0_4FLEETS_q1BOCA	S1.0_4FLEETS + Catchability fixed q=1 BOCADEVA
S1.0_4FLEETS_q1ECOREC	S1.0_4FLEETS + Catchability fixed q=1 ECOCADIZ-RECLUTAS
Sensitivity test of different selectivity assumptions for the ECOCADIZ survey	
S1.0 4FLEETS SelECO	S1.0 4FLEETS + logistic selectivity ECOCADIZ: two blocks (2004-2014, 2015-2023)
S1.0 4FLEETS SelvarECO	S1.0 4FLEETS + logistic selectivity ECOCADIZ: random walk (2004 2014) and fixed (2015 2023)
Priors on catchabilities exercise	
S4FLEETS_SelECO_Qprior	Qprior all surveys
S4FLEETS_SelECO_QpriorPelEcoR	Qprior PELAGO and ECOCADIZ-RECLUTAS
S4FLEETS SelECO QpriorEco.Boca	Qprior ECOCADIZ and BOCADEVA
S4FLEETS SelECO QpriorBoca.EcoR	Qprior BOCADEVA and ECOCADIZ-RECLUTAS
S4FLEETS_SelECO_QpriorEcoR	Qprior only ECOCADIZ-RECLUTAS
Sensibility to selectivity and natural mortality assumptions	
S4FLEETS_SelECO_Selfleet	S1.0_4FLEETS_SelECO + Parameterize age-based fishery selectivity where age-0==0 (for Q1 and Q2 only, estimated for Q3-Q4) and age-2==1, and age-1 and
S4FLEETS SelECO Mage	S1.0 4FLEETS SelECO + Estimate M for age-2+
S4FLEETS SelECO MageSel	Combination of S4FLEETS SelECO Selfleet and S4FLEETS SelECO Mage: Fishery selectivity and natural mortality
S4FLEETS_SelECO_MfixSel	Combination of S4FLEETS_SelECO_Selfleet and Mfix=S4FLEETS_SelECO_Mage: Fishery selectivity and natural mortality fixed.
Sensitivity to ECOCADIZ-RECLUTAS selectivity	
S4FLEETS_SelECO_Selfleet_EcoR	S4FLEETS_SelECO_Selfleet + Parameterize age_based ECOCADIZ-RECLUTAS selectivity where age-0==1 and ages-1, ages-2 and ages-3 are estimated
S1.0 4FLEETS SelECO EcoR	S1.0 4FLEETS SelECO + Parameterize age based ECOCADIZ-RECLUTAS selectivity where age-0==1 and ages-1, ages-2 and ages-3 are estimated
S1.0 4FLEETS SelECO EcoR3	S1.0 4FLEETS SelECO + Parameterize age based ECOCADIZ-RECLUTAS selectivity where age-3==0 and ages-0, ages-1 and ages-2 are estimated
ECOCADIZ-RECLUTAS as recruitment Index and natural mortality by age	
S1.0_4FLEETS_SelECO_RecIndex	S1.0_4FLEETS_SelECO + ECOCADIZ-RECLUTAS as recruitment Index
S1.0_4FLEETS_SelECO_RecIndex_M1_1.6	S1.0_4FLEETS_SelECO_RecIndex + Natural mortality by age fixed Mage-0=2.97,Mage-1=1.6,Mage-2=1.33,Mage-3=1.33
S1.0 4FLEETS SelECO RecIndex Mest2 3 M1 1.6	S1.0 4FLEETS SelECO RecIndex + Natural mortality by age fixed Mage-0=2.97,Mage-1=1.6, estimated Mage-2=3
S1.0 4FLEETS SelECO RecIndex Mnewfix	S1.0 4FLEETS SelECO RecIndex + Natural mortality by age fixed Mage-0=2.97,Mage-1=1.6,Mage-2=2.4,Mage-3=2.4
Further analysis	
S1.0_InitCond	S1.0_4FLEETS_SelECO_RecIndex_Mnewfix + Initial equilibrium catch was assumed to be equal to the average catch from 1989-1994 for each fleet and season
S1.0_InitCond_sigmaR	S1.0_InitCond + sigmaR=0.33, as specified by the sigma_R_info in SS3
S1.0 InitCond sigmaR SelP	S1.0 InitCond sigmaR + Selectivity PELAGO was fixed at 1 from age 1 onwards
S1.0 InitCond sigmaR SelP qpriorP	S1.0 InitCond sigmaR SelP + A normal prior with a standard deviation of 0.1 was applied to PELAGO catchability
S1.0_InitCond_sigmaR_qpriorP	S1.0_InitCond_sigmaR + A normal prior with a standard deviation of 0.1 was applied to PELAGO catchability

The scenarios highlighted in bold represent the options selected on each day of the benchmark.

Table 4.3.8. ane.27.9a Southern stock. Diagnostics of the scenarios tested during the benchmark.

Index	S0	**S1.0_4FLEETS**	S1.0_4FLEETS_WatageFix	S1.0_4FLEETS_q1PEL	S1.0_4FLEETS_q1ECO	S1.0_4FLEETS_q1BOCA	S1.0_4FLEETS_q1ECOREC	**S1.0_4FLEETS_SelECO**	S1.0_4FLEETS_SelvarECO	S4FLEETS_SelECO_Qprior
Convergency	0.000	**0.000**	0.000	12408.000	0.000	0.000	549.934	**0.000**	0.000	0.000
AIC	304	**264**	260	381	372	424	339	**254**	266	411
Total_like	139	**113**	111	173	168	194	152	**106**	112	185
N_Params	26	**38**	38	36	36	36	36	**42**	42	42
Survey_like	−13	**−12**	−13	10	12	27	4	**−13**	−13	5
Age_like	121	**135**	134	172	165	177	156	**128**	133	179
run_test_index_PELAGO	Passed	**Passed**	Passed	Failed	Passed	Passed	Passed	**Passed**	Passed	Passed
run_test_index_ECOCADIZ	Passed	**Passed**	Passed	Passed	Passed	Passed	Passed	**Passed**	Passed	Passed
run_test_index_BOCADEVA	Passed	**Passed**	Passed	Passed	Passed	Failed	Passed	**Passed**	Passed	Passed
run_test_index_ECORECLUTAS	Passed	**Passed**	Passed	Passed	Passed	Passed	Passed	**Passed**	Passed	Passed
run_test_age_SEINE	Passed	**NA**	NA	NA	NA	NA	NA	**NA**	NA	NA
run_test_age_PELAGO	Passed	**Passed**	Passed	Failed	Passed	Failed	Passed	**Passed**	Passed	Failed
run_test_age_ECOCADIZ	Failed	**Failed**	Failed	Failed	Failed	Failed	Failed	**Passed**	Failed	Passed
run_test_age_ECORECLUTAS	Passed	**Passed**	Passed	Passed	Passed	Passed	Passed	**Passed**	Passed	Passed
run_test_age_SEINE_Q1	NA	**Passed**	Passed	Passed	Passed	Passed	Passed	**Passed**	Passed	Passed
run_test_age_SEINE_Q2	NA	**Passed**	Passed	Passed	Passed	Passed	Passed	**Passed**	Passed	Passed
run_test_age_SEINE_Q3	NA	**Passed**	Passed	Passed	Passed	Passed	Passed	**Passed**	Passed	Passed
run_test_age_SEINE_Q4	NA	**Passed**	Passed	Failed	Passed	Passed	Passed	**Passed**	Passed	Passed
RMSE_index	41.1	**41.7**	41.1	50.2	51	55.9	48.1	**41.5**	41.4	48.3
RMSE_age	36.1	**29**	29	31.6	31.7	32.5	30.4	**27.4**	28.5	31.4
Retro_Rho_ssb	0.254	**0.046**	0.042	0.259	0.270	0.118	0.128	**0.035**	0.049	0.267
Forecast_Rho_ssb	0.296	**0.296**	0.296	0.296	0.296	0.296	0.296	**0.296**	0.296	0.296
Rho_f	−0.276	**−0.070**	−0.061	−0.230	−0.207	−0.047	−0.138	**−0.060**	−0.075	−0.227
Forecast_Rho_f	0.296	**0.296**	0.296	0.296	0.296	0.296	0.296	**0.296**	0.296	0.296

The scenarios highlighted in bold represent the options selected on each day of the benchmark. **Table 4.3.8. continues below**

Table 4.3.8. continued

Index	S4FLEETS_SelECO_QpriorPelEcoR	S4FLEETS_SelECO_QpriorEco.Boca	S4FLEETS_SelECO_QpriorBoca.EcoR	S4FLEETS_SelECO_QpriorEcoR	S4FLEETS_SelECO_Selfleet	S4FLEETS_SelECO_Mage	S4FLEETS_SelECO_MageSel	S4FLEETS_SelECO_MfixSel	S4FLEETS_SelECO_Selfleet_EcoR	S1.0_4FLEETS_SelECO_EcoR
Convergency	0.000	0.087	0.000	127.969	0.000	0.127	0.000	0.000	0.000	0.000
AIC	347	401	390	314	251	229	233	231	295	308
Total_like	152	179	174	136	103	93	93	93	124	132
N_Params	42	42	42	42	46	44	48	46	48	44
Survey_like	−3	9	8	−4	−13	−14	−14	−14	−8	−7
Age_like	152	166	162	141	126	119	118	118	141	148
run_test_index_PELAGO	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_index_ECOCADIZ	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_index_BOCADEVA	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_index_ECORECLUTAS	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
run_test_age_PELAGO	Passed	Failed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_ECOCADIZ	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_ECORECLUTAS	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Failed	Failed
run_test_age_SEINE_Q1	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE_Q2	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE_Q3	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE_Q4	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
RMSE_index	45.4	49.9	49.4	45.1	41.3	40.8	40.8	40.8	43.4	43.9
RMSE_age	29.3	30.2	30.6	28.4	27.1	26.8	26.7	26.7	45.5	47.9
Retro_Rho_ssb	0.182	0.220	0.130	0.102	0.042	−0.089	−0.063	−0.022	−0.072	−0.045
Forecast_Rho_ssb	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296
Rho_f	−0.183	−0.176	−0.071	−0.116	−0.057	0.006	0.048	0.026	0.097	0.060
Forecast_Rho_f	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296

The scenarios highlighted in bold represent the options selected on each day of the benchmark. **Table 4.3.8. continues below**

Table 4.3.8. continued

Index	S1.0_4FLEETS_SelECO_EcoR3	**S1.0_4FLEETS_SelECO_RecIndex**	S1.0_4FLEETS_SelECO_RecIndex_M1_1.6	S1.0_4FLEETS_SelECO_RecIndex_Mest2_3_M1_1.6	**S1.0_4FLEETS_SelECO_RecIndex_Mnewfix**	S1.0_InitCond	**S1.0_InitCond_sigmaR**	S1.0_InitCond_sigmaR_SelP	S1.0_InitCond_sigmaR_SelP_qpriorP	S1.0_InitCond_sigmaR_qpriorP
Convergency	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AIC	301	235	228	207	254	266	253	235	250	254
Total_like	129	98	95	83	108	110	103	96	104	104
N_Params	44	38	38	40	38	46	46	42	42	46
Survey_like	−11	−12	−12	−15	−10	−9	−9	−12	−11	−11
Age_like	149	120	117	111	129	130	131	127	131	131
run_test_index_PELAGO	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_index_ECOCADIZ	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_index_BOCADEVA	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_index_ECORECLUTAS	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
run_test_age_PELAGO	Passed	Passed	Passed	Passed	Passed	Failed	Failed	Passed	Passed	Passed
run_test_age_ECOCADIZ	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_ECORECLUTAS	Passed	NA	NA	NA	NA	NA	NA	NA	NA	NA
run_test_age_SEINE_Q1	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE_Q2	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE_Q3	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
run_test_age_SEINE_Q4	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
RMSE_index	42	42	41.6	40.3	42.6	43	43	41.6	42.4	42.4
RMSE_age	28.6	28.2	28.1	27.7	27.4	27.5	27.8	27.8	28.7	28.7
Retro_Rho_ssb	−0.041	0.003	−0.065	−0.138	−0.071	0.001	−0.107	−0.077	0.052	0.043
Forecast_Rho_ssb	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296
Rho_f	0.027	−0.012	0.102	0.099	0.128	0.004	0.260	0.239	−0.076	−0.048
Forecast_Rho_f	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296	0.296

The scenarios highlighted in bold represent the options selected on each day of the benchmark.

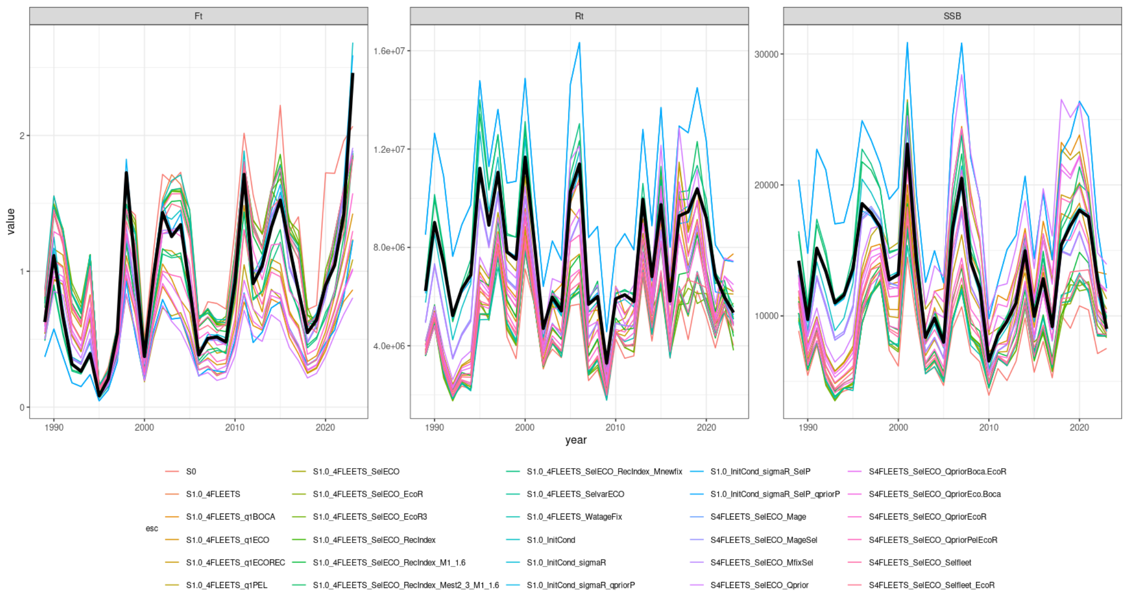


Figure 4.3.13a. ane.27.9a Southern stock. Comparison of Fishing Mortality (Ft), Recruitment (Rt), and Spawning Stock Biomass (SSB) across scenarios. The black line represents the final run selected during the benchmark process (S1.0_InitCond_sigmaR).

The scenarios highlighted in bold in Tables 4.3.7 and 4.3.8 represent the options selected each day of the benchmark, leading to the final model and are described in detail below.

Weight-at-age exercise

As weight-at-age showed no clear temporal trend, reviewers requested a sensitivity analysis assuming time-invariant weight-at-age by quarter to mitigate potential survey-related noise. The analysis produced similar outputs (Figure 4.3.13), with only marginally improved diagnostics (Table 4.3.9), confirming that time-varying weight-at-age is appropriate to capture potential future trends. A linear mixed-effects model was applied to the data, using log-transformed weight as the dependent variable and age as a fixed effect. The modelled values were subsequently used as input observations.

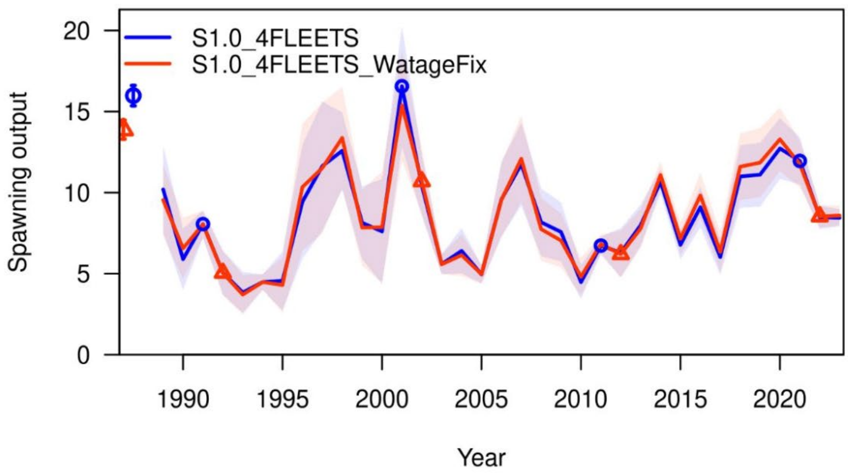


Figure 4.3.13. ane.27.9a Southern stock. Comparison Spawning Biomass by scenario.

Table 4.3.9. ane.27.9a Southern stock. Comparison diagnostics by scenario.

Metric	S1.0_4FLEETS	S1.0_4FLEETS_WatageFix
convergency	0.0001	0.0000
Total_like	113.1470	110.9530
Survey_like	-12.0770	-13.4894
Age_like	134.7390	134.0430
RMSE_index	41.7000	41.1000
RMSE_age	29.1000	29.0000

Selectivity blocks for the ECOCADIZ survey

The initial run showed high abnormal residuals for the *ECOCADIZ* survey, particularly for age 0 in recent years (Figure 4.3.14), acceptable retrospective patterns, but high Mohn's rho values (0.42 for SSB and -0.26 for F, Table 4.3.8) and elevated survey catchability estimates (Figure 4.3.15). Figure 4.3.16 shows a notable change in age composition between the periods 2004–2014 and 2015–2023. Evidence suggests that the shift in the survey timing from June to July, implemented in 2007, may have triggered this change in the availability of age-0 individuals. However, a significant increase in the occurrence of age-0 individuals was not observed until 2015. For this reason, the selectivity of the *ECOCADIZ* survey was divided into two periods (2004–2014 and 2015–2023). These selectivity blocks allowed for a better fit to the mean age composition of *ECOCADIZ* during the first period (pre-2015) (Figure 4.3.17) and improved the overall fit to the age composition and survey index observations (Table 4.3.8, **S1.0_4FLEETS _SelECO**) .

Figure 4.3.14. ane.27.9a Southern stock. Residuals of age proportions for the *ECOCADIZ* survey (initial run, S1.0_4FLEETS).

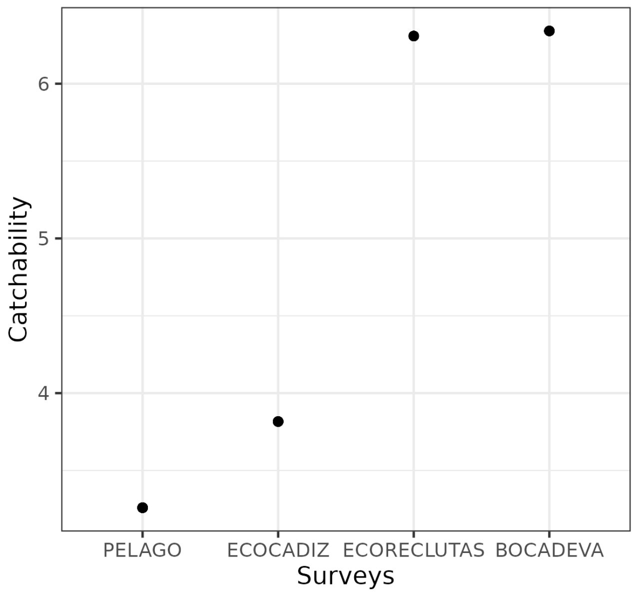


Figure 4.3.15. ane.27.9a Southern stock. Catchability estimated in the initial run (S1.0_4FLEETS).

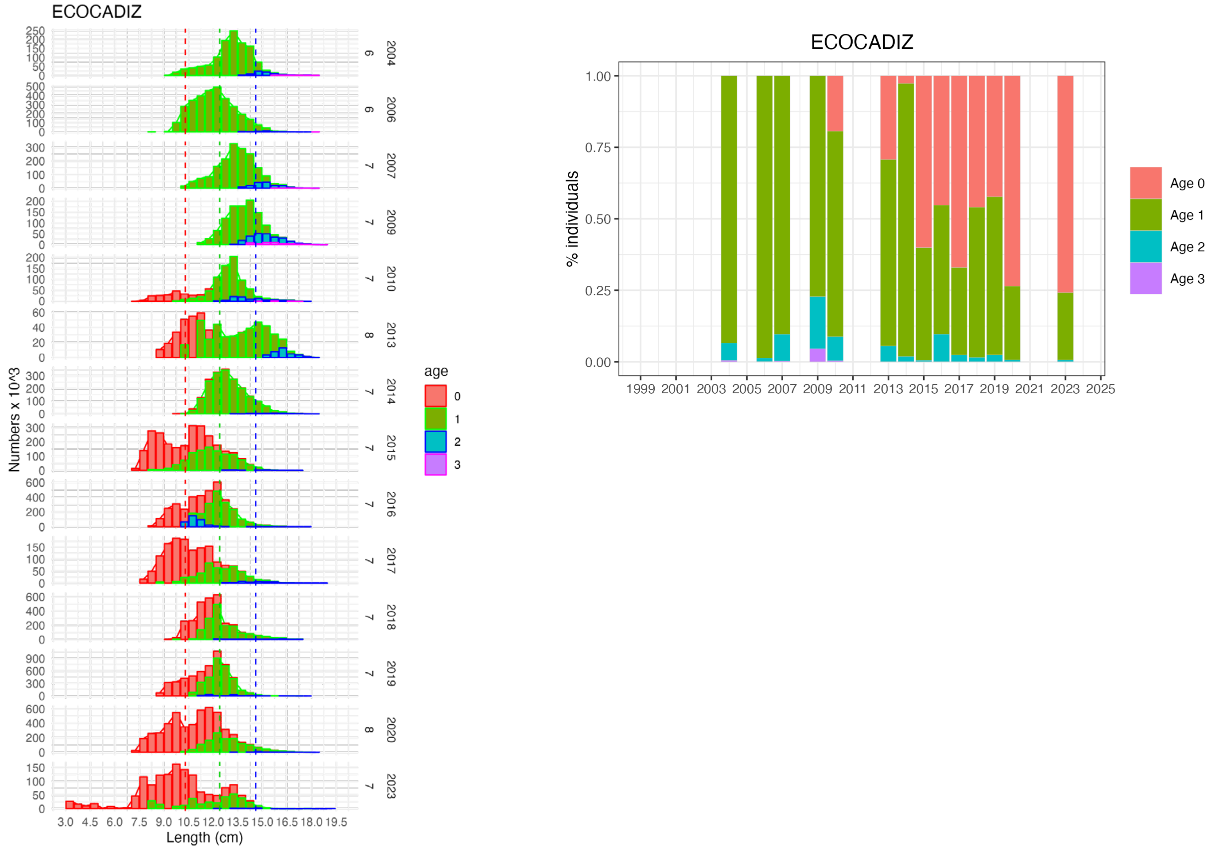


Figure 4.3.16. ane.27.9a Southern stock.. Southern component. *ECOCADIZ* summer survey series 2004 - 2023. Left panel: Length at age structure. Red, green and blue lines represent the historical mean length for age-0: 10.3 cm,age-1:12.4 cm and age-2: 14.6 cm, respectively. Top right panel: Age proportion by year.

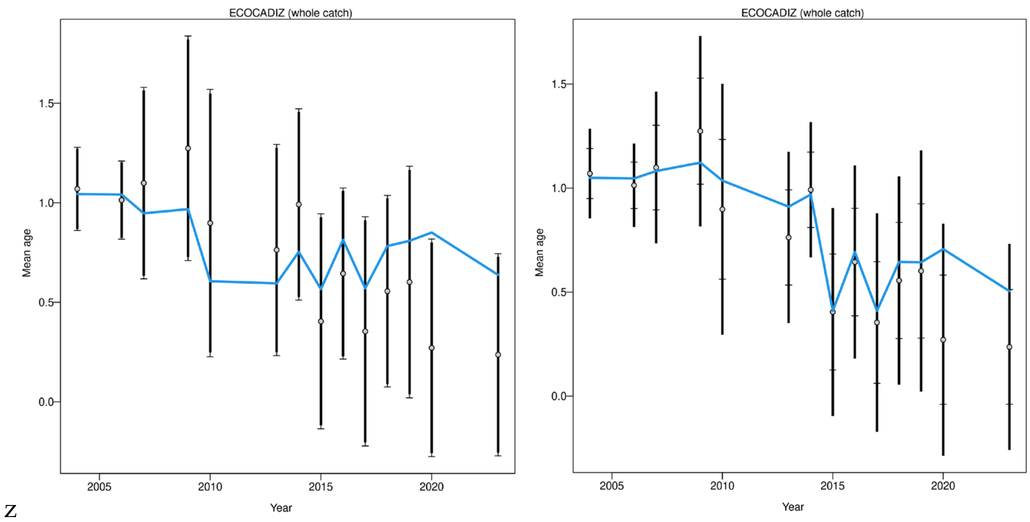


Figure 4.3.17. ane.27.9a Southern stock. Fit to the mean age composition of the *ECOCADIZ* survey. The left panel shows the initial run (S1.0_4FLEETS), while the right panel illustrates the fit when the selectivity of the *ECOCADIZ* survey is divided into two periods (2004–2014 and 2015–2023) (S1.0_4FLEETS_SelECO).

Selectivity for ECOCADIZ-RECLUTAS survey assumed as a recruitment index

It was recommended not to use a logistic function for *ECOCADIZ-RECLUTAS*, as the survey focuses on juveniles and serves as a recruitment index (Figure 4.3.18, left panel). After testing alternative sensitivity scenarios (for example, selectivity as a parameter for each age for *ECOCADIZ-RECLUTAS* survey, assuming selectivity at age 0 equal to 1 and estimating the other ages selectivities or assuming selectivity at age-3 equal to 0 and estimating the other ages selectivities), it was decided to use only the biomass of age-0 recruits from *ECOCADIZ-RECLUTAS*, with selectivity fixed at 1 for age 0 and at 0 for all other ages, consistently over time (Figure 4.3.18, right panel).

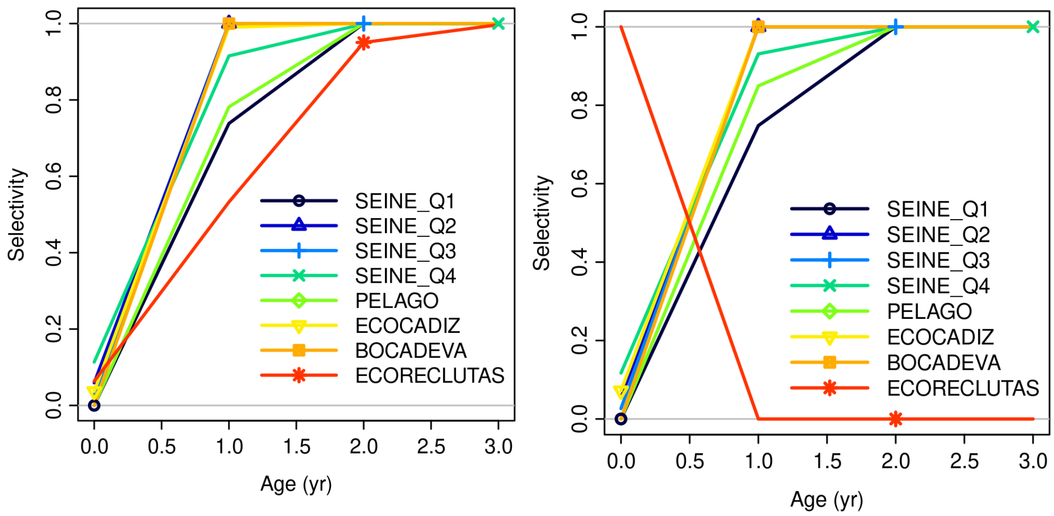


Figure 4.3.18. ane.27.9a Southern stock. Left panel: Left panel: Selectivities for the initial run (S1.0_4FLEETS). Right panel: Selectivities for the scenario treating the *ECOCADIZ-RECLUTAS* survey as a recruitment index (S1.0_4FLEETS_SelECO_RecIndex).

Natural mortality

The age-specific natural mortality values used in the initial run were estimated using the Gislason et al. (2010) method, which models mortality as a function of growth parameters derived from a nonlinear mixed-effects model. The resulting values were: M-at-age-0 = 2.97, M-at-age-1 = 1.33, M-at-age-2 = 1.33, and M-at-age-3 = 1.33 (see Section 4.3.6).

The sensitivity of the assumed structure was evaluated through various sensitivity runs to determine the appropriate values for natural mortality (M). Since natural mortality is known to increase with age in some short-lived species due to senescence (as described by Uriarte *et al.*, 2016, for anchovy in Division 8), reviewers recommended testing scenarios with higher natural mortality for ages 2 and 3+ compared to age 1. Two main approaches were tested:

- **Natural mortality (M) estimated for ages 2 (M2) and 3 (M3):** Natural mortality was fixed at 1.33 for age 1 and estimated for M2+ (ages 2 and 3+). Fishery selectivity for ages 0, 1, and 3+ was treated as a parameter, while sel.age2 was fixed at 1. Additionally, *ECOCADIZ-RECLUTAS* continued to include all age classes and was modeled with a logistic selectivity function (Figure 4.3.19). This configuration improved the likelihood function (Table 4.3.8), increased the estimated biomass (Figure 4.3.20), and reduced survey catchabilities (2 and 2.5 for *PELAGO* and *ECOCADIZ*, and 4.5 for *BOCADEVA*) (Figure 4.3.21).

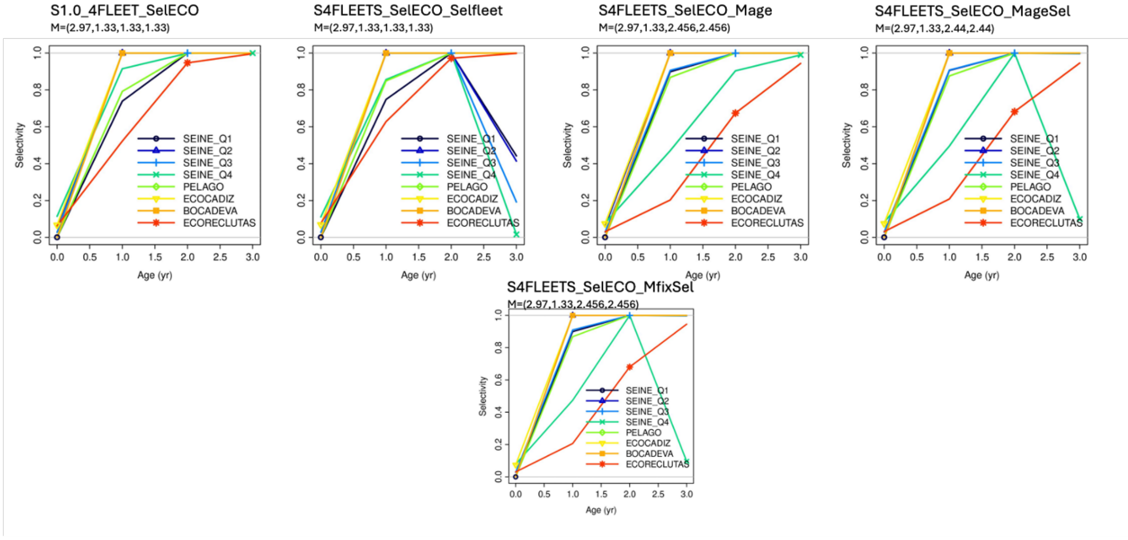


Figure 4.3.19. ane.27.9a Southern stock. Comparison Selectivities by scenario.

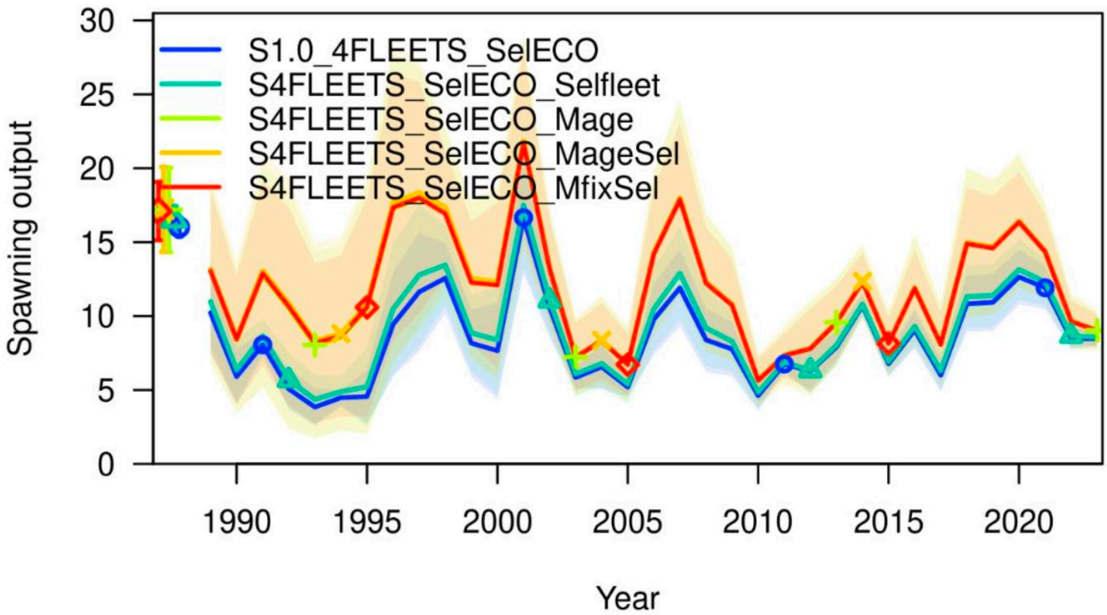


Figure 4.3.20. ane.27.9a Southern stock. Comparison of Spawning Biomass by scenario.

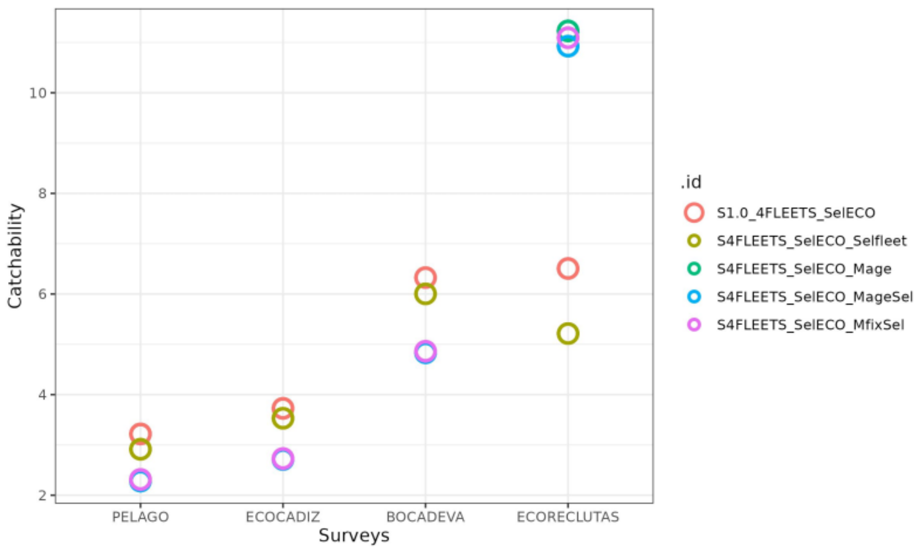


Figure 4.3.21. ane.27.9a Southern stock. Comparison of the survey Catchability by scenario.

- **Two-phase exercise to determine a U-shaped natural mortality pattern:** *ECOCADIZ-RECLUTAS* was used exclusively as a recruitment index, with a vector of age-0 estimates.

  - *Phase 1:* Different values of natural mortality for age 1 were evaluated using a likelihood profile conditioned on M0=2.97, while natural mortality for ages 2 and 3+ was estimated freely (Figure 4.3.22, left panel).
  - *Phase 2:* Various values of natural mortality for ages 2+ were tested using a likelihood profile conditioned on M0 and the optimal M1 value obtained in Phase 1 (Figure 4.3.22, right panel).

The exercise identified an optimal natural mortality pattern with the following values: M1=1.6, M2=2.48, and M3=2.48.

The results of the compared scenarios (Table 4.3.10) indicate that the likelihood profile analysis concluded the U-shaped natural mortality pattern, with a lower value for age-1 and increasing values for older ages, is an appropriate configuration. This approach improved all components of the likelihood function (Table 4.3.8), reduced survey catchability to approximately 1.9 and 2.2 for *PELAGO* and *ECOCADIZ*, around 4 for *BOCADEVA*, and close to 1 for *ECOCADIZ-RECLUTAS* (Figure 4.3.23), and increased the estimated biomass (Figure 4.3.24).

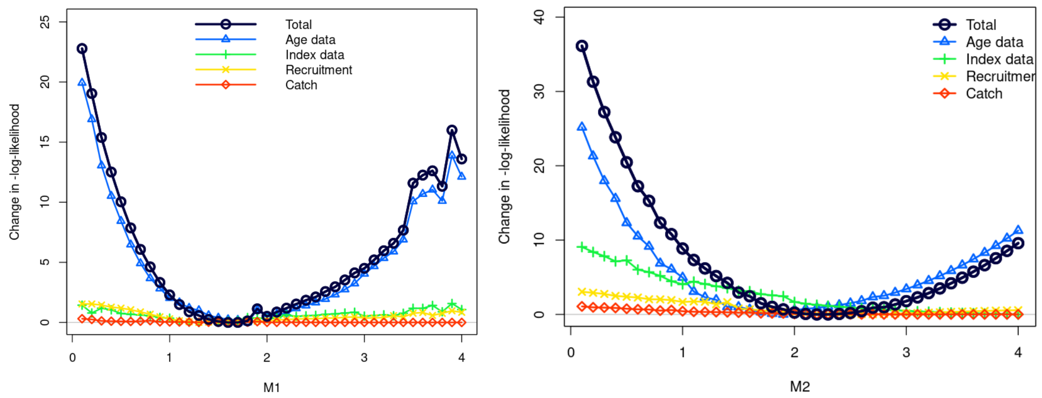


Figure 4.3.22. ane.27.9a Southern stock. Left panel: Likelihood profile for M at age 1 from Phase 1. Right panel: Likelihood profile for M at age 2 from Phase 2.

Table 4.3.10. ane.27.9a Southern stock. List and description of the scenarios tested during the benchmark

.id	X0	X1	X2	X3
S1.0_4FLEETS_SelECO	2.97	1.33	1.33000	1.33000
S1.0_4FLEETS_SelECO_RecIndex	2.97	1.33	1.33000	1.33000
S1.0_4FLEETS_SelECO_RecIndex_M1_1.6	2.97	1.60	1.33000	1.33000
S1.0_4FLEETS_SelECO_RecIndex_Mest2_3_M1_1.6	2.97	1.60	2.48352	2.48352

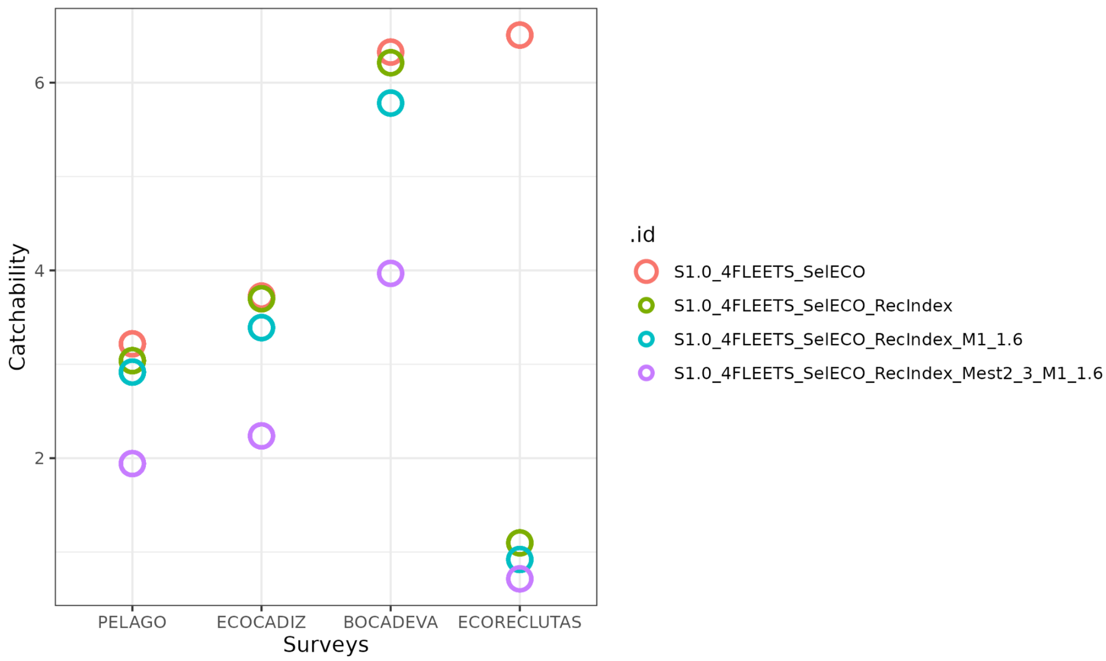


Figure 4.3.23. ane.27.9a Southern stock. Comparison of survey Catchability by scenario.

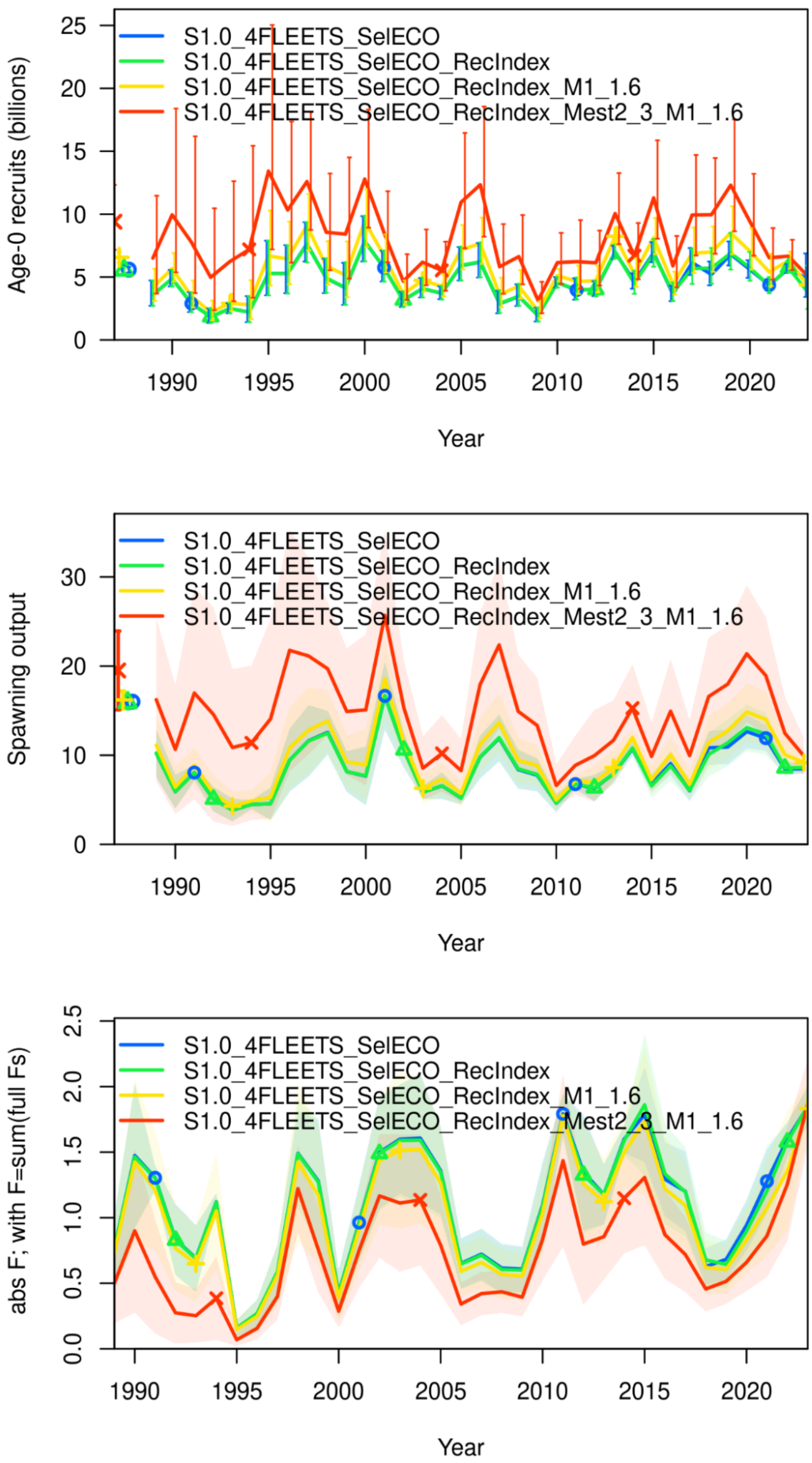


Figure 4.3.24. ane.27.9a Southern stock. Comparison of Recruitment, Spawning Biomass, and Fishing mortality by scenario.

Equilibrium Catches

In the initial run, equilibrium catches were set to 0 tonnes for all quarters in 1988. Initial equilibrium catches were then assumed to equal the average catches from 1989 to 1994 for each fleet and season. This period was selected because 1989 marks the start of the catch time series, and 1994 represents the first breakpoint identified through a structural break analysis using the strucchange package. The model begins in 1988, assuming an exploited equilibrium population with seasonal catches as follows: Q1 = 1,208 tonnes, Q2 = 2,033 tonnes, Q3 = 683 tonnes, and Q4 = 223 tonnes (S1.0_initCond scenario).

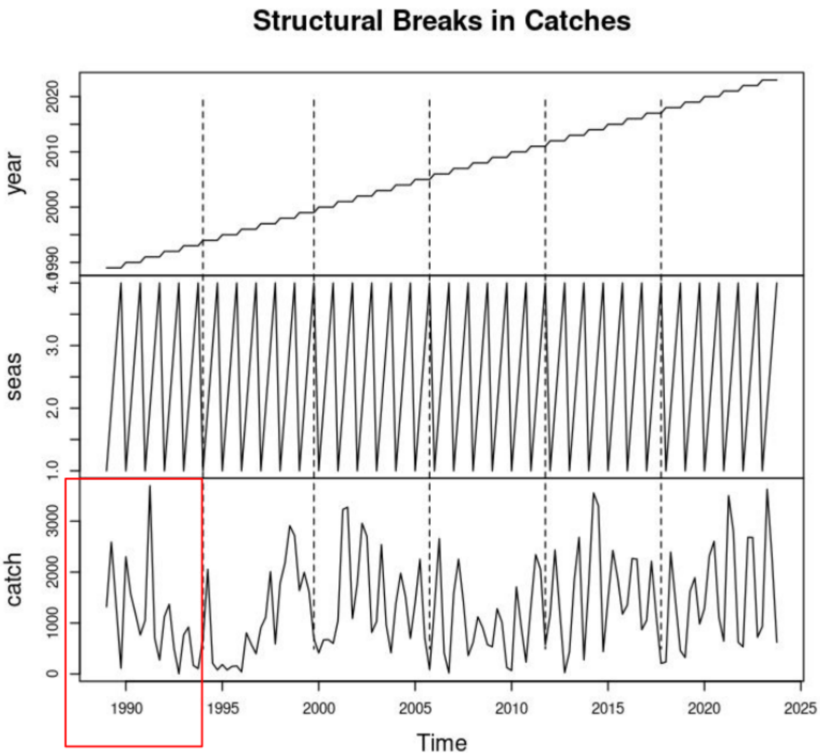


Figure 4.3.25. ane.27.9a Southern stock. Structural break analysis of quarterly catch time series.

Recruitment

In the initial run, annual recruitments were modelled as lognormal deviations from the Beverton-Holt curve. Equilibrium recruitment (R0) was estimated, with steepness (h) fixed at 0.8 and sigmaR set at 0.6. This value of h aligns with reports for Pacific saury (0.82, Hsu *et al.*, 2024) and estimates for clupeiforms (~0.75, CV=0.23, Thorson, 2020). Given its relevance in determining stock productivity and resilience, a likelihood profile analysis was conducted to assess this assumption (Figure 4.3.26). The analysis indicated an optimal value of 0.55 based on age data and 0.9 according to index data. The overall optimal value was 0.6, with minimal variation between 0.5 and 0.8. While the recruitment time series did not provide definitive evidence for a precise h value, h=0.8 was deemed consistent with the literature and compatible with the estimated data. Therefore, h=0.8 value was adopted for the assessment. This value is biologically reasonable for small pelagic species due to their fast growth, early maturity, and short lifespan, allowing them to maintain high reproductive potential at low biomass levels.

The recruitment standard deviation (sigmaR) was adjusted after 5 iterations, starting from an initial value of 0.6 and converging to the recommended value of sigmaR = 0.33, as specified by the sigma_R_info object in SS3.

The early recruitment deviations for the initial population were estimated from 1961.7. A recruitment bias adjustment ramp (Methot and Taylor, 2011) was applied to this early period, and bias-adjusted recruitment was estimated for the main period. Recruitment deviations for the main period were estimated for 1991 - 2023.

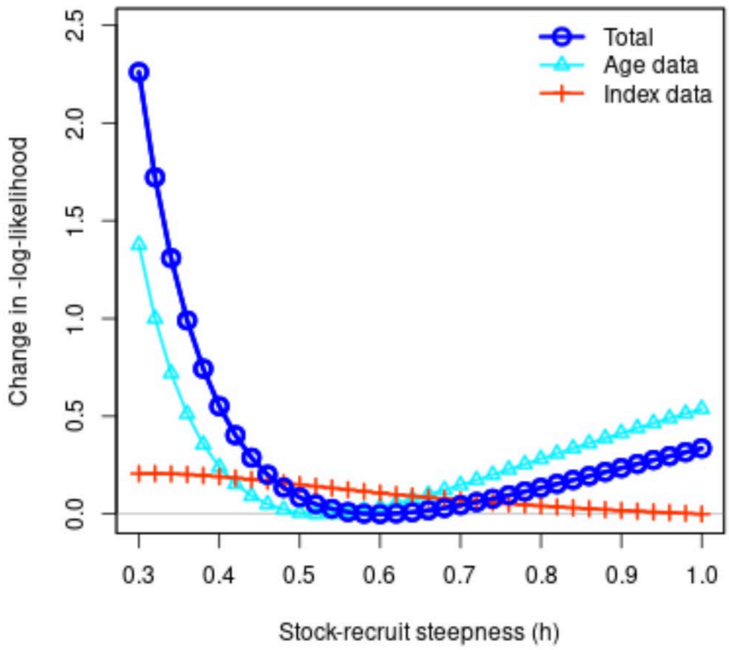


Figure 4.3.26. ane.27.9a Southern stock. Profile of the steepness. The lines of different colours show the changes in likelihood of different components and in black the total likelihood.

Following these tests, a logistic selectivity for the *ECOCADIZ* survey was assumed, divided into two blocks (2004–2014 and 2015–2023), with the *ECOCADIZ-RECLUTAS* survey treated as a recruitment index. Natural mortality at age was fixed as follows: M0=2.97, derived using the Gislason methodology, and M1=1.6, M2=2.48, and M3=2.48, obtained from the model's likelihood profiles. Initial equilibrium catches were set as the average catches from 1989 to 1994 for each fleet and season, along with recruitment deviations modeled with sigmaR=0.33. Data weights were assigned standard errors of 0.05 for catches and 0.3 for surveys, while age compositions, modeled with a multinomial error structure (sample size of 100), were iteratively adjusted using the Francis method over five iterations.

Comparison of Benchmark Runs with Corrected ECOCADIZ-RECLUTAS Index

Following the BOG review conducted after the benchmark, an error was identified in the biomass index used for the *ECOCADIZ-RECLUTAS* survey, where total biomass was used instead of age-0 biomass. To address this issue, a new run was performed using the corrected values. The following comparison includes the initial run (initial run: S1.0_4FLEETS), the final run accepted by the benchmark reviewers (Final run: S1.0_InitCond_sigmaR), and the additional run with the corrected *ECOCADIZ-RECLUTAS* index (Corrected Final Run: S1.0_InitCond_sigmaR_AdjindexRec) (Table 4.3.11, Figures 4.3.27, 4.3.28 and 4.3.29).

The corrected final model shows a loss of fit for the *ECOCADIZ-RECLUTAS* index (Table 4.3.11 and Figure 4.3.28) but improves the retrospective pattern compared to the initial and final benchmark runs, with rho SSB=-0.084 and rho F=0.180 (Table 4.3.11). Catchabilities slightly decrease for *PELAGO* and *ECOCADIZ-RECLUTAS* (3.0 and 0.51, respectively) and remain similar for *ECOCADIZ* and BOCADEVA (2.37 and 4.38, respectively) compared to the final benchmark run (*PELAGO*=3.2, *ECOCADIZ*=2.35, *BOCADEVA*=4.39, and *ECOCADIZ-RECLUTAS*=0.75). No significant differences in scale or trend are observed between the final benchmark model and the corrected model (Figure 4.3.29).

The results of the model runs can be downloaded from the following repository:

- Initial run: https://github.com/ices-taf/2024_ane.27.9a_south_benchmark/tree/main/model/run/S1.0_4FLEETS
- Final run benchmark: https://github.com/ices-taf/2024_ane.27.9a_south_benchmark/tree/main/model/run/S1.0_InitCond_sigmaR
- Corrected final run: https://github.com/ices-taf/2024_ane.27.9a_south_benchmark/tree/main/model/run/S1.0_InitCond_sigmaR_AdjIndexRec

Table 4.3.11. ane.27.9a Southern stock. Comparison of diagnostic Benchmark Runs (Initial and Final) and Corrected *ECOCADIZ-RECLUTAS* Index (Corrected Final Run).

Scenario			Likelihood			RMSE		Rho	
	Convergency	AIC	Total	Survey	Age	Index	Age	SSB	F
Initial run	0.000009	264.2	113.1	-12.2	134.8	41.7	29	0.046	-0.070
Final run	0.000026	252.7	103.4	-9.0	130.7	43	27.8	-0.107	0.260
Corrected Final Run	0.000042	263.4	108.7	0.03	127.08	46.6	27.5	-0.084	0.180

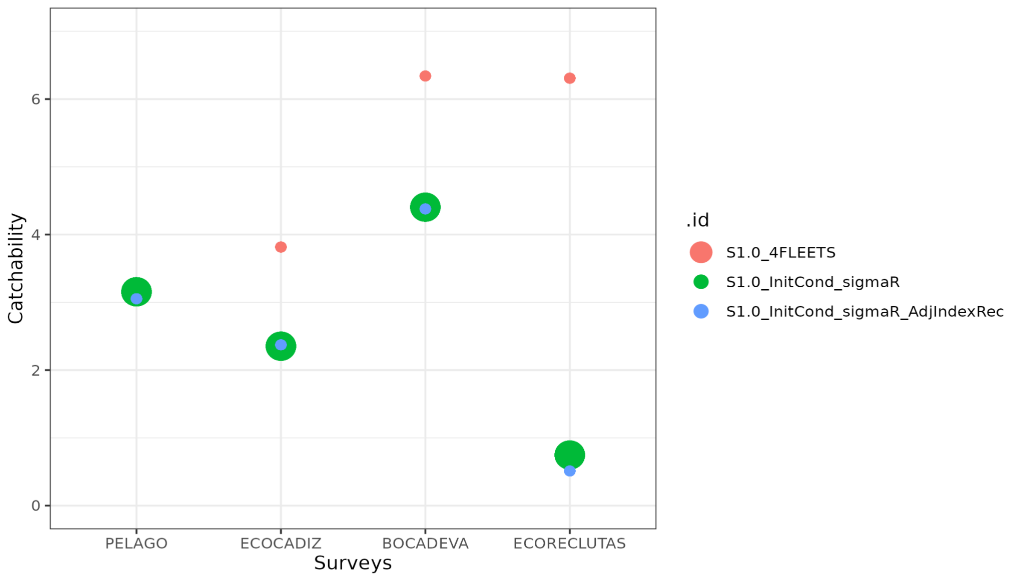


Figure 4.3.27. ane.27.9a Southern stock. Comparison of survey Catchability by scenario.

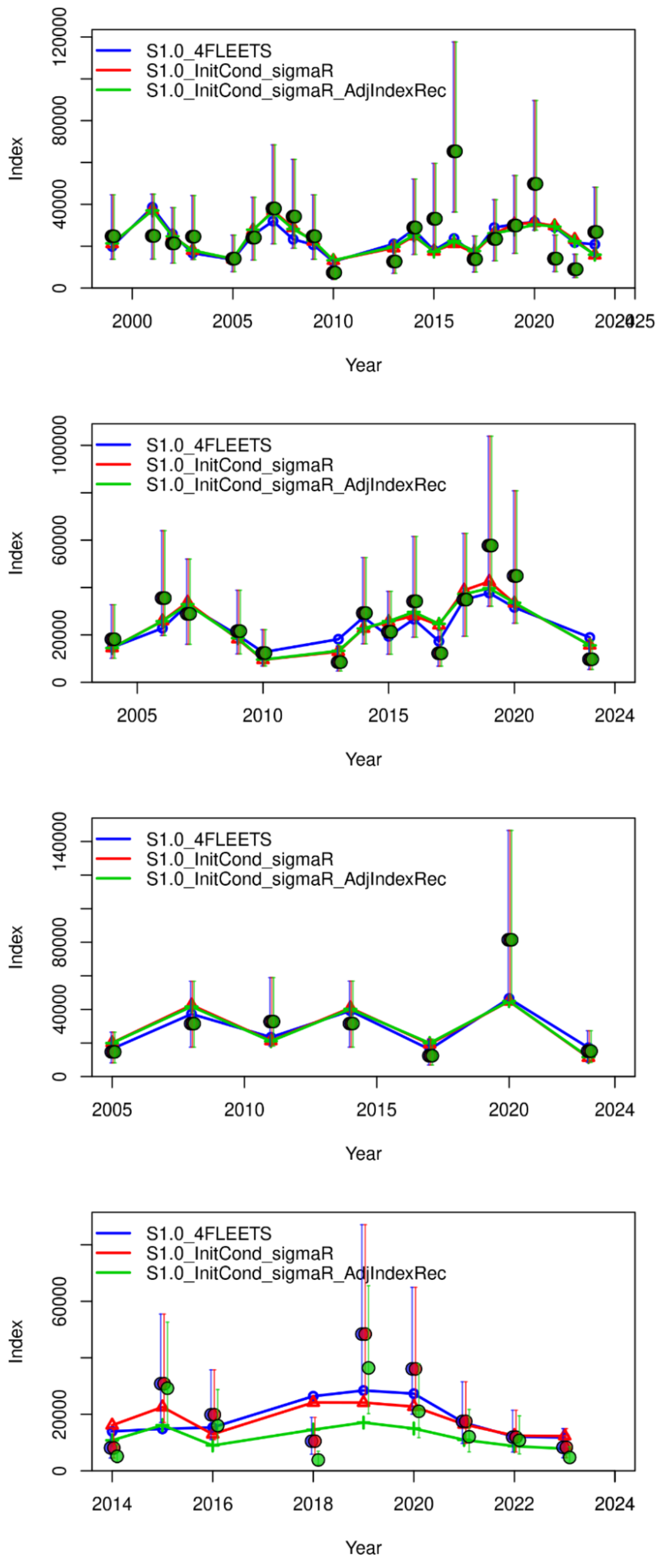


Figure 4.3.28. ane.27.9a Southern stock. Comparison of Recruitment, Spawning Biomass, and Fishing mortality by scenario.

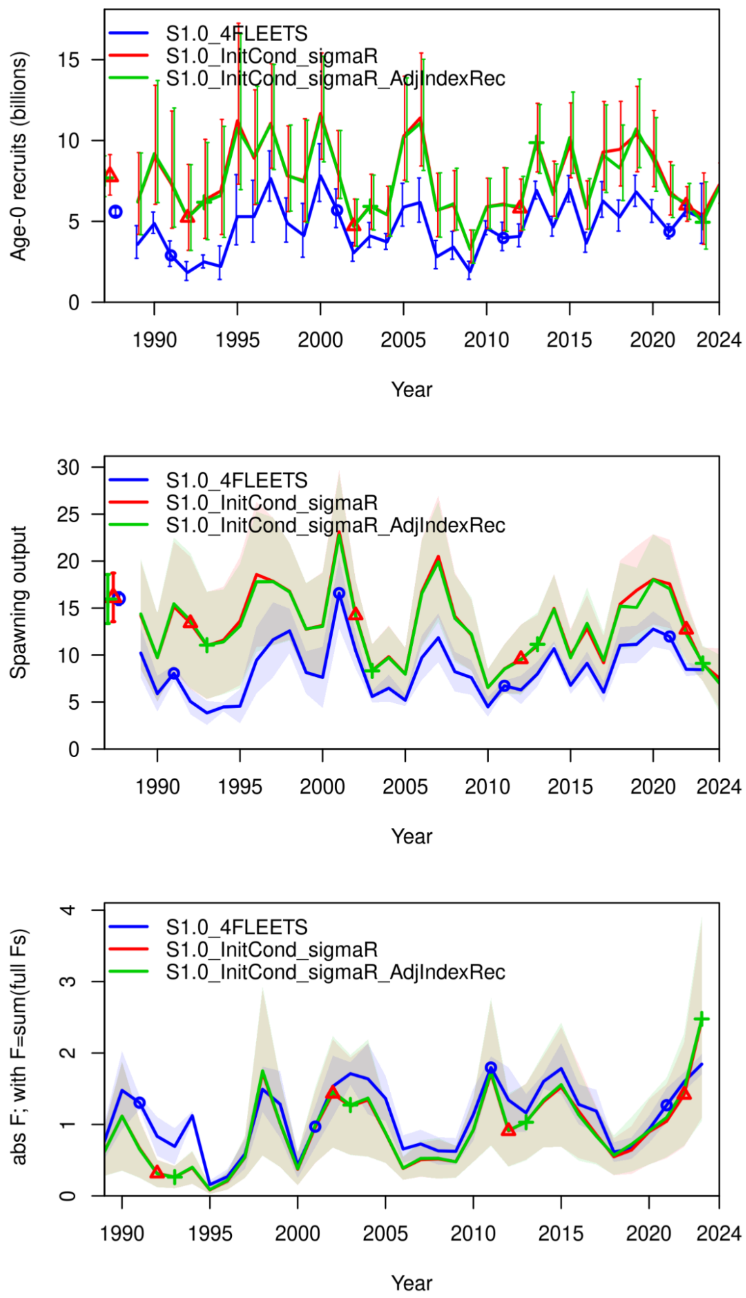


Figure 4.3.29. ane.27.9a Southern stock. Comparison of Recruitment, Spawning Biomass, and Fishing mortality by scenario.

4.4.2 Final assessment

4.4.2.1 Model configuration

A summary of the final configuration for the assessment model (**S1.0_InitCond_sigmaR_Adjin-dexRec** in the previous section) is given in Table 4.3.12. The model incorporates four quarters (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Nov), with the commercial fleet divided into four separate fleets to account for seasonal differences in selectivity patterns.

The input data includes total catch (in biomass) and age composition of the catch (in proportion) for the commercial SEINE fleet, as well as abundance (in biomass) and age composition from the *PELAGO* and *ECOCADIZ* surveys. Age composition data from *PELAGO* was included only for the period 2014–2023, when age-length keys were available, as specified by WKPELA 2018. The biomass index from the *ECOCADIZ-RECLUTAS* survey, based on the biomass of age-0 individuals, provides a direct measure of recruitment. Spawning stock biomass (SSB) estimates are derived from the triennial *BOCADEVA* survey using DEPM. To account for seasonal variability in catches, the *SEINE* fleet has been subdivided into four quarterly fleets.

Spawning occurs at the beginning of April, and settlement is set at the beginning of July. Age-specific natural mortality was fixed as M0=2.97 (Gislason methodology) and M1=1.6, M2=M3=2.48 (from likelihood profiles). All individuals were assumed to mature at age 1, with no maturity at age 0, and growth was not explicitly modelled.

Recruitment was based on lognormal deviations from the Beverton-Holt curve, with equilibrium recruitment (R0) estimated, steepness (h) fixed at 0.8, and sigmaR = 0.33. Early recruitment deviations were estimated starting from 1962 with a recruitment bias adjustment ramp applied, and main period deviations were estimated for 1991–2023. The initial population, assumed to be in equilibrium, was calculated based on age composition data and average catches (1989–1994) for each season, with initial catches set as Q1=1208, Q2=2033, Q3=683, and Q4=223 tonnes.

Fishing mortality was calculated using the hybrid F method, aligning observed catches with tuned F values.

Surveys were treated as relative abundance indices, with catchability modelled via a q linear model, and selectivity was defined as logistic functions fixed over time, except for *BOCADEVA*, where selectivity was set at 1 from age 1, and *ECOCADIZ*, which was split into two periods (2004–2014 and 2015–2023) to account for differences in age patterns. Data weights were set with standard errors of 0.05 for catches and 0.3 for surveys, and age compositions were modelled using a multinomial error structure with a sample size of 100, adjusted iteratively using the Francis method over five iterations.

Further details on the model specifications and results can be found in *Zúñiga et al. 2024 WD: S1.0_InitCond_sigmaR_AdjIndexRec - Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component*).

Table 4.3.12. ane.27.9a Southern stock. Final configuration for SS3 assessment model.

Input data	Benchmark 2024 (data until 2023)
Catch	Total catch biomass 1989-2023 by quarters (tonnes)
	Catch-at-age 1989-2023 by quarters (proportion)
PELAGO spring acoustic survey	Total Biomass 1999-2023 (missing years: 2000, 2004, 2011, 2012) (tonnes)
	Number-at-age 2014-2023 (proportion)
ECOCADIZ summer acoustic survey	Total Biomass 2004-2023 (missing years: 2005, 2008, 2011, 2012, 2021, 2022) (tonnes)
	Number-at-age 2004-2023 (missing years: 2005, 2008, 2011, 2012, 2021, 2022) (proportion)
BOCADEVA DEPM survey	Total SSB 2005, 2008, 2011, 2014, 2017, 2020 and 2023 (tonnes)
ECOCADIZ-RECLUTAS autumn acoustic survey	Recruit Biomass 2014-2023 (missing year: 2017)
Weight-at-age in the catch and stock	The mean weight estimates by quarter and year (1989–2023) were obtained using a linear mixed-effects model that incorporated the entire dataset.
Maturity-at-age	All individual mature at age-1 (maturity at age-0=0)

Table 4.3.12. continued

Model structure and assumptions	Benchmark 2024
Starting year	1989
Ending year	2023
Equilibrium catches	1208 t in 1st quarter, 2033 t in 2nd quarter, 683 t in 3rd quarter and 223 t in 4th quarter, assuming the average catch between 1989-1994 for each quarter.
Number of areas	1
Number of seasons	4 (jan-mar, apr-jun, jul-sep, oct-nov)
Spawning time	1st april
Recruitment settlement time	1st july
Genders	1
Data age bins	age-0 to age- 3
Natural mortality	M-at-age-0=2.97, M-at-age-1=1.6, ,M-at-age-2=2.48, M-at-age-3=2.48

Model structure and assumptions	Benchmark 2024
Recruitment	Annual recruitments are modelled as lognormal deviations from the Beverton-Holt recruitment curve. Equilibrium recruitment (R0) was estimated, while steepness (h) was fixed at 0.8 and sigmaR at 0.33. Main recruitment deviations were estimated for the period 1991–2023, while early recruitment deviations were estimated starting from 1962.1
Initial population	N-at-age in the first year are parameters derived from an input initial equilibrium catch, equilibrium recruitment and selectivity in the first year and adjusted by recruitment deviations estimated from the data on the early years of the assessment.
Fishery selectivity-at-age	Logistic functions fixed over time.
PELAGO spring acoustic survey selectivity-at-age	Logistic functions fixed over time.
ECOCADIZ summer acoustic survey selectivity-at-age	Logistic functions split into two periods: 2004-2014 and 2015-2023.
BOCADEVA DEPM survey selectivity-at-age	Fixed at 0 for age-0 and fixed at 1 for all ages, over time
ECOCADIZ-RECLUTAS autumn acoustic survey selectivity-at-age	Fixed at 1 for age-0 and fixed at 0 for all ages, over time
PELAGO spring acoustic survey catchability	Linear catchability parameter
ECOCADIZ summer acoustic survey catchability	Linear catchability parameter
BOCADEVA DEPM survey catchability	Linear catchability parameter
ECOCADIZ-RECLUTAS autumn acoustic survey catchability	Linear catchability parameter
Log-likelihood function:	
Weights of componentes	All components have equal weight
Data weights	The sample size of age composition data, determined after one iteration of the Francis method, was as follows: 12 for quarter 1, 11 for quarter 2, 13 for quarter 3, and 12 for quarter 4 in the commercial fishery; 9 for the *PELAGO* acoustic survey; and 17 for the *ECOCADIZ* acoustic survey.

Variance estimates for all estimated parameters are calculated from the Hessian matrix. Minimisation of the likelihood is implemented in phases using standard ADMB processes. The phases in which estimation will begin for each parameter are shown in the control file available in the TAF repository for this stock (https://github.com/ices-taf/2024_ane.27.9a_south_benchmark/tree/main/model/run/S1.0_InitCond_sigmaR_AdjIndexRec).

Model diagnostic

The model successfully converged, as evidenced by the Hessian matrix being positive definite and the final gradient being relatively small, with a gradient value of 0.000042. The "Status" column in Table 4.3.13 shows that the initial model configuration has allowed for adequate optimization of the parameters. Additionally, the gradient for all parameters is relatively small. It is important to note that the bounds imposed on the initial parameters have not restricted the search for optimized values, as reflected in the "Afterbound" column. The jittering test, performed over 60 iterations, resulted in 77% of runs converging to the same total likelihood value (Figure 4.3.30). These findings provide no evidence to reject the hypothesis that the final model parameter optimization successfully reached the global solution (Carvalho *et al.*, 2021).

The Figure 4.3.31 shows that the abundance indices from the acoustic surveys exhibit a high level of variability, as reflected by the width of the assumed confidence intervals, with a maximum coefficient of variation of 30%. The model follows the overall trend of the indices, though it encounters some difficulties in accurately fitting the extreme biomass values, both the highest and lowest. However, it adequately reproduces the general trend of variability in biomass levels presented by the survey estimates.

Figure 4.3.32 shows that the residuals from the fit of the biomass indices are randomly distributed, with p-values greater than 0.05 (*PELAGO* = 0.448, *ECOCADIZ* = 0.889, *BOCADEVA* = 0.358, *ECOCADIZ-RECLUTAS* = 0.5). The estimated root mean square error (RMSE) for the joint residual analysis is 46.6%.

Estimated mean age for the *SEINE* fleet (one by quarter) with a 95% confidence interval based on current sample sizes, is presented in Figure 4.3.33. The mean age for the *PELAGO* and *ECOCADIZ* surveys is presented in Figure 4.3.34.

The Figure 4.3.35 shows the estimated age compositions aggregated over time for the different age data sources: *SEINE*, *ECOCADIZ* and *PELAGO*. Overall, a high proportion of young individuals (ages 0 and 1) is observed in both the commercial fleet catches and acoustic surveys, with a significant decline in the proportions of older age classes. The green lines represent the model fits, demonstrating an adequate fit, with the aggregated age compositions well reconstructed.

Figure 4.3.36 to 39 show the estimated age composition for the commercial fleet by quarter. Although the aggregated fits show an overall adequate result, some years exhibit variability in the age composition of the commercial fleet (*SEINE*) catches. This pattern is also evident in the annual data fits for the *PELAGO* survey, especially in the later years of the series (2020-2023), where there is a tendency to overestimate age-1 and underestimate age-2 (Figure 4.3.40). In the *ECOCADIZ* survey, there are difficulties in estimating ages-0, with a tendency to overestimate age-0 and underestimate age-1 years 2020 and 2023 (Figure 4.3.41). Figure 4.3.42 shows bubble plots of the residuals for the SEINE data fit, while Figure 4.3.43 presents bubble plots of the residuals for the surveys' age-data fit.

The Figure 4.3.44 shows that the residuals from the age proportion fits are randomly distributed, with p-values greater than 0.05 for both the commercial fleet (*SEINE_Q1*: 0.202, *SEINE_Q2*: 0.267, *SEINE_Q3*: 0.206, *SEINE_Q*4: 0.806) and the acoustic surveys (*ECOCADIZ*: 0.532, *PELAGO*: 0.103). The root mean square error (RMSE) estimated for the combined residual analysis is 27.5%.

Figure 4.3.45 shows a retrospective pattern in both spawning biomass and fishing mortality in the base model. The retrospective analysis of the assessment model reveals that, in terms of Mohn's rho (mean of retrospective anomalies), the reduction in data leads to a pattern of underestimation in fishing mortality (rho = 0.17961) and overestimation in spawning biomass (rho = -0.084419). These Mohn's rho values were inside the bounds of recommended values, according to the rule proposed by Hurtado-Ferro et al. (2014), which states that Mohn's rho index values should be less than 0.30 and greater than -0.22 for short-lived species.

Table 4.3.13. ane.27.9a Southern stock. Parameters estimated by the final model.

Parameter	Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Afterbound
SR_LN(R0)	15.855100	1	1.0	25.0	20.0	OK	0.0833350	0.00004195980000	OK
InitF_seas_1_flt_1SEINE_Q1	0.422549	1	0.0	3.0	0.3	OK	0.0828993	0.00000096885800	OK
InitF_seas_2_flt_2SEINE_Q2	0.836572	1	0.0	3.0	0.3	OK	0.1070740	0.00000168668000	OK
InitF_seas_3_flt_3SEINE_Q3	0.452368	1	0.0	3.0	0.3	OK	0.1200510	0.00000072663300	OK
InitF_seas_4_flt_4SEINE_Q4	0.295798	1	0.0	3.0	0.3	OK	0.1219040	0.00000050956400	OK
LnQ_base_PELAGO(5)	1.116270	1	-7.0	5.0	0.0	OK	0.2766870	0.00000303950000	OK
LnQ_base_ECOCADIZ(6)	0.864166	2	-7.0	5.0	0.0	OK	0.1613330	0.00000136163000	OK
LnQ_base_BOCADEVA(7)	1.476870	2	-7.0	5.0	0.0	OK	0.1935140	0.00000189311000	OK
LnQ_base_ECORECLUTAS(8)	-0.670434	1	-7.0	5.0	0.0	OK	0.1296960	0.00000013990900	OK
Age_inflection_SEINE_Q1(1)	0.923691	2	0.0	4.0	0.0	OK	0.8599050	0.00000067767000	OK
Age_95%width_SEINE_Q1(1)	0.198601	2	0.1	0.3	0.2	OK	2.2347700	-0.00000001715740	OK
Age_inflection_SEINE_Q2(2)	0.194195	2	0.1	0.3	0.2	OK	2.2130600	0.00000000272771	OK
Age_95%width_SEINE_Q2(2)	0.220030	2	0.0	4.0	0.5	OK	2.3623700	-0.00000000959833	OK
Age_inflection_SEINE_Q3(3)	0.803830	2	0.0	4.0	0.0	OK	0.1409650	-0.00000313695000	OK
Age_95%width_SEINE_Q3(3)	0.611710	2	0.0	4.0	0.5	OK	0.0735133	0.00000403564000	OK
Age_inflection_SEINE_Q4(4)	1.191060	2	0.0	4.0	0.0	OK	0.2792700	-0.00000034081200	OK
Age_95%width_SEINE_Q4(4)	1.238230	2	0.0	4.0	0.5	OK	0.1359800	0.00000024847000	OK
Age_inflection_PELAGO(5)	0.994477	2	0.0	3.5	0.9	OK	0.0946087	-0.00000323867000	OK
Age_95%width_PELAGO(5)	0.253710	2	0.1	0.4	0.3	OK	3.6223100	0.00000000150067	OK
Age_inflection_ECOCADIZ(6)	1.750000	2	0.0	3.5	0.2	OK	39.1278000	-0.00000000363607	OK
Age_95%width_ECOCADIZ(6)	0.204133	2	0.0	3.5	0.5	OK	1.0519800	0.00000380114000	OK
Age_inflection_ECOCADIZ(6)_BLK1repl_2004	0.326222	4	0.0	3.5	0.5	OK	1.6814300	-0.00000248635000	OK
Age_inflection_ECOCADIZ(6)_BLK1repl_2015	0.159927	4	0.0	3.5	0.0	OK	0.8244110	-0.00000071914400	OK

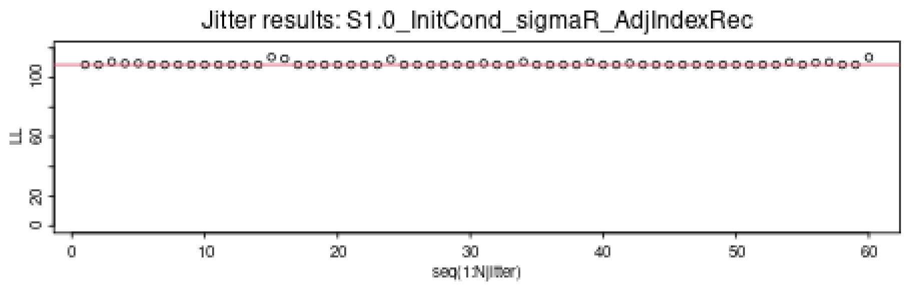


Figure 4.3.30. ane.27.9a Southern stock. Jittering results for the final model. Circles represent the total likelihood obtained from jittered model runs. The red horizontal dashed line represents the total likelihood value from the final model.

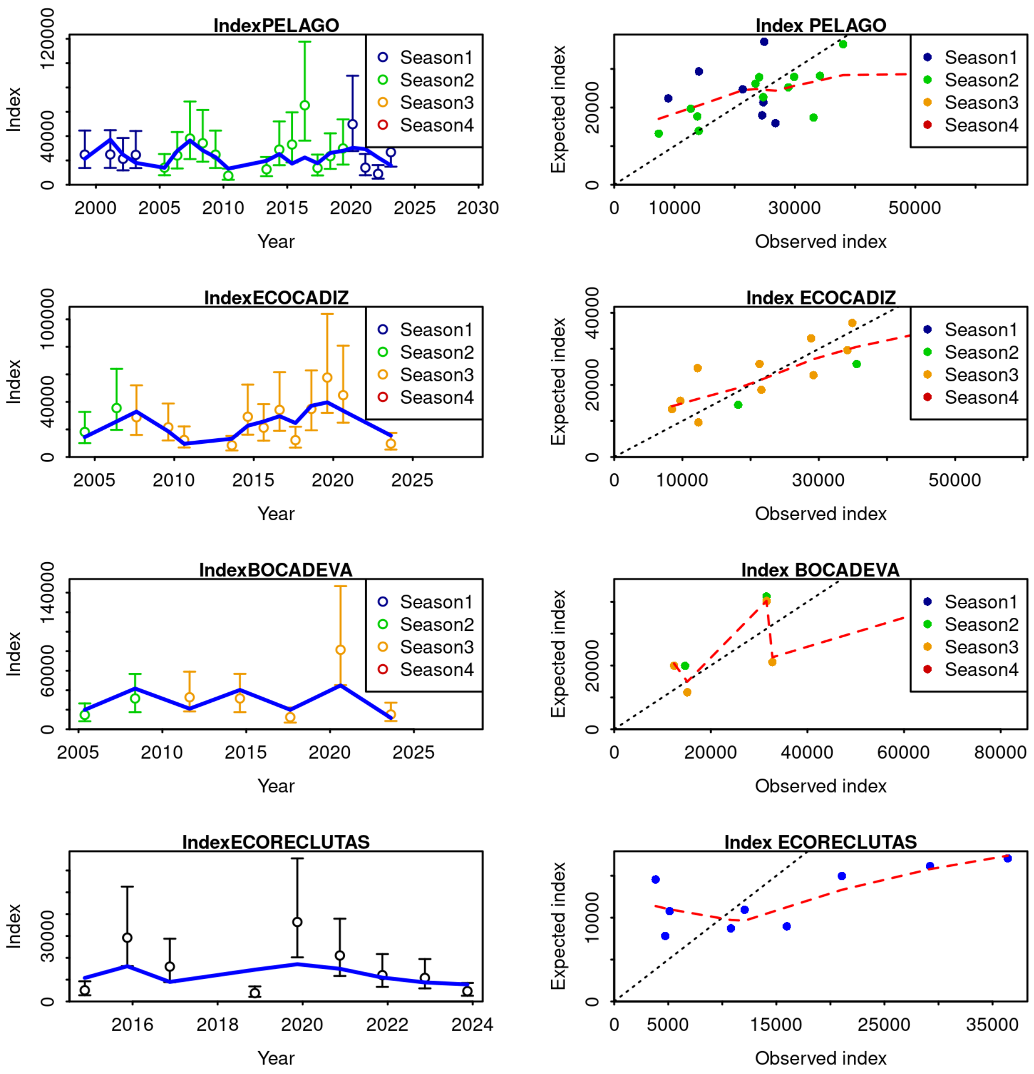


Figure 4.3.31. ane.27.9a Southern stock. Model fit to the data (left panel) and observed versus expected values (right panel) of the indices from the surveys *PELAGO*, *ECOCADIZ*, *BOCADEVA* and *ECOCADIZ-RECLUTAS* . The lines indicate a 95% uncertainty interval around the index values based on the lognormal error model assumption.

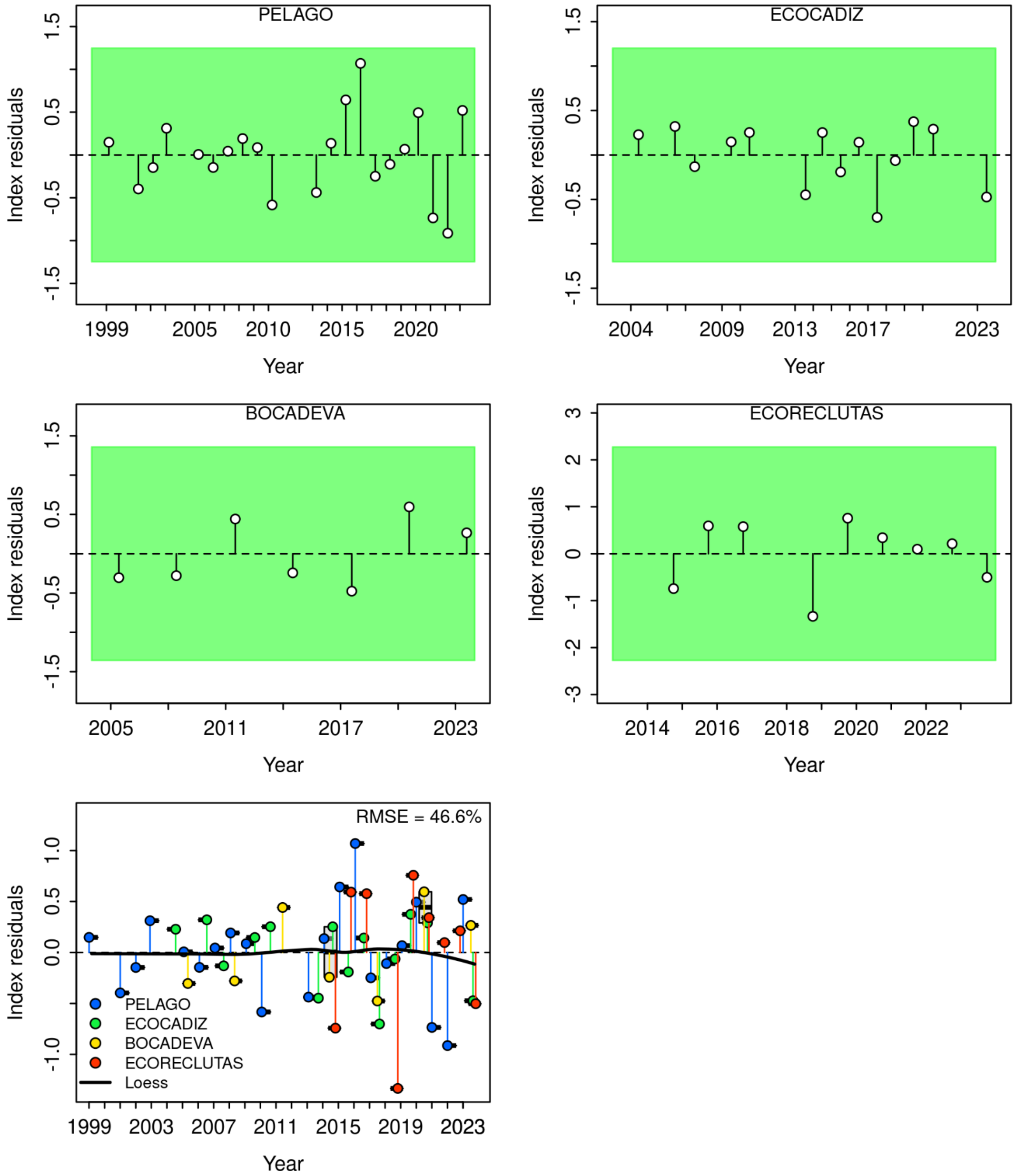


Figure 4.3.32. ane.27.9a Southern stock. a) Run test plots for the fit of acoustic and DEPM survey indices. Green shading indicates no evidence (p>=0.05) and red shading indicates evidence (p<0.05) for rejecting the hypothesis of a randomly distributed residual time series, respectively. The shaded area (green/red) spans three standard residual deviations on either side of zero, and red points outside the shading violate the three-sigma limit for that series. b) Joint residual plots for the fit of acoustic and DEPM survey indices (bottom left panel). Vertical lines with points show the residuals, and the solid black line shows loess smoother through all residuals. Boxplots indicate the median and quantiles in cases where residuals from multiple indices are available for a given year, with the solid black line showing a loess smoother. The root mean square error (RMSE) is included in the top right corner of the panel.

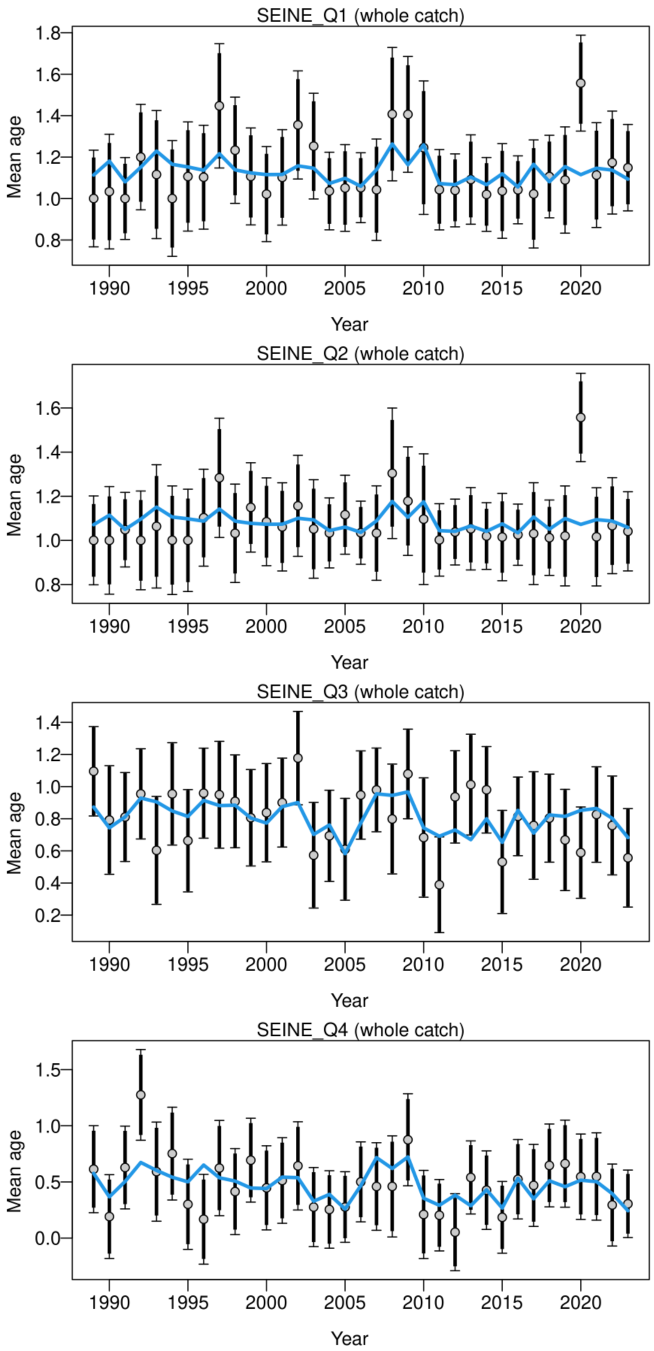
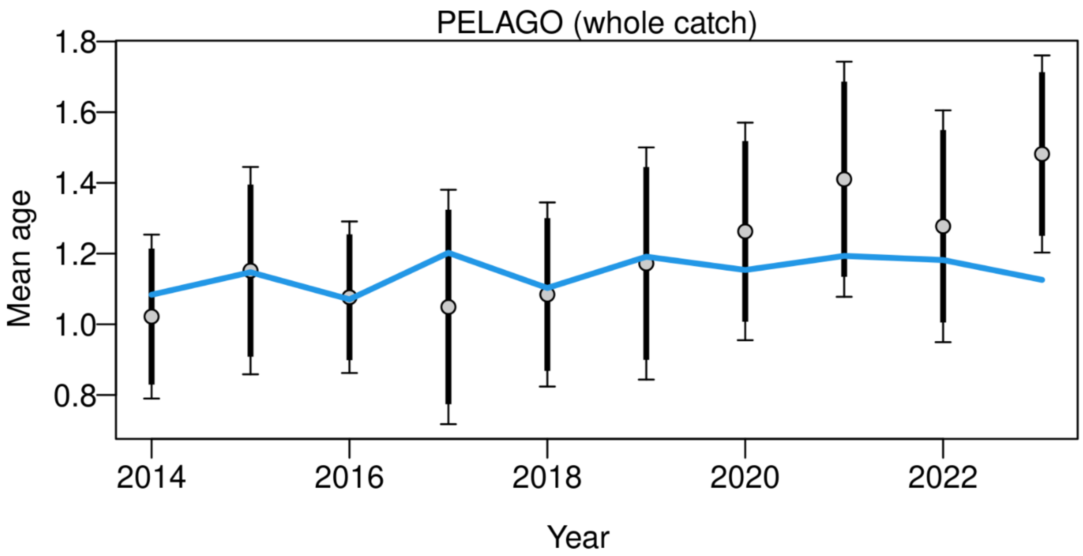


Figure 4.3.33. ane.27.9a Southern stock. Mean age for commercial fleet by quarters with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.



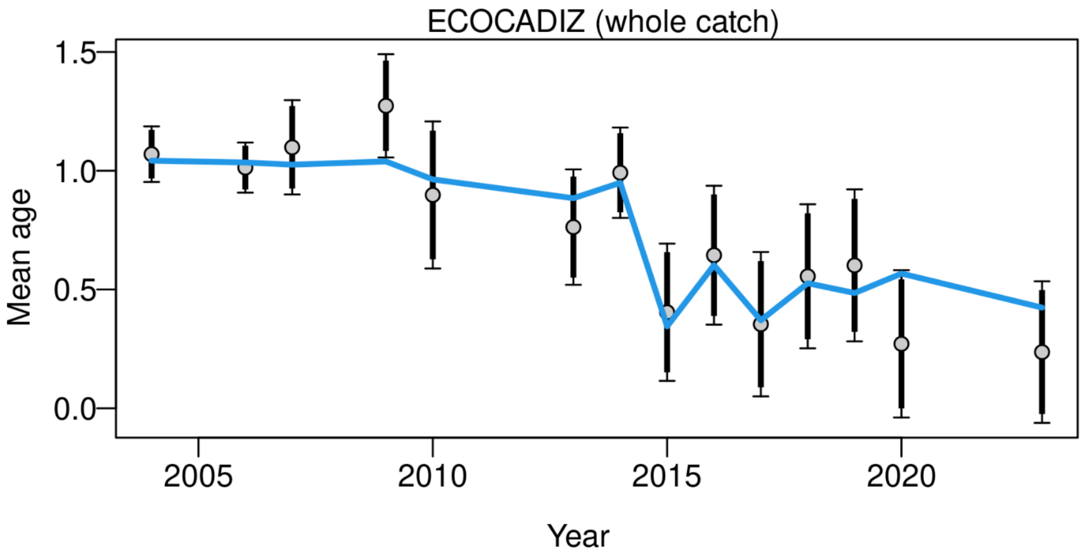


Figure 4.3.34. ane.27.9a Southern stock. Mean age for and with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.

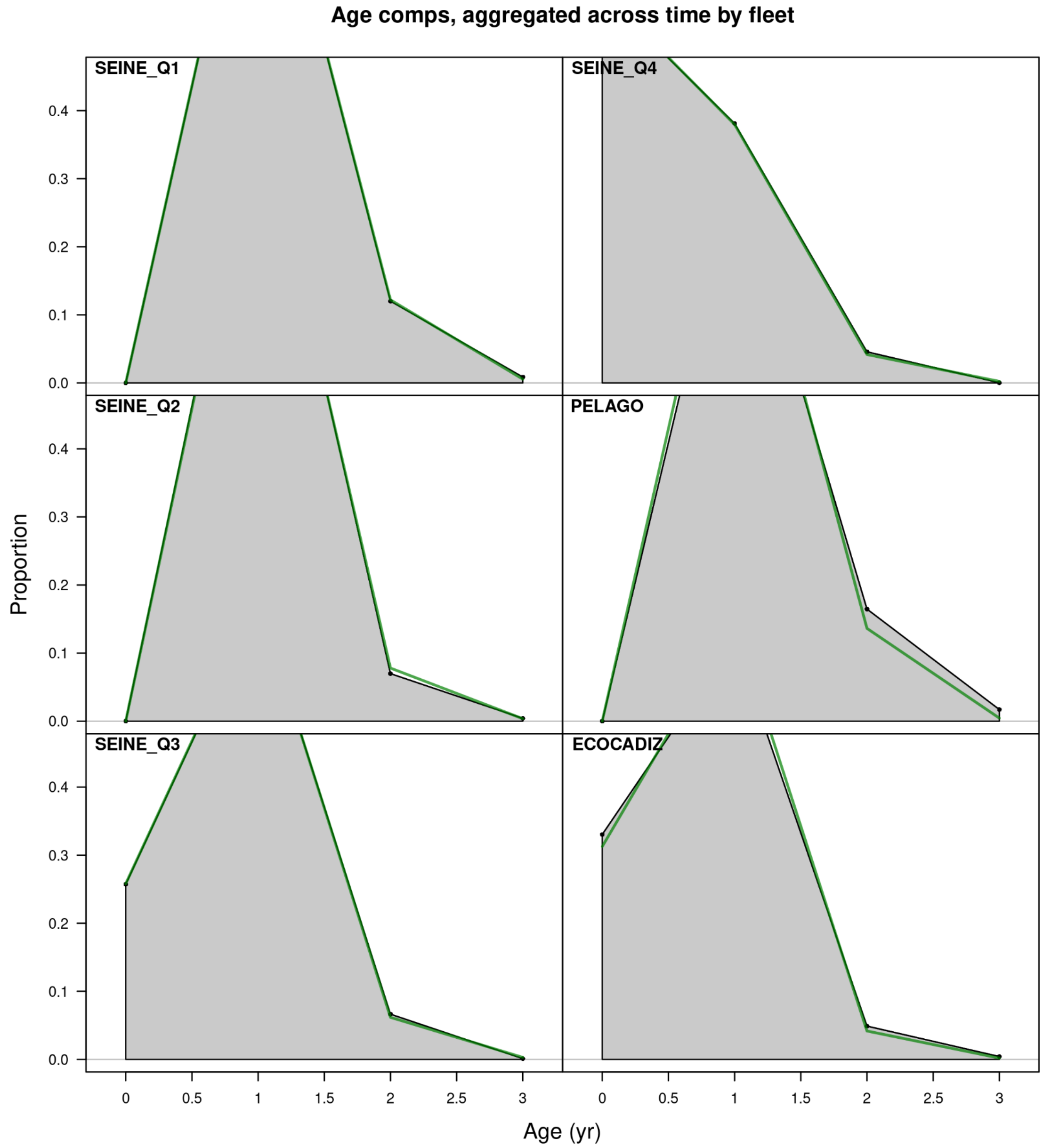


Figure 4.3.35. ane.27.9a Southern stock. Model fit to the aggregated age composition data from the fishery, and the acoustic surveys *PELAGO* and *ECOCADIZ*. The green line represents the model estimates, while the shaded grey area shows the observed data.

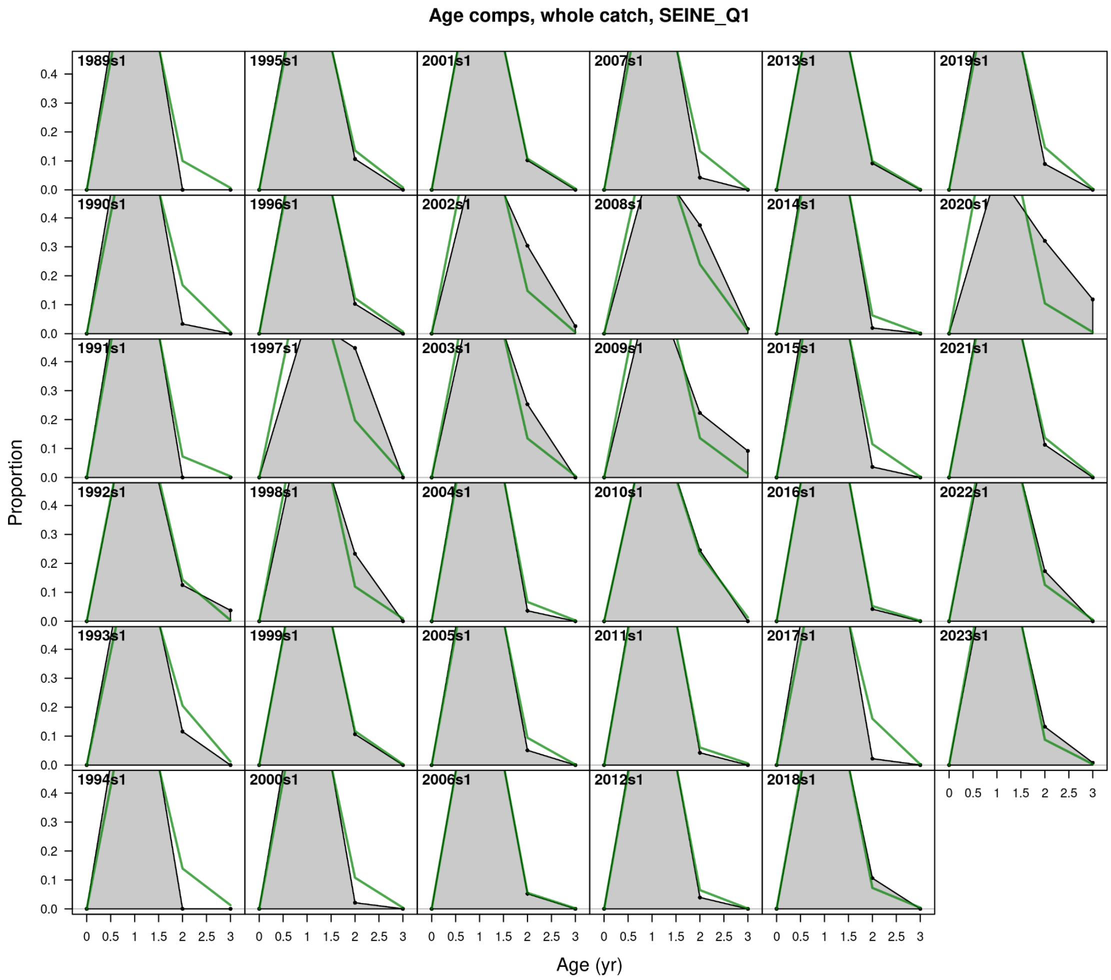


Figure 4.3.36. ane.27.9a Southern stock. Model fit to the age composition data from the *SEINE_Q1* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

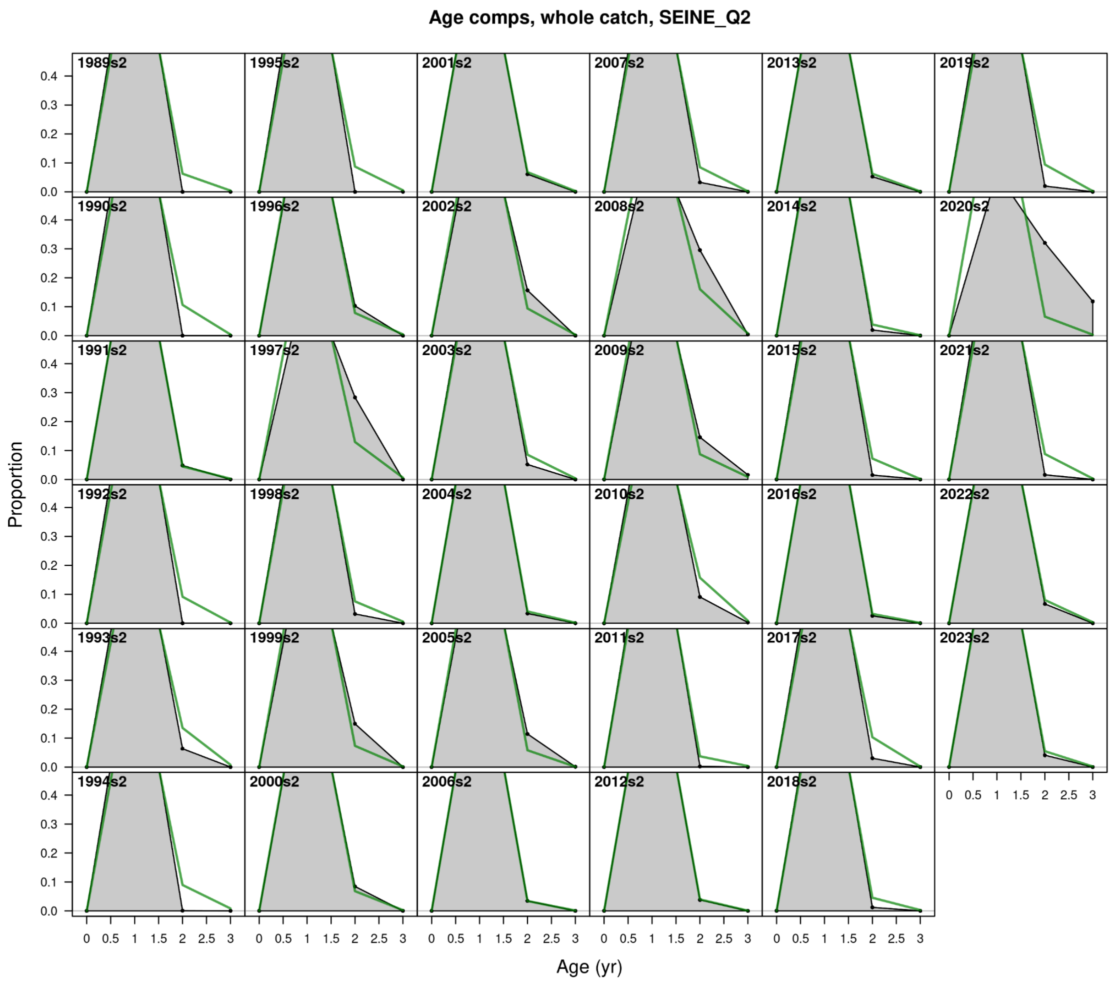


Figure 4.3.37. ane.27.9a Southern stock. Model fit to the age composition data from the *SEINE_Q2* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

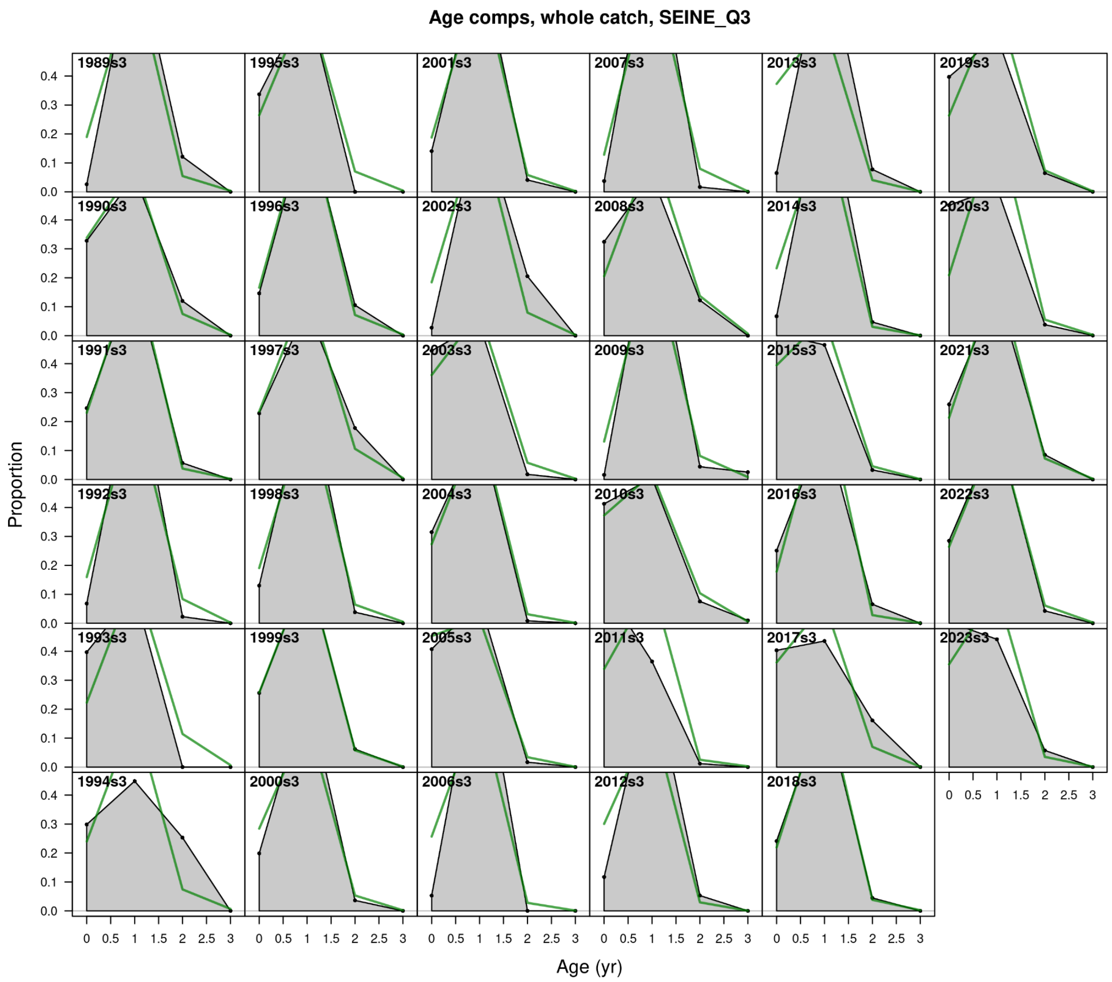


Figure 4.3.38. ane.27.9a Southern stock. Model fit to the age composition data from the *SEINE_Q3* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

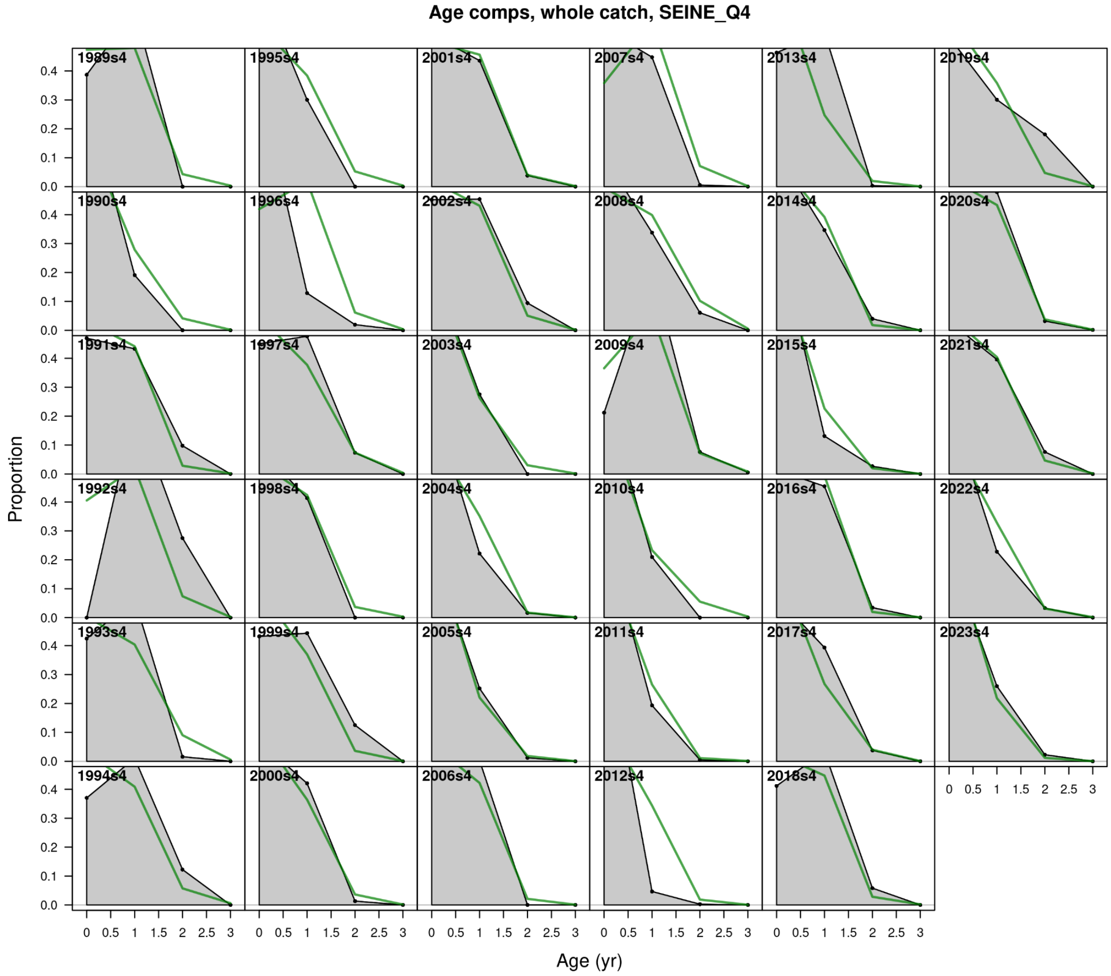


Figure 4.3.39. ane.27.9a Southern stock. Model fit to the age composition data from the *SEINE_Q4* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

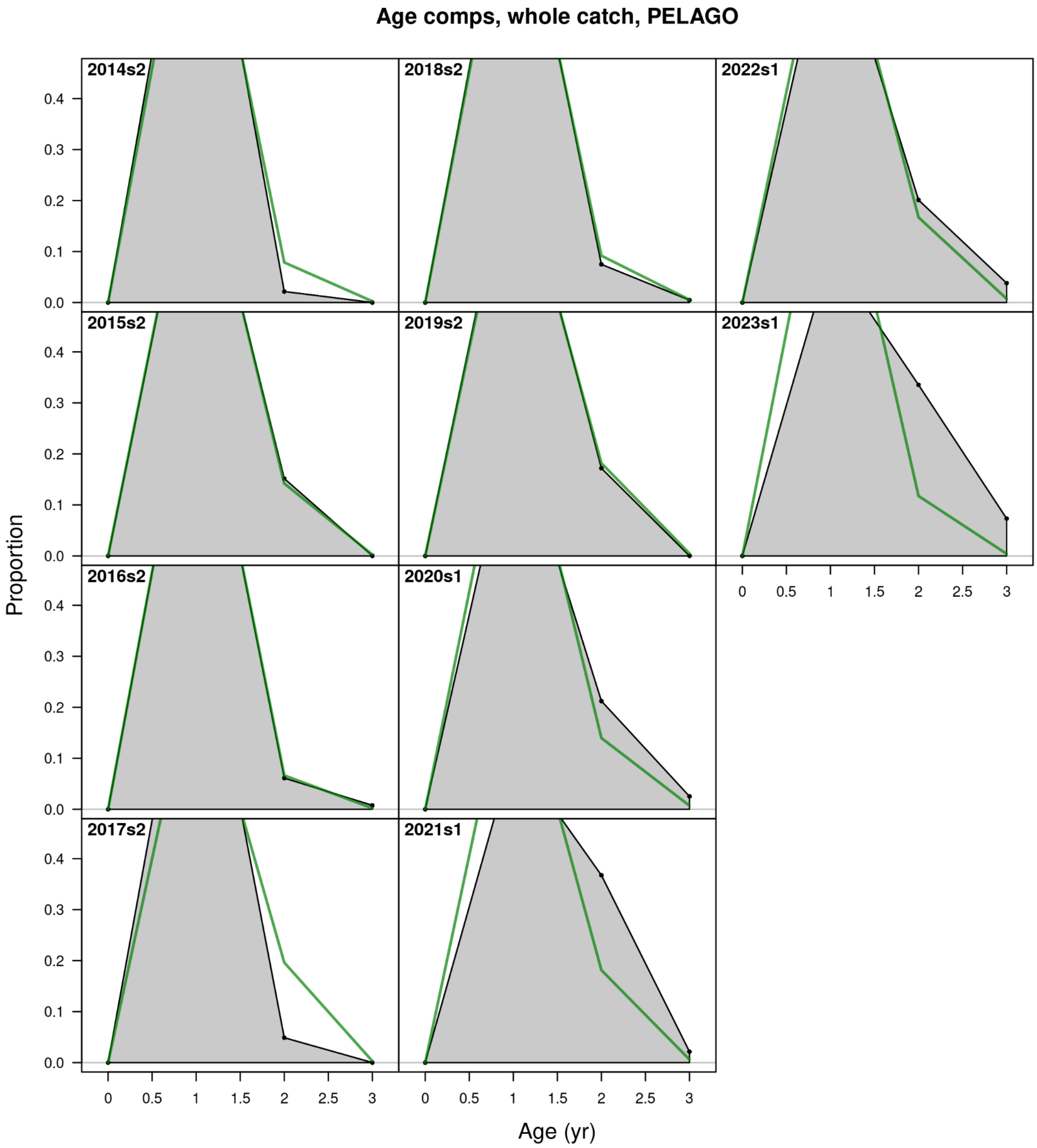


Figure 4.3.40. ane.27.9a Southern stock. Model fit to the age composition data from the *PELAGO* spring survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

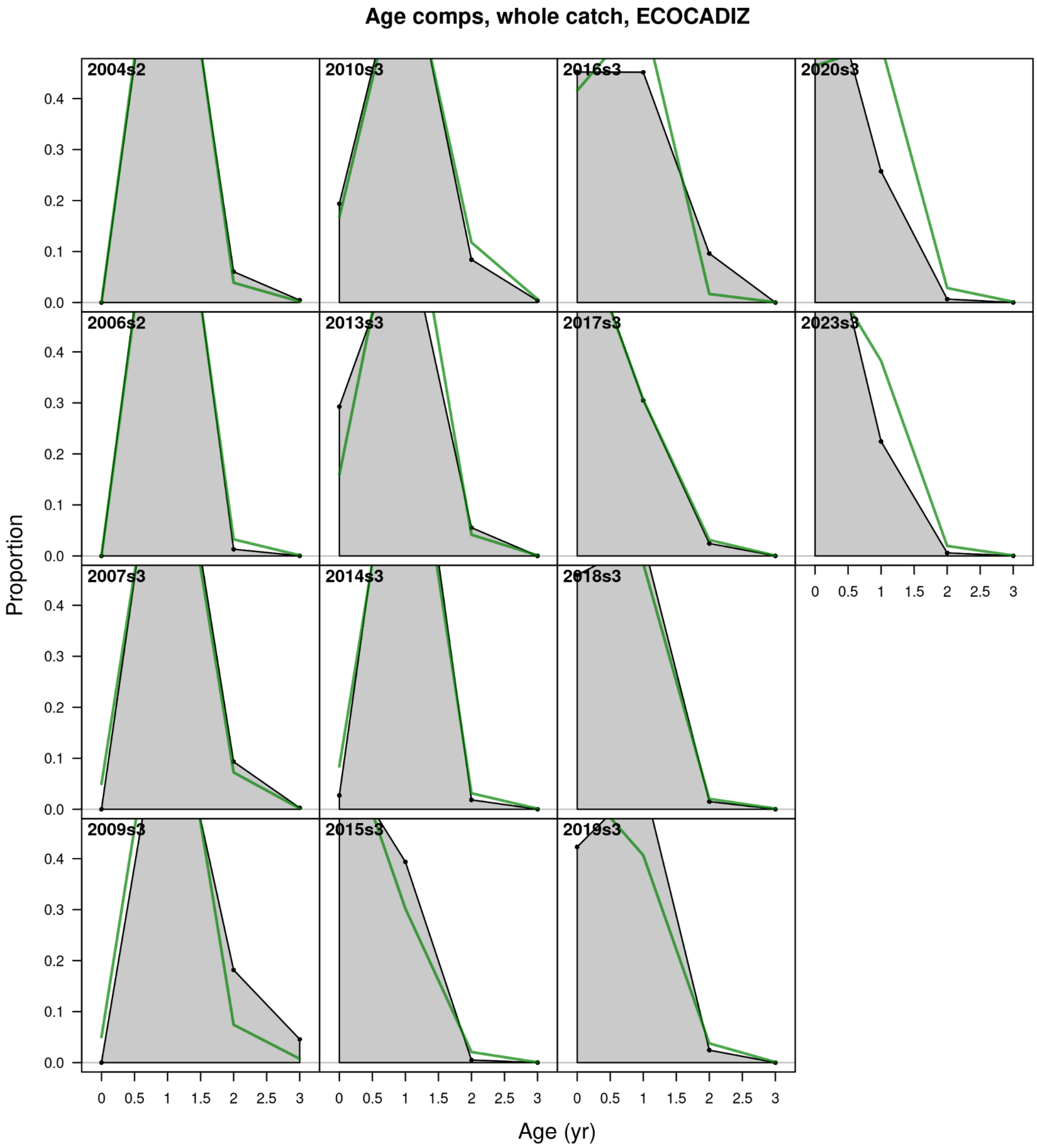


Figure 4.3.41. ane.27.9a Southern stock. Model fit to the age composition data from the *ECOCADIZ* summer survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

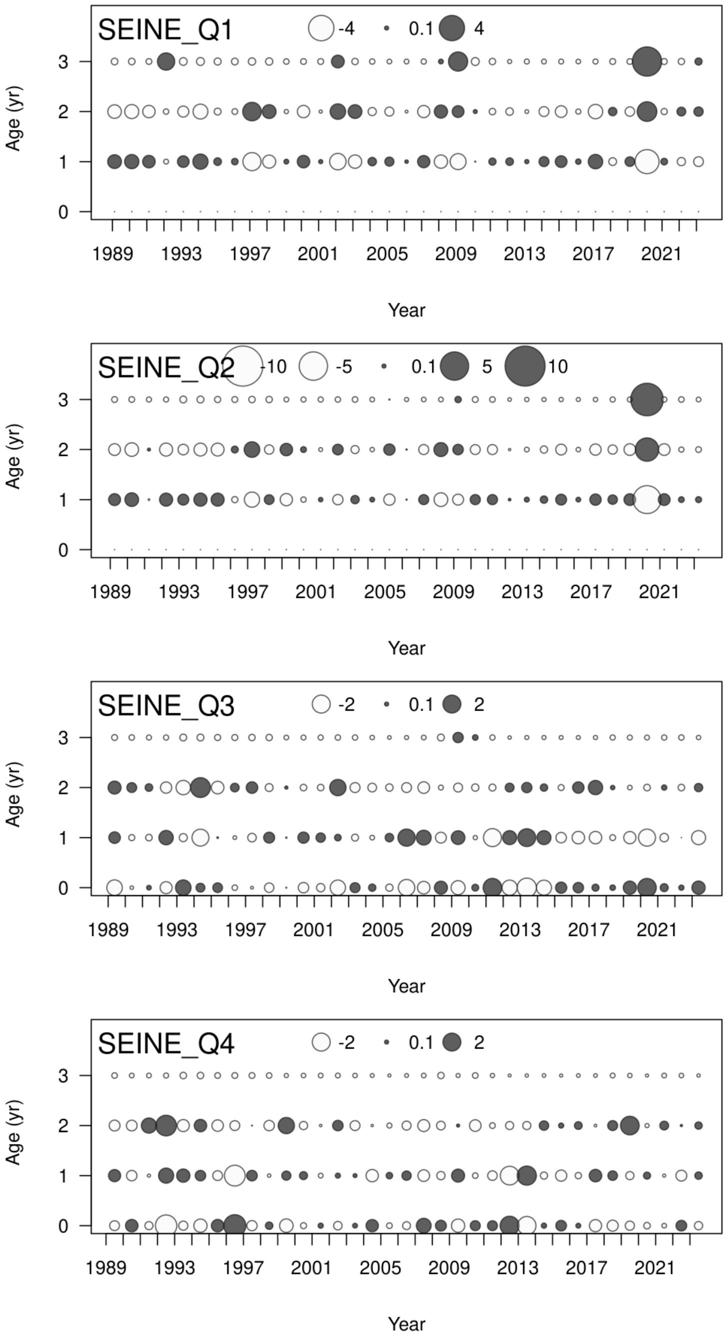


Figure 4.3.42. ane.27.9a Southern stock. Pearson residuals, comparing across fleets. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

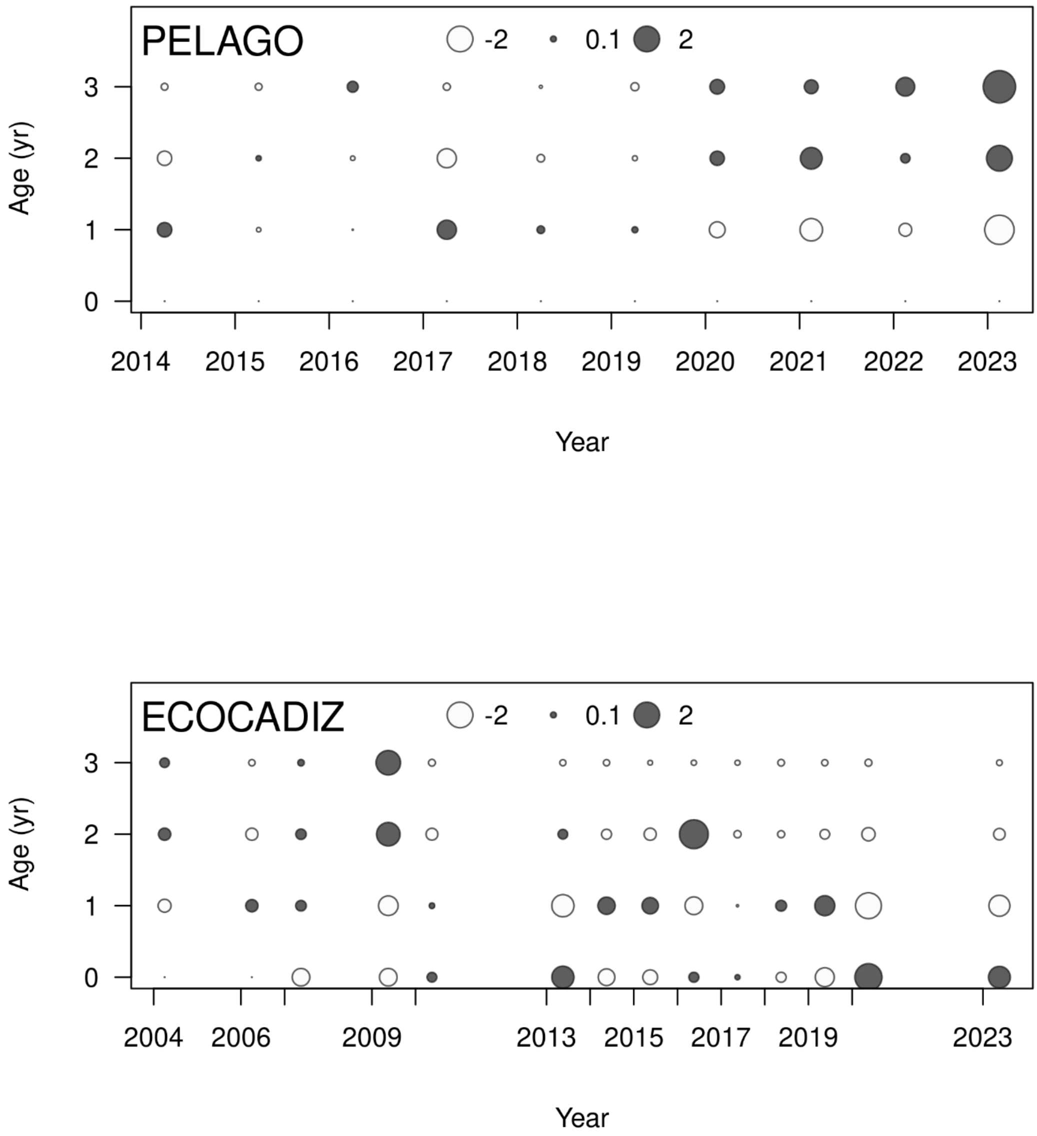


Figure 4.3.43. ane.27.9a Southern stock. Pearson residuals, comparing across surveys. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

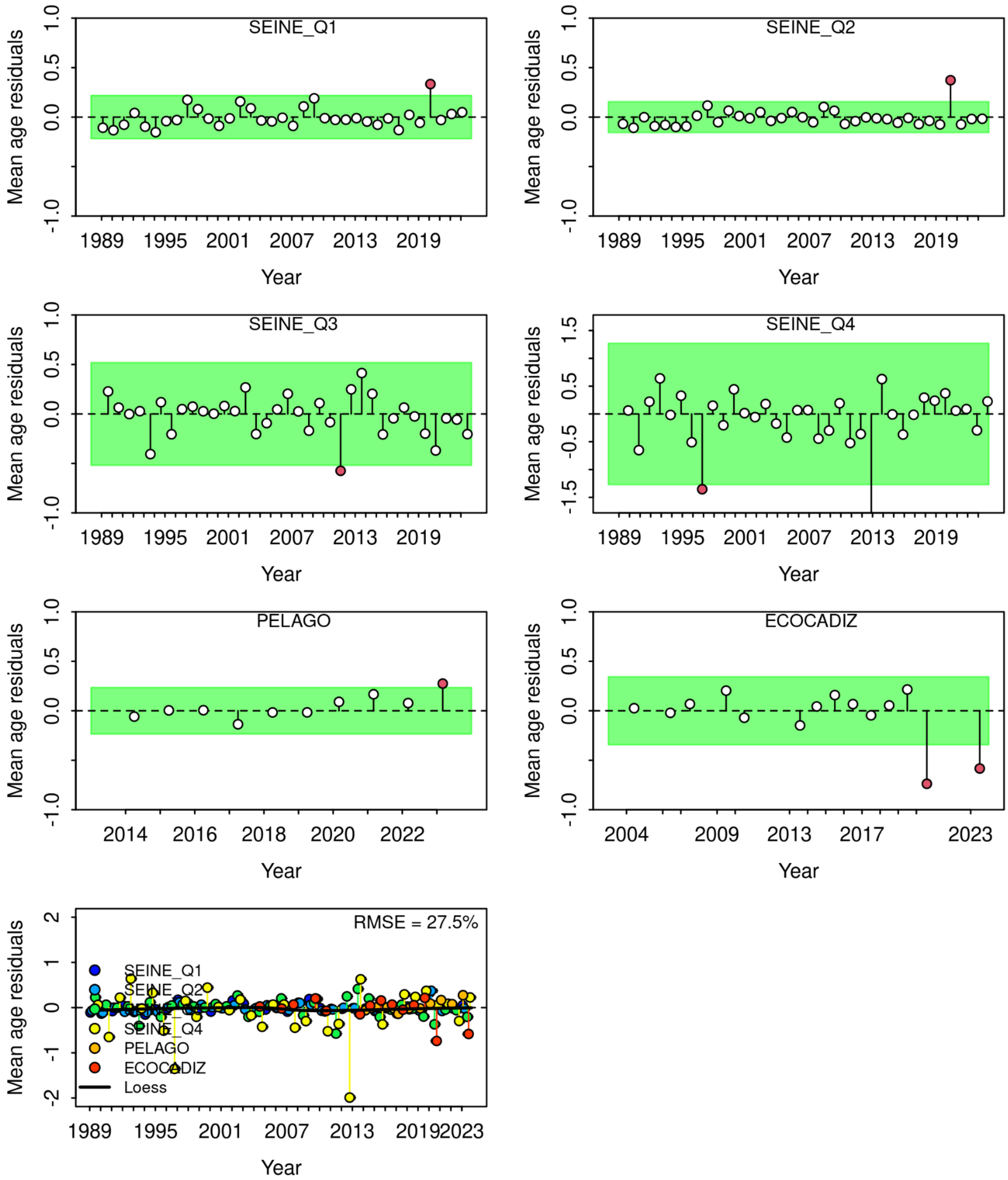


Figure 4.3.44. ane.27.9a Southern stock. a) Runs test results for fits to annual mean age estimates for the surveys (*PELAGO* and *ECOCADIZ)*, and the fishery (*SEINE*). Green shaded (green/red) area spans three residual standard deviations to either side from zero, and the red points outside of the shading violate the 'three-sigma limit' for that series. b) Joint residual plots for annual mean length estimates for surveys and fishery (bottom left panel). Vertical lines with points show the residuals, and the solid black line shows loess smoother through all residuals. Root-mean squared error (RMSE) is included in the upper right-hand corner of the panel.

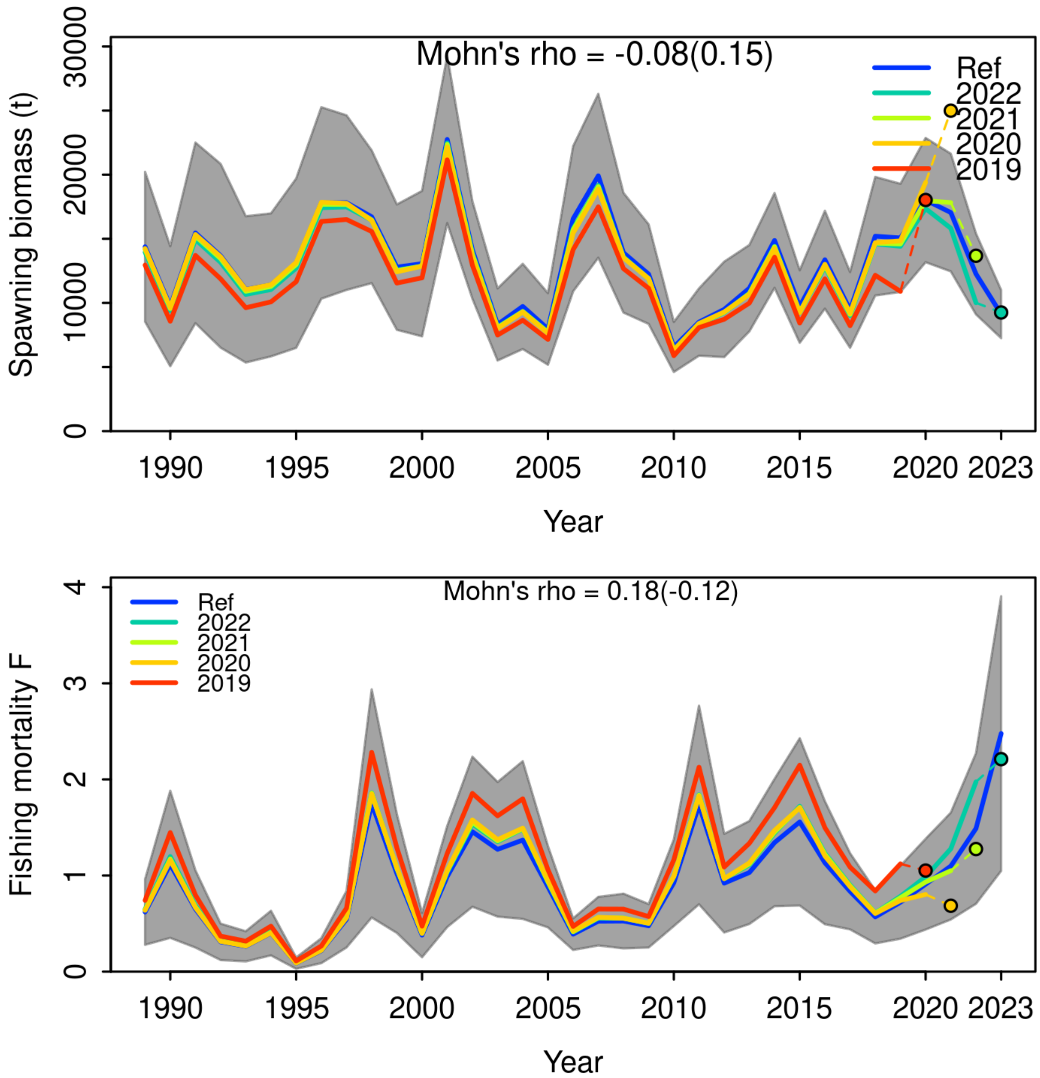


Figure 4.3.45. ane.27.9a Southern stock. Retrospective analysis of spawning stock biomass (SSB) and fishing mortality (F). Models conducted by re-fitting the reference model (Ref) after removing five years of observations, one year at a time sequentially. The retrospective results are shown the entire time series. Mohn's rho statistic and the corresponding 'hindcast rho' values (in brackets) are printed at the top of the panels. One-year-ahead projections denoted by color-coded dashed lines with terminal points are shown for each model. Grey shaded areas are the 95% confidence intervals from the reference model.

Comparison of Biomass of SS3 model and Abundance Indices

Figure 4.3.46 presents the biomass data from the surveys used as input in the SS3 model, along with the estimated catchability parameters. The results indicate that catchability values greater than 1 are associated with the highest biomass levels recorded by the *BOCADEVA* survey, which consistently reports the highest biomass compared to other surveys conducted in the same years. The *PELAGO* survey follows, with elevated biomass values observed in 2016, 2020, and 2023, while the *ECOCADIZ* survey shows a peak in 2019. In contrast, the estimated catchability for the *ECOCADIZ-RECLUTAS* survey is below 1. Notably, the biomass data entered for *ECOCADIZ-RECLUTAS* corresponds exclusively to age-0 biomass rather than total biomass.

Figure 4.3.47 presents the biomass estimated by the SS3 model, which exhibits a relatively stable trend with moderate fluctuations over time. Figure 4.3.48 compares the variability observed in survey data with the estimates from the SS3 model. The *PELAGO* survey shows significant variability, with notable peaks in years such as 2020, indicating high biomass levels. *ECOCADIZ* reports a distinct peak in 2019, while *BOCADEVA* consistently records the highest biomass levels among all surveys, with substantially elevated values in certain years. In contrast, *ECOCADIZ-RECLUTAS*, representing age-0 (recruit) biomass, consistently shows lower values compared to the other estimates.

The biomass observed in the surveys varies significantly in magnitude and scale compared to the SS3 model estimates. *BOCADEVA* stands out as the survey with the highest biomass values, potentially explaining the higher catchability estimates associated with this data. In comparison, the *PELAGO* and *ECOCADIZ* surveys show values closer to the SS3 model estimates in several years, albeit with occasional peaks of high biomass.

The catch standard error is set at 0.05, assuming the catch is known. This ensures that the estimates from the SS3 model align with the input catch values. Consequently, the fits to the catch data (Figure 4.3.49) show no evidence of underfitting or overfitting, providing strong support for the appropriateness of the assessment scale.

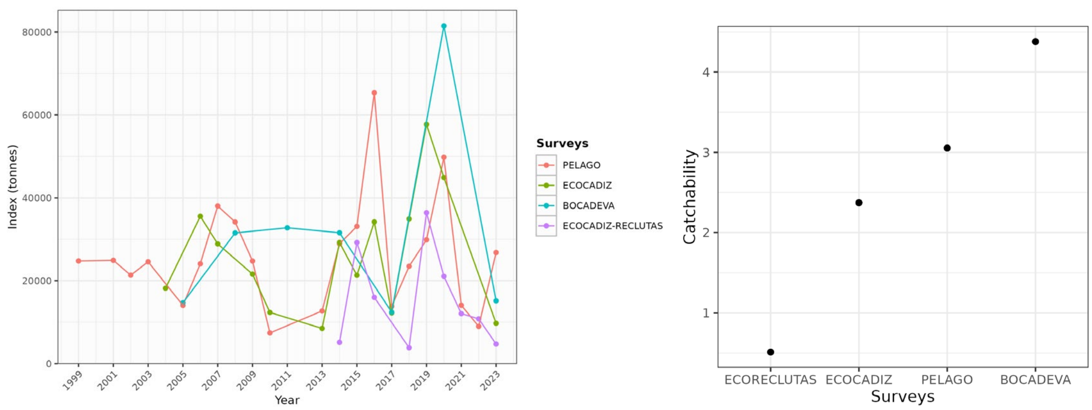


Figure 4.3.46. ane.27.9a Left panel: Biomass estimates from the *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS* surveys. Right panel: Estimated catchability parameters for the different survey indices based on the corrected final run.

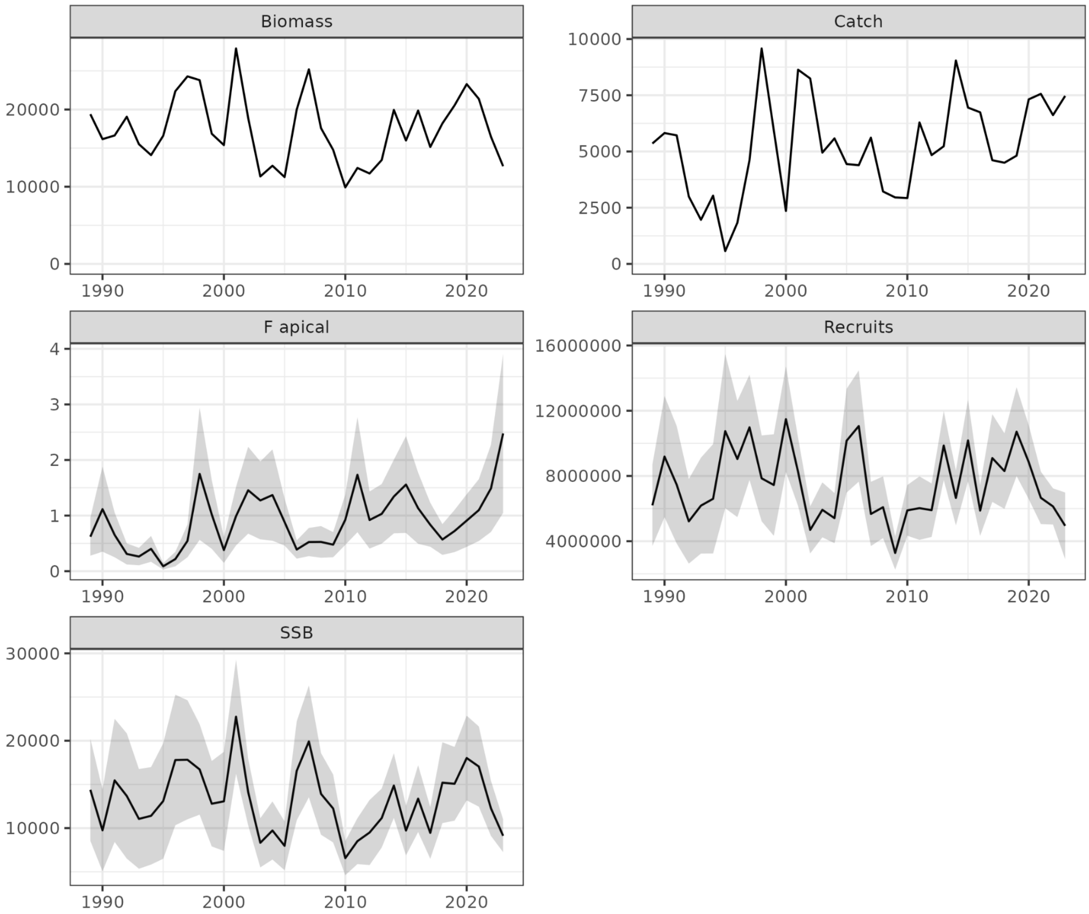


Figure 4.3.47. ane.27.9a Southern stock. Time series estimated by the model for annual catches estimated by the model (in tons), recruitment (millions of fish), total biomass and spawning biomass (in tons), and fishing mortality (year-1) based on the corrected final run.

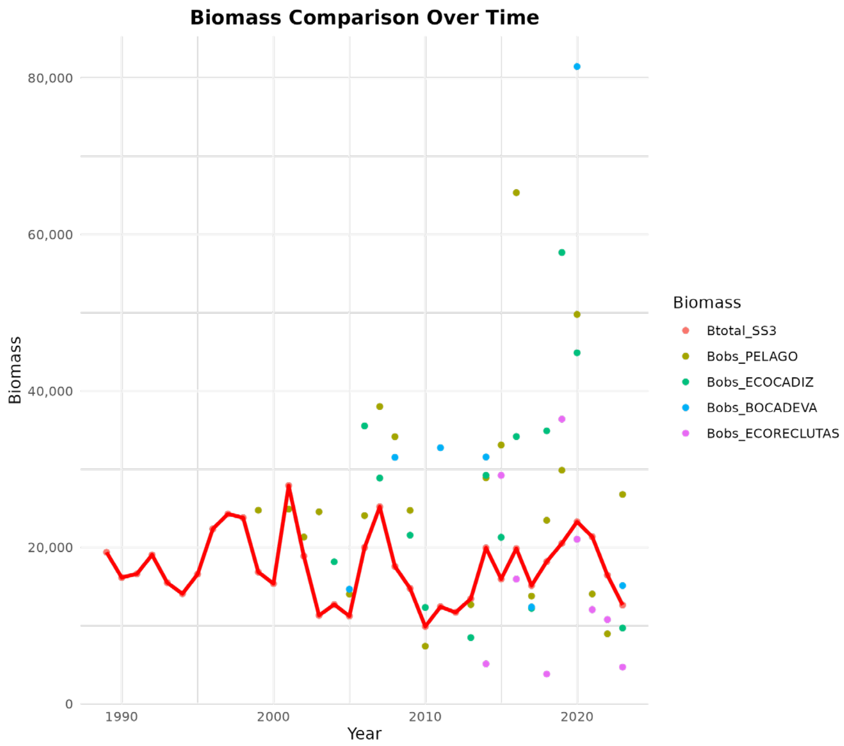


Figure 4.3.48. ane.27.9a Southern stock. Comparison of biomass scales: total biomass estimated by the SS3 model (red line) versus observed biomass from surveys (points) (*PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS*).

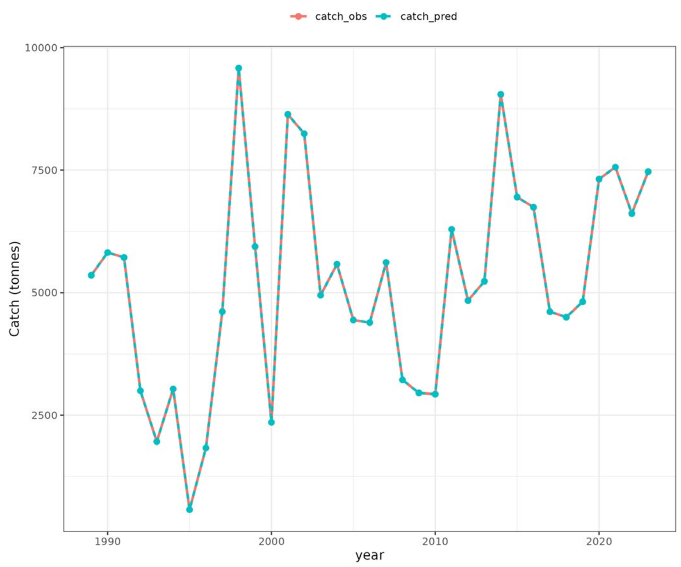


Figure 4.3.49. ane.27.9a Southern stock. Comparison of catches scales: catch estimated by the SS3 model (light blue line) versus observed catch (red line).

4.5 Comparison with current assessment

Fishing mortality (F), spawning stock biomass (SSB), and exploitation rate (total annual catch/SSB) from the final Stock Synthesis (SS3) model were compared with the most recent outputs from the Gadget model, as presented in the WGHANSA-1 2024 assessment (ICES 2024). It is important to note that these estimates are not directly comparable due to differences in model structure, input data, and reference periods for outputs. Specifically, Gadget outputs represent the period from June of one year to July of the following year, while SS3 outputs correspond to calendar years (January to December), among other methodological differences.

Despite these limitations, the comparison between the two models reveals that, although the issue with catchability estimates persists in the SS3 model (Figure 4.3.50), it shows similar levels of fishing mortality (except for the final year), a significant increase in absolute biomass levels, and a reduction in exploitation rates compared to Gadget (Figure 4.3.51). Furthermore, Figure 4.3.52 indicates that the weights-at-age estimated by Gadget are consistently lower than the empirical weights-at-age derived from all available data sources (see Section 4.3.4). This discrepancy in weights-at-age likely explains, at least partially, the differences in biomass estimates between the two models.

It should be emphasised that the Gadget model was used solely for comparative purposes, without delving into model structure analysis, parameter correlation evaluations, or additional diagnostics. This was due to the computational constraints of Gadget (over three hours per run), which limited the feasibility of conducting sensitivity analyses during the benchmark process.

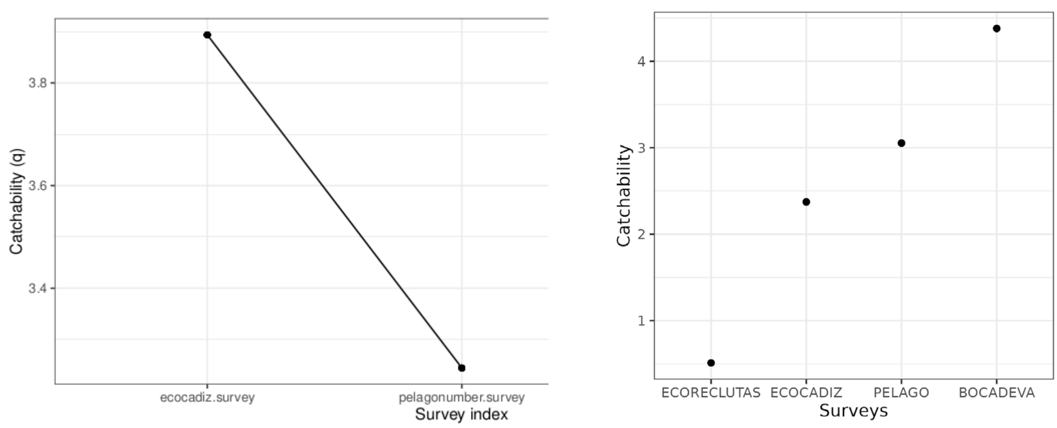


Figure 4.3.50. ane.27.9a Southern stock. Estimated catchability parameters for different survey indices. Left panel: Gadget model; Right panel: SS3 model.

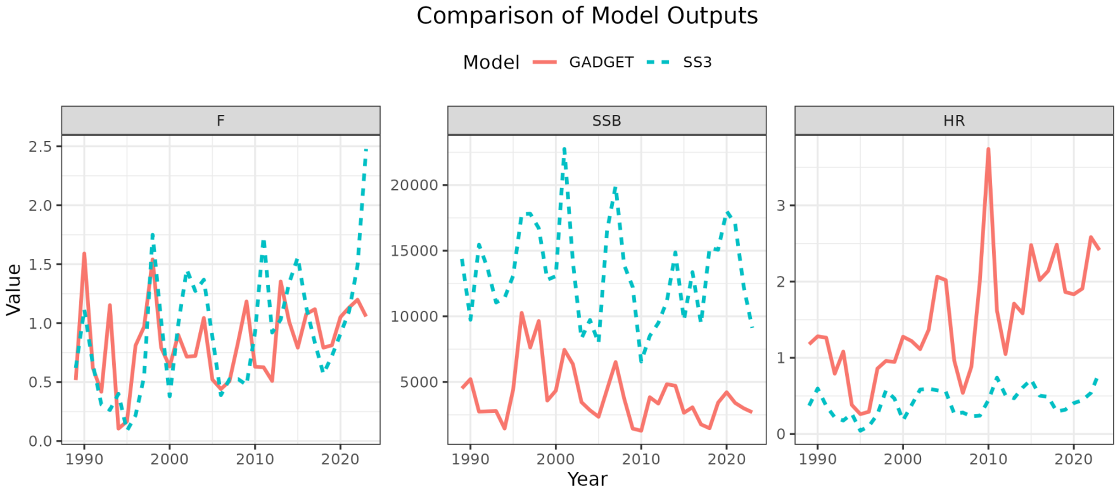


Figure 4.3.51. ane.27.9a Southern stock. Comparison of fishing mortality (F), spawning biomass (SSB), and harvest rate (HR) estimates between the Gadget and SS3 models.

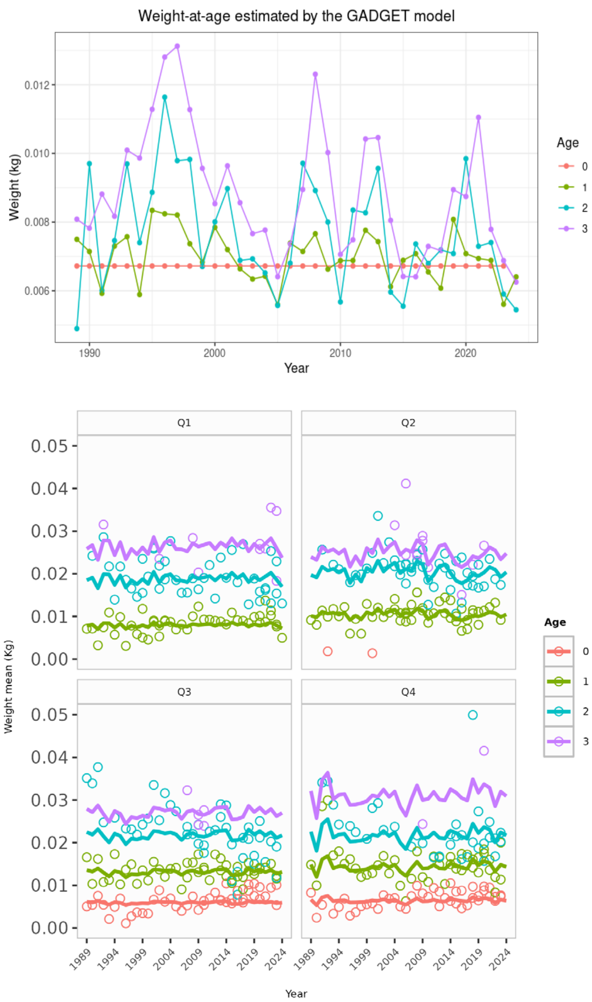


Figure 4.3.52. ane.27.9a Southern stock. Top panel: Estimated mean weights-at-age from the Gadget model. Bottom panel: Observed and estimated mean weights-at-age for the four quarters. Circles represent observed data points, while solid lines represent estimates from the linear mixed-effects model (input data SS3).

4.6 Short term forecast

The SS3 forecast module was used to perform short-term projections, considering the model's final year conditions, associated uncertainties, and varying fishing intensities. The initial stock size was derived from the abundance at ages 0-3 on January 1 of the final assessment year, while the spawning stock biomass (SSB) was estimated for April 1. Natural mortality and maturity rates were held constant, with selectivity and weight-at-age averaged over the last three years. Recruitment for the forecast year was projected using the Stock Synthesis Beverton-Holt stock-recruitment relationship. Status quo fishing mortality (Fsq) was calculated as the average across the last three years, by fleet and season ($F_{fleetQ1}$=0.29, $F_{fleetQ2}$=1.65, $F_{fleetQ3}$=2.93, $F_{fleetQ4}$=1.7).

Multipliers of the status quo fishing mortality (Fsq*Mult) of 0, 1, 1.2, 1.6, and 2 were evaluated. Additionally, an iterative process was used to identify the multiplier that would achieve a 2024 catch with probabilities of 5% and 50% that SSB in 2024 would fall below B_{lim} ($p(SSB_{2024} \leq B_{lim})$ = 0.05 and 0.5, respectively).

Table 4.2.2 presents the management options derived from these short-term projections, evaluated at different fishing mortality levels. It includes projected catches for 2024 (in tons), estimated SSB for 2024 (in tons), and the probability that SSB_{2024} falls below B_{lim}. For more detailed information, see the working document by *Zúñiga et al. 2024 WD: Reference points and short-term forecast for WKBANSP 2024: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).*

Table 4.4.2 ane.27.9a Southern stock. Short-term forecast for management options. Catch and SSB in tonnes.

	F apical 2024	Catches 2024	SSB 2024	Probability SSB_{2024} <B_{lim}
$F=F_{sq}$*0	0.00	0	8072	0.03
$F=F_{sq}$*1	1.64	5149	7639	0.04
$F=F_{sq}$*1.2	1.97	5765	7555	0.04
$F=F_{sq}$*1.6	2.63	6770	7391	0.05
$F=F_{sq}$*2.0	3.28	7561	7230	0.06
$p(SSB_{2024}<B_{lim})$=5%	2.87	7087	7330	0.05
$p(SSB_{2024}<B_{lim})$=50%	6.70	10078	4707	0.50

The results presented in Table 4.4.2 regarding management options and projections for 2024 should be considered provisional. This is because the values correspond to the preliminary scenario (S1.0_InitCond_sigmaR), which was subsequently adjusted in the corrected final model (S1.0_InitCond_sigmaR_AdjIndexRec).

In the corrected final model, a revised biomass index for the *ECOCADIZ-RECLUTAS* survey was used, which may result in slight variations in the projected catch values, spawning stock biomass (SSB), and probabilities associated with Blim. However, these differences are expected to be minor, as the magnitudes between the two model runs are similar.

4.7 Biological reference points

$B_{lim} = B_{pa}$ * exp(-1.645 * SigmaB) = 4721 tonnes, with $B_{pa} = B_{loss}$ and SigmaB = 0.2 (as used in other fisheries).

Reference points were calculated following ICES guidelines for calculation of reference points for category 1 and 2 stocks. In those guidelines, the S-R plot characteristics classify this stock as a "stock type 5" (i.e. stocks showing no evidence of impaired recruitment or with no clear relation between stock and recruitment (no apparent S-R signal)). According to this classification, B_{loss} estimation is possible according to the standard method and it corresponds to the estimated SSB in 2010, B_{loss} = 6561 tonnes. The fact that the methodology adopted B_{loss} as B_{pa} instead of as B_{lim}, corresponds more with the guidelines for Type 6 stocks (stocks with a narrow dynamic range of SSB and showing no evidence of past or present impaired recruitment).

This new methodology compared to the previous is justified by the fact that assuming B_{lim} equal to B_{loss}, as previously, will imply B_{lim}=0.4*B_0 which is a very big proportion, thus suggesting the range of biomasses being covered by the assessment was rather narrow yet. For further details, refer to the working document by *Zúñiga et al. 2024 WD: Reference points and short-term forecast for WKBANSP 2024: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).*

Table 4.4.3 ane.27.9a Southern stock. Biological Reference points.

BRP	Value (tonnes)	Technical basis
B_{lim}	4721	$B_{lim} = B_{pa}$*exp(-1.654 * sigmaB) sigmaB =0.20
B_{pa}	6561	$B_{pa} = B_{loss}$

4.8 Conclusion

1. Stock Structure

- Separation into two stocks: During the latest benchmark, the anchovy stock was divided into two components: 9.a West and 9.a South. This decision was based on evidence of differences in subpopulation structure, dynamics, and distribution.
- Implications: While catch advice was already provided separately for each component, this division allows for more targeted and specific management strategies tailored to each stock.

2. Assessment Methods

- Model transition: The Gadget model, previously used for assessment, was replaced by the age-structured Stock Synthesis (SS3) model.
- Advantages of SS3:
  - Provides parameter uncertainty estimates.
  - Offers greater flexibility and technical support.
  - Reduces computation time significantly (<1 minute per run).
  - Biomass estimates showed a significant increase compared to the Gadget model, reflecting improved accuracy and reliability in the assessment.

3. Data and Analysis

- Additional time series: The *ECOCADIZ-RECLUTAS* and *BOCADEVA* surveys were incorporated, providing additional indices for abundance and recruitment.
- Seasonality of the fishery: The purse seine fleet was divided into four seasonal fleets to account for seasonal differences in selectivity.
- Weight-at-age: Adjusted using mixed-effects models to ensure consistency in estimates over time.
- Recruitment index: The *ECOCADIZ-RECLUTAS* index was used exclusively as a recruitment measure, representing age-0 biomass.
- Natural mortality: A U-shaped mortality pattern was adopted, with higher values for older ages, reflecting potential senescence effects.

4. Model Diagnostics

- Convergence: The final model demonstrated appropriate convergence, with low gradient values and a good overall fit to the data.
- Retrospective analysis: Mohn's rho values were within acceptable limits for spawning stock biomass (rho = -0.084) and fishing mortality (rho = 0.18), supporting the validity and reliability of the assessment.

5. Short-Term Projections

- First stochastic projection: The initial short-term projection was conducted using the SS3 forecast module. Various fishing mortality multipliers (Fsq*Mult) were evaluated to identify management options that limit the probability of spawning stock biomass (SSB) falling below Blim.

6. Biological Reference Points

- Blim and Bpa:
  - Blim = Calculated as Bpa * exp(-1.645 * SigmaB), with SigmaB = 0.2.
  - Bpa = Equivalent to Bloss (the SSB estimated in 2010).
- Justification of the approach: Using Bloss as Bpa instead of Blim avoids excessively high Blim estimates, aligning more closely with the guidelines for this type of stock.

The implementation of the SS3 model and the incorporation of new data have significantly enhanced the accuracy and robustness of the stock assessment for anchovy in Subdivision 9.a South. These advancements support more sustainable and adaptive management decisions, taking into account the specific dynamics of this stock.

4.9 Recommendations:

1) Optimize Catchability Assumptions

Explore adjustments to catchability parameters, particularly for BOCADEVA, and test alternative model configurations to improve overall model fit.

2) Review BOCADEVA Time Series

Analyze potential biases in the BOCADEVA time series and evaluate alternative methods to reduce catchability estimates while enhancing the fit of other indices.

3) Assess Fcap Through MSE

Conduct a Management Strategy Evaluation (MSE) to define a maximum fishing mortality threshold (Fcap) that ensures sustainability and enhances model performance.

These recommendations aim to refine model accuracy and support sustainable management decisions.

4.10 References

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4.11 Stock-specific working documents

- Ramos et al. 2024 WD. Ane.27.9a stock (Anchovy in ICES Division 9a). Southern component (Anchovy in ICES Subdivision 9a South): Fishery, Biological and Surveys data. Data availability and trends.
- Zúñiga et al 2024 WD: Data consistency analysis of survey age-length data available for the Southern component of anchovy 9a stock
- Zúñiga et al 2024 WD: Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).
- Rincón et al 2024 WD: Growth and natural Mortality parameters estimation for anchovy 9a South, 2024
- Rincón 2024 WD: Comparison of Gadget implementations with the same data input as the age-based SS3 model plus length distributions.
- Zúñiga et al 2024 WD: **S1.0_4FLEETS** -Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)
- Zúñiga et al 2024 WD: **S1.0_InitCond_SigmaR** -Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).
- Zúñiga et al 2024 WD: **S1.0_InitCond_sigmaR_AdjIndexRec** -Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).
- Zúñiga et al 2024 WD: Reference points and short-term forecast for WKBANSP 2024: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).

5 Anchovy (*Engraulis encrasicolus*) in Subdivision 9a West (Western Iberian waters) (stock code: ane.27.9aW)

5.1 Issue list

The issue list for anchovy in Subdivision 9a is described in Table 3.1.1, and the only issue related to the western stock is the stock structure of anchovy in Division 27.9a and is described in Section 3. During this benchmark, no modification of the current assessment method for the western Iberian stock was conducted. The assessment in place follows the stock-specific MSE work conducted during 2023 (ICES, 2023). Additionally, an analysis of the consistency of the surveys carried out in western Iberia was presented to the benchmark.

5.2 General

5.2.1 Main changes and conclusions on stock definition

A summary of the evidence presented to the benchmark meeting on the stock definition of anchovy in Division 9a, the comments of the SIMWG that reviewed the information and the decisions taken during the benchmark are described in Section 3. A full description of the evidence on anchovy stock structure can be found in the WD Garrido et al. 2024.

Changes to the stock structure that occurred during the benchmark were the separation of the former anchovy stock in Division 9a in two stocks, corresponding to the former western and southern components. The current anchovy (*Engraulis encrasicolus*) stock in Subdivision 9.a West (Western Iberian waters, ane.27.9aW) corresponds to the former western component, comprising areas 9a North, 9a Central-North and 9a Central-South. Considering that the advice on fishing opportunities was already given separately for the two components, such a change does not affect the current assessments or the provision of separate advice and catch options.

5.2.1 Fishery information

The Portuguese and Spanish purse-seine fleets (PS_SPF_0_0_0) account on average for more than 95% of total catches of anchovy from the Western Iberian waters, although the bulk of anchovy catches mainly comes from the Portuguese fishery in area 9a Central-North (WD Garrido et al. 2024). These fleets mainly target sardines, but in recent years fishing effort has been directed towards multiple pelagic fish species such as chub mackerel (*Scomber colias*), horse mackerel (*Trachurus trachurus*) and anchovy. This is due to the implementation of stricter regulations in the sardine fisheries. Incidental catches are also landed by Spanish and Portuguese bottom trawl (OTB_DEF_>=55_0_0) and artisanal polyvalent vessels (MIS_MIS_0_0_0_HC). Discards are considered negligible. Landings data are collected by the Spanish and Portuguese government official entities responsible for fisheries data (General Fisheries Secretariat in Spain, General Fisheries Directorate in Portugal). For both countries, landings are not considered to be significantly under reported. Commercial catch data are then obtained from the national laboratories of both Spain (IEO) and Portugal (IPMA) and provided to the ICES WGHANSA by area/quarter/métier. Discards are sampled by Portugal and Spain within their respective EC-DCF-based National Sampling Schemes.

5.2.2 Acoustic surveys

Acoustic survey methodologies deployed by the respective national Institutes (IPMA and IEO) are thoroughly described in ICES (2008, 2009, 2017). Collaborative work between Portugal (IPMA) and Spain (IEO) over the years, led to increased coordination of the surveys and standardisation of surveying and analysis methodologies, and many developments have been achieved under the auspices of the ICES groups SGSBSA (Study Group on the Estimation of Spawning–stock Biomass of Sardine and Anchovy) and WGACEGG (Working Group on Acoustic and Egg Surveys for small pelagic fish in NE Atlantic). Table 5.2.2.1 summarises the seasonal and regional scope of each of these pelagic surveys.

Table 5.2.2.1. Acoustic surveys conducted in Subdivision 9a West which provide anchovy population estimates.

Area	Spring	Autumn
9a N	PELACUS (ES)	IBERAS (SP)
9a C-N	PELAGO (PT)	JUVESAR (PT) IBERAS (SP)
9a C-S		JUVESAR (PT)* IBERAS (SP)*

*for most years, only the northern part of the 9aC-S area is covered.

All the above-mentioned survey series are currently funded by the EU through the European Maritime and Fisheries Fund (EMFF), within the respective National Program of collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy.

Several acoustic surveys are conducted covering parts of the spatial distribution of anchovy in Subdivision 9a West. During the first semester of the year, both *PELACUS* and *PELAGO* surveys are conducted in spring covering the full distribution. In the second semester, there is partial coverage of the stock with the IBERAS survey series (continuing and extending the former *JUVESAR* survey series).

Surveys are coordinated within ICES WGACEGG. Full descriptions on survey design, sampling strategies and data analysis can be found in Doray *et al.* (2021). The spring surveys *PELACUS* and *PELAGO* are used for providing a single abundance index by length and age class. The autumn IBERAS survey series, likely only partially covers the distribution of the stock, as for some years, fish are found at the outermost stations of the transects, suggesting some fish might be distributed further offshore.

5.2.2.1 PELAGO survey series (Portuguese Spring acoustic survey in 9a C-N, 9a C-S and 9a S)

The *PELAGO* surveys (Portuguese spring acoustic survey, until 2006 termed as *SAR* spring surveys) are conducted every year since 1999 by IPMA with the RV *Noruega*, surveying the waters of the Portuguese continental shelf and those of the Spanish Gulf of Cadiz (subdivisions 9a C-N, 9a C-S, and 9a S), between 20 and 200 m depth.

Originally it was routinely performed for the acoustic estimation of the sardine abundance in Division 9a off the Portuguese continental shelf and Gulf of Cadiz during March-April (sardine late spawning season). From 2007 on, spring surveys are being conducted as 'pelagic community' surveys. Anchovy estimates from these survey series started to be available since March 1999, with gaps in 2000, 2004 and 2012. Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) of the estimated population in numbers and biomass, but age-structured estimates are provided by IPMA since 2008.

The survey track follows a parallel grid, with transects perpendicular to the coastline. The acoustic energy in the inter-transect track is not taken into account. The transects are spaced by 8 nautical miles in the West Coast, and also covers the Golf of Cadiz (Figure 5.2.2.1.1). Acoustic data from 38 kHz are stored with MOVIES+ software as standard HAC files along the transects. Trawl hauls are performed whenever significant amounts of fish are found but mainly targeting sardine and anchovy. Trawl data are used to identify the echotraces, obtain the length structure of the population, obtain the species proportion and get biologic samples.

The identification of the echotraces is made by eye, with the aid of the trawl hauls. If it is not possible to separate the species schools by eye, the energy of the ESDUs (Elementary Sampling Distance Unit) is split using the haul species proportion, in number, and taking into account the target strength and the species length compositions.

The weight of the hauls is always the same, since a post-stratification is made, and the overall area is divided into small homogeneous areas, with similar length composition. To partition the acoustic energy by species, using the trawl species proportion, the hauls are not weighted by the energy around the haul, assuming that the species mixture is independent of the acoustic energy density. The acoustic energy is extracted from the EK500 echograms, school by school, using MOVIES+ software. Plankton and very small schools are rejected.

For each species, the acoustic energy is also partitioned by length classes according to the length structure found in the trawl hauls. The biomass is derived from the number of individuals, applying the weight–length relationship obtained from the haul samples.

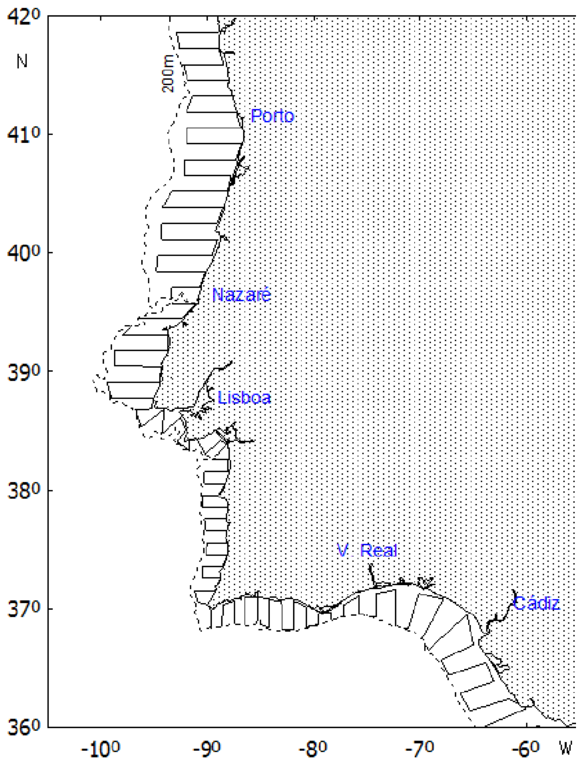

Figure 5.2.2.1.1: ane.27.9a Western stock. Acoustic transects sampled during the *PELAGO* acoustic survey.

5.2.2.2 PELACUS survey series (Spanish Spring acoustic survey in 8c and 9a N)

The *PELACUS* time-series started in 1991 as an evolution of the previous *SARACUS* one (1983–1990), mainly targeting sardine. *PELACUS*, together with a change from the EK400 to the EK500, extended the surveying area until the 1000 isobath in order to assess the main pelagic fish species (mackerel, horse mackerel, blue whiting and bogue together with sardine and anchovy), but covering the same area between the northern Spanish–Portuguese border and the French/Spanish border in the Bay of Biscay. Along this period (1991–2016), some methodological changes have occurred. From 1998 onwards, acoustic records were restricted to daytime hours. Besides, in 1997, the RV *Cornide de Saavedra* was replaced by RV *Thalassa*, which was also substituted in 2013 by the RV *Miguel Oliver*. An intercalibration exercise between both vessels was conducted in spring 2014 in French waters around the Garonne area. Intra-ship variability of both echointegrated energy and fish proportion and length distributions obtained from the fishing stations were of the same order as the inter-ship ones (Carrera, 2014) and, therefore, no correction in the survey abundance indices obtained from this time-series was needed.

Survey methods and data analysis are described in Doray *et al.* (2021). The surveyed area follows along a systematic parallel grid with random start, with transects equally spaced each 8 nautical miles and normal to the shoreline (Figure 5.2.2.2.1). Echograms are recorded using several frequencies (18, 38, 70, 120 and 200 kHz), allowing a direct allocation of echotraces to fish species by analysing the frequency response, the school parameters, the area and the catch species composition obtained at the fishing stations as well as other ancillary variables (e.g. egg counts from CUFES). When direct allocation is not possible, echointegrated energy is split into fish species using as ground-truth of the pelagic fish community, the catch species proportion by length class obtained at the fishing stations by applying the Nakken and Dommasnes method (Nakken and Dommasnes, 1975). On a regular basis, several fishing stations are used to characterize a particular echotype (i.e. a set of similar echotraces recorded on a given area), although the nearest haul was also used as a proxy of the fish community close to a particular mile. No additional weights are used but the relative fish proportion by length (i.e. neither the surrounding energy, nor the absolute level of fish number by species).

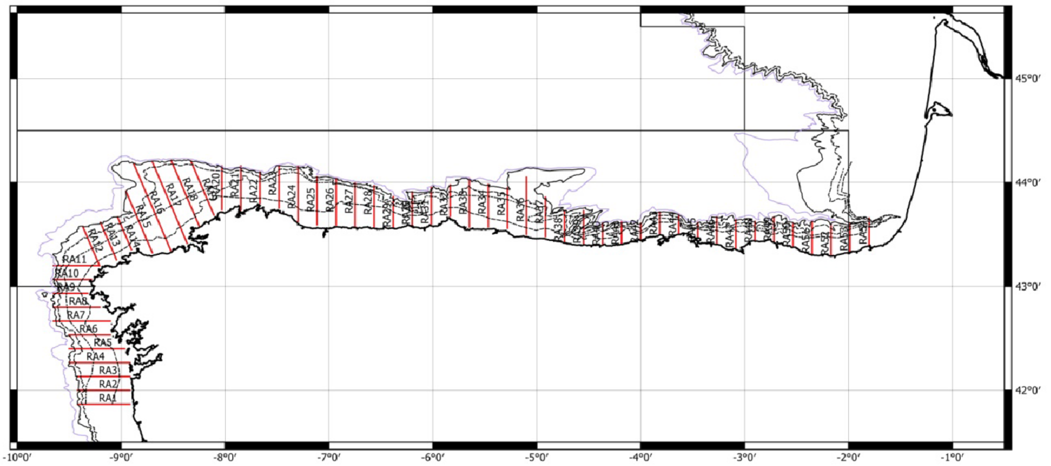

Figure 5.2.2.2.1: ane.27.9a Western stock. Acoustic transects sampled during the *PELACUS* acoustic survey.

This Spanish Spring acoustic survey series is the only one that annually samples in Subdivision 9a N. This series provides the size and age composition (LFD) of the estimated anchovy population in numbers and biomass in 9a N since 2008.

5.2.2.3 SAR (autumn)/JUVESAR survey series (Portuguese Autumn acoustic survey in 9a C-N) and IBERAS survey series (Spanish Autumn acoustic survey in 9a N, C-N, C-S)

The *SAR* autumn acoustic survey series aimed to cover the sardine early spawning and recruitment season in Division 9a, but also cover the anchovy recruitment season. This survey started in 1984 but does not have temporal continuity (e.g. from 1984 to 2008 with gaps in 1988–1991 and 1993–1996) This series re-started again from 2013 onwards as the *JUVESAR* survey series. The spatial coverage was not always the same (the *SAR* series covered the same survey area as *PELAGO*, and *JUVESAR* now only covering the shallower waters of Subdivision 9a C-N, from 24 to 60 m depth, the main recruitment area for sardine in Portuguese waters).

The *SAR* autumn series has provided anchovy acoustic estimates from 1998 to 2008, but these estimates are not age-structured. In the case of *JUVESAR* surveys, the scarce presence and abundance of anchovy in the 2013 and 2014 surveys prevented it from providing any acoustic estimate for the species. Population estimates are provided without a measure of dispersion.

From 2018 onwards, the surveyed area of the *JUVESAR* survey was extended to the whole Iberian western coast, including Sub-divisions 9aN, 9aCN and 9aCS (IBERAS survey series) in a survey conducted by the IEO in collaboration with IPMA. Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray *et al.*, 2021).

5.3 Survey consistency

The consistency of the spring acoustic adult surveys used to derive the current survey index used in the assessment (PELACUS and PELACUS) and the consistency with the recruitment survey series (JUVESAR/IBERAS), carried out in the western Iberian coast during autumn for the estimation of sardine and anchovy juveniles was investigated during the benchmark (details in Garrido et al. WD survey consistency 2024).

5.3.1 Intra-survey consistency

Results show that there is low intra survey consistency for the spring acoustic surveys PELACUS and PELAGO but, when considering the survey index (abundance of anchovy resulting from the combination of both PELACUS and PELAGO acoustic surveys), there was a significant correlation between Age 2 and 3 (Fig. 5.3.1.1).

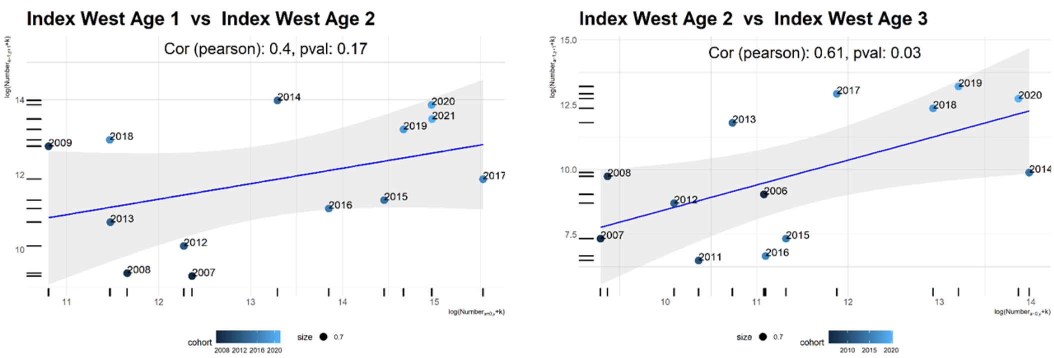

Figure 5.3.1.1: ane.27.9a Western stock. Combined PELACUS 9aN + PELAGO 9aCN and 9aCS spring survey series. Correlation of consecutive ages (age x in year n with age x+1 in year n+1) for Age 0 and Age 1, left panel and Age 1 and Age 2, right panel.

5.3.2 Inter-survey consistency

The JUVESAR survey series was conducted by IPMA during the autumn in the part of western Iberia considered to be a recruitment hotspot for both species in this coast (9aCN and part of 9aCS). This survey has been recently expanded (JUVESAR/IBERAS from 2018) to the entire western coast (9a N, 9aCN and 9aCS). No significant correlation of recruitment surveys and spring acoustic surveys was found for the western component (Fig 5.3.2.1).

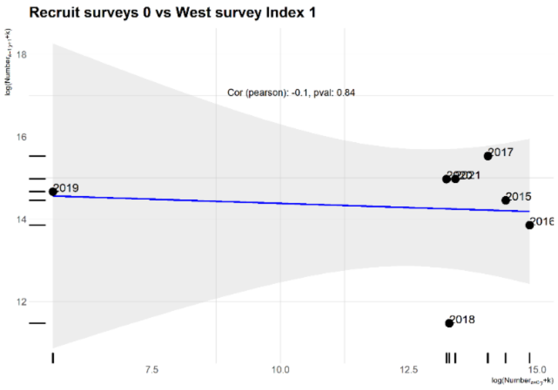

Figure 5.3.2.1: ane.27.9a Western stock. Correlation of anchovy abundance of at Age 0 for juvenile surveys (JUVESAR and IBERAS) and Age 1 in the stock index (PELACUS+PELAGO spring acoustic surveys) the following year.

Moreover, peak abundance years tracked by both the spring and recruitment surveys mainly correspond for fish of Age 1 or older, and frequently the size distribution of the recruitment survey overlaps that of the acoustic survey, failing to catch recruits (Fig. 5.3.2.2). The lack of Age 0 fish in the recruitment survey suggests that the area covered by the survey is failing to cover the total distribution of juveniles, that might be spread further offshore or possibly to the north, in the Cantabrian Sea, which should be further investigated.

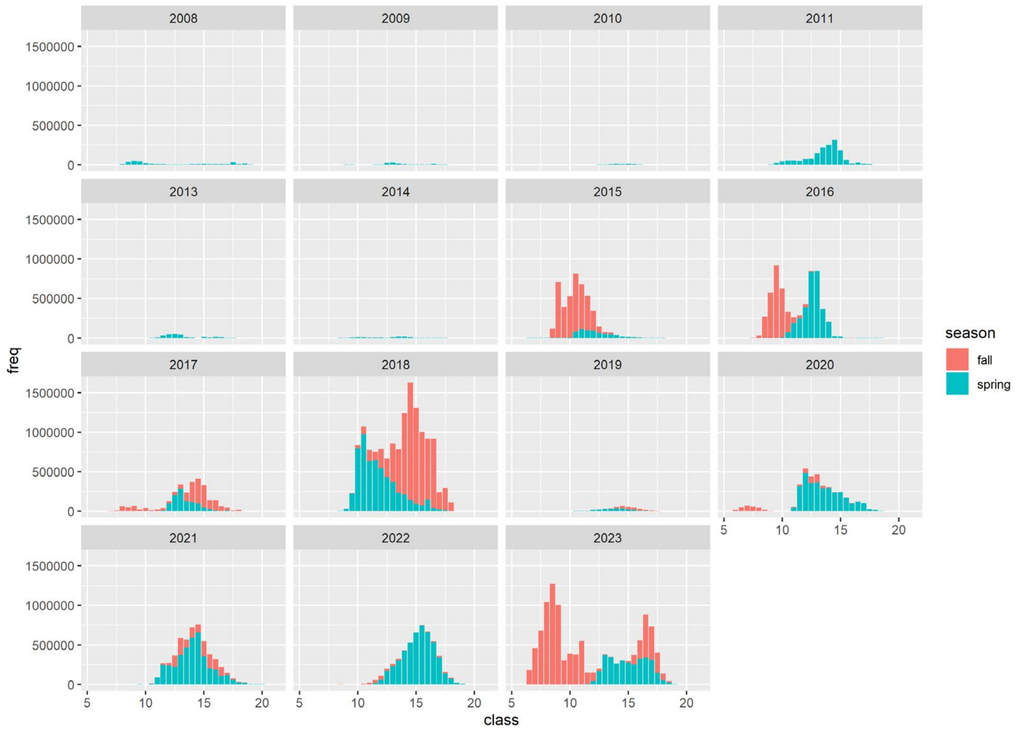

Fig. 5.3.2.2: ane.27.9a Western stock. Size frequency distribution of anchovy estimated in the recruitment surveys (JUVESAR and IBERAS, in orange) and in the spring acoustic surveys (PELACUS+PELAGO, in blue).

5.4 Stock assessment

5.4.1 Input data for the assessment

Anchovy in Subdivision 9a West consists mostly of 1 and 2 year-olds in both the population and the catches. Moreover, there is only a time-series of the composition by length and age of the catches since 2017, mostly because this population (and catches) only increased in abundance during the last decade. For these reasons, this population was considered by WKPELA 2018 as a category 3 stock (ICES, 2018).

The anchovy biomass indicator (*I*) for the stock is computed in this interim procedure as the sum of *PELACUS* (9a N) and *PELAGO* (9a C-N and 9a C-S) acoustic estimates. Total catches from the western area were also used during the first year.

5.4.2 Model used of basis of the advice

The timing of the advice for anchovy in Subdivision 9a West should be made available in-year (during the assessment WG in late June in year *y*), after the *PELACUS* (April) and *PELAGO* (May–June) surveys estimates are available. Therefore, the trend-based assessment includes acoustic data up to year *y*. The catch advice is framed in a management calendar set from 1st July (*y*) to the following 30th June (*y+1*), instead of calendar years.

As starting catch for C_{y-1} , catches landed during the period July 2017 to June 2018 (for an in-year advice based on a management calendar lasting from July in the year *y* to June in the year *y+1*) were considered. It implied having an approximate value of the catches for the first half in 2018, since the exact total number were not available at the time the WGHANSA meets (last week of June). From then onwards, the catch advice of the former management period was used as the starting catch until 2023 when the chr HCR was adopted.

During WKBANSP, no modification to the assessment method for anchovy in Subdivision 9a West was conducted. The assessment in place follows the stock-specific MSE work (ICES, 2023) and considers the high sensitivity of the CHR advice rule to the value of the catchability of the survey index (which is very uncertain). Since 2023, the advice for anchovy in Subdivision 9a West is based on a CHR with a HRmsy.proxy = 0.25 applied to the most recent survey-based biomass index derived by the combination of the PELACUS and PELAGO survey in areas 9aN, 9aCN and 9aCS. Advice is applied in the current seasonal management calendar (July to June). In addition, a biomass safeguard factor based on Itrigger = Iminpa = 1.64 * min(Ihist) = 2017 tonnes is considered.

5.4.3 Biological reference points

Reference points were estimated assuming that 70% of the catches occurred in the second semester. The limit biomass (B_{lim}) was set as 20% of the virgin biomass B0 (Smith et al., 2009). A proxy for F_{MSY} ($F_{MSYproxy}$) was based on $F_{40\% B0}$ (Punt et al., 2014), i.e., the fishing mortality rate associated with a biomass of 40% B0 at equilibrium.

5.5 Future considerations/recommendations

The results presented to the Benchmark were considered enough to support the separation of the 9a west and 9a south anchovy stock components, but the stock limits to the north deserve more exploration. The results from stock identity work show a likely connectivity of the 9a west stock with the anchovy stock in the Bay of Biscay (Subarea 8). In agreement with the recommendation of the SIMWG, a more comprehensive and holistic stock identification programme should be implemented to address the stock structure of anchovy, in particular the connectivity of western Iberian populations with anchovy in Subarea 8.

5.6 References

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5.7 Stock-specific working documents

- Garrido S, Naiara Rodríguez-Ezpeleta, Natalia Díaz, Ana Machado, Tatsuya Sakamoto, Fernando Ramos, Margarita Rincón, Ana Moreno, M Paz Jiménez, Maria Santos, Pablo Carrera, Silvia Rodri-guez-Climent, Diana Feijó, Leire Ibabarriaga, Leire Citores, Guillermo Boyra, Erwan Duhamel (2024) Population structure of the European Anchovy (Engraulis Encrasicolus) In ICES Division 9a. Working document presented to the ICES Stock Identification Methods Working Group (SIMWG) and ICES Benchmark workshop on anchovy species (WKBANSP).
- Susana Garrido, Laura Wise, Margarita Rincón, Fernando Ramos, Pablo Carrera, Ana Moreno. Investigation of consistency of acoustic surveys targeting anchovy off Western Iberia (JUVESAR/IBERAS, PELACUS, PELAGO). Working document presented to the: ICES Workshop on Anchovy stocks (WKBANSP). 23-27 September 2024.

6 Reviewer Report for WKBANSP

This report provides an independent scientific peer review of anchovy stocks presented during the 2024 benchmark meetings.

The data evaluation workshop was held remotely on 5-7 March 2024 and the assessment methods workshop was hosted by IFREMER in Nantes, France, during 23-27 September 2024 with a hybrid option available for remote participants. Two interim meetings were held remotely on 25 June and 10 September. At these interim meetings, the assessment teams provided updates and additional information on input data, assumptions, and modelling progress. There were two meetings after the assessment method workshop on 3 and 14 October to finalize the assessment models and reference points. Some decisions were taken by e-mail correspondence.

6.1 External chair's comments

The ICES chair led each of the meetings and maintained a flexible agenda to provide ample opportunity for the reviewers to ask clarifying questions, make recommendations, and for the assessment teams to complete modeling work. Unfortunately, an error was discovered in the seasonal application of the SS3 model the week prior to the assessment methods meeting that required development of a new executable by the SS3 developer. As such, data and stock identification issues were discussed at the beginning of the week to provide additional time for the modelers to complete their analyses.

Two stocks were assessed as part of this benchmark: anchovy in subarea 8 (Bay of Biscay) and anchovy in Division 9.a (Atlantic Iberian waters). Anchovy in Division 9.a. is currently composed of two substocks: the western (9.aW) and southern (9.aS). To date, these two substocks have been assessed separately with differing methods, but advice provided jointly with one advice sheet. The Stock Identification Methods Working Group (SIMWG) recently reviewed evidence for separation of the western and southern components in Division 9.a into two separate stocks. The SIMWG concluded that while there was likely population structure within the Division 9.a stock area, it is not appropriate to establish a separate stock for the western component due to its potential connectivity with the area 8 stock. Within this benchmark assessment, the body of evidence for the separation of 9a.W and 9a.S into separate stocks as well as the conclusions of the SIMWG were further examined. The reviewers and external chair unanimously supported the recommendation of the WKBANSP benchmark group that 9a.W (Western Iberian waters) and 9a.S (Gulf of Cadiz) should be assessed separately and two distinct advice sheets should be produced, given the SIMWG's conclusion that the 9a.W component could not be classified as a separate stock not due to potential connectivity with 9a.S but instead due to potential connectivity with Subarea 8.

Numerous data and modelling assumptions were explored over the course of model development and substantial improvements were made through the development of Stock Synthesis models for the subarea 8 and Division 9a.S stocks. Strong retrospective patterning and residual patterning were apparent in many of the explored runs, and power functions in catchability, random walks in catchability, selectivity blocking and random walks in selectivity were examined to improve model diagnostics. State-space models, such as SAM or WHAM, may be able to more fully account for changes in catchability and selectivity due to the ability to include random effects and account for both process and observation errors in model development. Furthermore, state-space models could also account for the potential connectivity between the stocks through the estimation of survival deviations that could serve as a proxy for immigration and emigration.

Accordingly, it is recommended that state-space models be explored in future benchmark assessments.

For this benchmark, the review panel unanimously supported the final analytical models developed for subarea 8 and 9.aS and recommended that they be implemented as category 1 assessments.

6.2 Reviewer feedback by issue and substock

6.2.1 Separation of western and southern components of Division 9a stock

- The review on scientific studies regarding the stock identity of anchovy within Division 9a prepared for this Benchmark (and for examination of SIMWG) was extensive and systematic, covering most relevant biological and population issues affecting the definition of stocks by regions: covering populations distribution throughout the year (from surveys) and from the fishery, population dynamics in terms of age structure, historical perspectives of the survey index and catches, population life history traits (mean weights and length at age), connectivity (correlations between cohorts and areas, larval dispersal, etc), morphometrics, stable isotope analysis as well as genetics.
- The reviewers endorse the conclusion of WKBANSP group for a separation of the populations inhabiting Division 9a into two stocks, one in 9a South and the other in the western areas of division 9a (9aN, 9a CN, 9aCs), acknowledging at the same time that the connectivity of these two stocks with their respective northern and southern regions needs further research.
- Therefore, further research on the connectivity between the stock population in 9a West (9aN, 9a CN, 9aCs) with the northern anchovy populations (in the Division 8c and with the entire stock in subarea 8) should be considered to better understand the implications it may have on the shelf sustainability of the ressource in the western areas of 9a and for management. Similarly, and with the same purpose, further research on the connectivity between the stock in 9a South with the populations inhabiting the Atlantic Morocco region should be carried out as well. These points should be added to the issue list for these anchovy stocks to be considered for future benchmarks.
- The reviewers understand that the SIMWG analysis concluded that there was insufficient evidence to conclude that anchovy in 9aW and 9aS were two distinct stocks, after examining the supporting evidence of every particular item provided in the WD by Garrido et al. 2024. The reviewers along with WKBANSP group agree that a holistic consideration of the analysis conducted in the stock ID WD points to two independent stocks: 9.a West and 9.a South, beyond the debatable substantive power of some particular issues included in the WD when looked in isolation.

6.2.2 Anchovy in Division 9a South

General conclusions

The stock assessment of anchovy 9a South presented to the working group makes appropriate use of available data sources, and assumptions were well founded and represent the best available science. It provides an improvement over previous modelling approaches with Gadget. Even though the issue of large surveys' catchability estimates remains, the current assessment increases substantially the absolute levels of biomass compared with Gadget. The calculation of biological reference points followed ICES guidelines and provided reasonable results which should be used for providing advice on the management of the stock. An MSE to assess what maximum fishing mortality can be applied (Fcap), to ensure that in the long-term the risk of falling below Blim is <0.05, should be conducted as soon as possible.

Background

Prior to this benchmark, this stock was assessed with Gadget using length- and age information, though it was ultimately decided that GADGET was only indicative of trends. The assessment team decided to move toward Stock Synthesis (SS3), which is an integrated statistical catch at age model. For comparison and as a back-up solution, runs were also done in Gadget and SPiCT using the same input data (including length data for Gadget), however, no finetuning took place.

Data and first model setup

The assessment model was fit to updated data previously used in the Gadget model excluding length data. Data inputs to the model included: 1) quarterly commercial fishery removals, 2) three acoustic surveys, one for recruits (juveniles) and two for adults, 3) a Daily Egg Production method (DEPM) survey on adults, 4) time-varying weight-at-age data by quarters. For the initial runs, natural mortality was estimated based on growth estimates, using Gislanson's method to set the natural mortality at age 0 (M=2.97), however M on ages 1-3+ were fixed equal among them to the average value across several M-estimator methods (M1+=1.33). For the age composition of surveys and of the fishery, the selectivities were modelled following logistic functions constant in time. The commercial fishery was initially parameterized as a single fleet running over quarters (with a random walk); however, it was reparameterized as four distinct fleets (one for each quarter), each having their respective modelled selectivity, to improve model diagnostics. All surveys are assumed to be relative indices of abundance, with catchability modelled using a simple q linear model. No time blocks for the estimation of catchability or selectivity were adopted for the initial runs.

Model diagnostics, fitting to data and steps in redefining the model

The first run was characterized by some high abnormal residuals of the acoustic Ecocadiz survey, particularly for age 0 in the last years of the series, and by an assessment with acceptable retrospective pattern but high hindcasting Mhon's rho value (0.42 for SSB and -0.26 for F), and high catchability values for the surveys (between 3 and 8). This led to a long discussion of how to best deal with the high catchability among the surveys and further sensitivity runs were suggested to the assessment team. The initial high catchability of surveys estimates was a matter of concern because:

- In addition, Anchovy in Division 9a South has four independent surveys (3 acoustics and 1 DEPM) which are usually taken as surveys with Q=1 (as for instance with

Northsea herring, Baltic sprat, Californian sardine and anchovy) and when estimated they usually result in Q values around 1 (as for the Bay of Biscay anchovy). Therefore, estimating catchabilities for four of these surveys at high Q levels should be carefully justified.

- There may be strong implications for management: high Qs lead to very high Fs and the sustainability of the fishery itself would be questioned without a clear basis for accepting those high catchability values for these surveys.

The following points for improving the assessment were discussed in plenary and examined in detail by the stock assessors. The final decisions were unanimously supported by the whole group:

- Selectivity of the commercial fleets and the surveys:
  - Four fleets were modelled, each for the four quarters of the year. This allowed having different selectivity patterns at age by quarters and improved the overall fitting to the age proportions of the catch.
  - For the final proposed run, the selectivity of the ECOCADIZ survey was blocked into two periods (2004 to 2014 and 2015 to 2023) due to a noticeable change in age composition between these two periods, characterized by weak versus strong occurrence of age 0 in the survey, respectively. There was evidence that changes in the timing of the survey from June to July could have triggered such a change in the availability of age 0 individuals. Even though the timing of the survey was changed in 2010, it was not until 2015 that the occurrence of age 0 became substantial. These selectivity blocks allowed a better fitting to the mean age of the ECOCADIZ age composition over the first time period (before 2015) and improved the fit of the overall age composition and survey index observations.
  - A logistic function for the EcoCadiz Reclutas was judged to be inadequate because the survey targets juveniles and is considered a recruitment index. Initial sensitivity analyses indicated an optimal selectivity was found by fixing age 1 selectivity to 1 and estimating the selectivity for the other ages. For simplicity, the final run retained only the information on age 0 recruits from EcoCadizReclutas and was used solely as a recruitment index (with a vector of age 0 estimates being used as the input for the assessment from this survey).
  - All other selectivities (of the quarterly fisheries and surveys) were defined as logistic functions fixed over time.

- Weight-at-age: As the weight-at-age did not show a trend over time, the reviewers asked the stock assessor to complete a sensitivity analysis assuming time-invariant weight-at-age by quarter to avoid potentially adding noise that could be a survey artifact. This did not have a strong impact on the overall assessment (just some slightly better diagnostics but very similar outputs); therefore, it was concluded that time-varying weights at age should be used to enable possible future trends to be picked up by the model. In order to account for both fixed and random variability in the data, for each quarter and each subset, a linear mixed-effect model was fitted, with log-transformed weight as the dependent variable and age as the fixed effect. These modelled values were used as the input observations

None of the changes above led to a major revision of the catchability estimates by surveys. More options about natural mortality and cathability were explored:

- Natural mortality: The level of natural mortality for each age class was discussed, and the sensitivity to the assumed structure was tested based on a number of sensitivity runs to determine the appropriate values for M. As natural mortality is known to increase with age for some short lived-species due to senescence (see Uriarte et al., 2016 describing this for anchovy in 8), the reviewers suggested sensitivity runs assuming higher natural mortality of the ages 2 and 3+ compared to age 1. Two exercises were carried out:
    - Natural mortality was fixed at 1.33 for age 1 and estimated for M2+ (ages 2 and 3+). For this exercise the fishery selectivity for ages 0, 1 and 3+ were taken as parameters while fixing sel.age2=1. In addition, EcoCadiz Reclutas was still being input with all age classes and as a logistic selectivity function. It was found that M2+=2.46. Fixing M2+ to this value (regardless of final fishery selectivity model) improved all components of the likelihood function and led to an upward revision of assessed biomass and a reduction of catchability of the surveys (to 2 and 2.5 for PELAGO and ECOCADIZ and to about 4.5 for DEPM BOCADEVA).
    - A further two-phase exercise in search of the optimal Natural Mortality at age pattern was also completed to determine a preferred U-shape mortality pattern. This exercise departed from the case where EcoCadiz Reclutas was treated only as a recruitment index (with a vector of age 0 estimates): First, a range of NatMortality at age 1 values were used to profile the likelihood (conditional to the M0= 2.97) while allowing natural mortality for ages 2 and 3+ to be estimated and, next ,a range of values for NatMort at ages 2+ was used to make a likelihood profile conditional to the M0 and to the optimal estimate for M1 from the former exercise). This joint two-phase exercise resulted in the following optimal M pattern at age: M1=1.6 / M2=2.48 / M3+=2.48
    - After inspecting the former likelihood profile where the natural mortality was varied for ages 2 and 3 (conditional to the optimal M1), the reviewers agreed that the proposed U-shaped M vector at age, which was lowest at age 1 and increased with older ages, appeared to be a sensible setting. The configuration led to an improvement of all components of the likelihood function, an upward revision of assessed Biomass, and a reduction of catchability of the surveys (to around 1.9 and 2.2 for PELAGO and ECOCADIZ and to about 4 for DEPM BOCADEVA, while resulting in a Q=1 for EcoCadizReclutas). However, those catchabilities still would change as a result of the further revisions concerning SigmaR and equilibrium catches for the initial population

- Recruitment was modeled as deviations from a Beverton and Holt SRR, by assuming a steepness of 0.8 and a SigmaR = 0.3. The presumed value for steepness is very close to the value given for the pacific Saury (of 0.82) by Hsu et al. 2024 and to the values given by Thorson 2020 for cupleiformes of around 0.75 (CV=0.23). Because presuming steepness (h) is debatable (as it determines the productivity / resilience of the assessed population), a further analysis on this assumption was completed A likelihood profile on h showed that from the age data the optimal h was about 0.55 but that the index data pointed towards a value of approximately 0.9. The overall likelihood optimal value was 0.6 but with little change between 0.5 to 0.8. The group agreed that from the time series of estimated recruitment, little evidence could be obtained about the actual value of steepness and that the assumed value (h=0.8) was consistent with the literature and visually compatible with the estimated recruitment series. As such, h=0.8 was adopted for this assessment. Regarding Sigma R, the value adopted was the one suggested by SS3 iteratively after rerunning the model several times

The group unanimously supported the final model run. This included: Four fishing fleets (one by quarter), modelled by logistic selectivity functions fixed over time, two blocks for the ECOCADIZ selectivity at age (2004-2014 and 2015-2023), the final natural mortality vector at age, surveys treated as relative indices of abundance (with linear catchability models) and fitted with logistic selectivity, and effective sample size for the age compositions initially set at 100 but iteratively adjusted using the Francis method. Recruits were modelled as deviations from a fitted Beverton and Holt function with an assumed steepness of 0.8. The model achieved a successful convergence, residuals passed runs tests (except for mean age of PELAGO) and no major abnormal high residuals appeared either for the survey indices or for the fishery age compositions, although discrepancies for the mean age composition in 2020 appeared for the fishery in the first two quarters, probably due to the filling of missing information (due to the COVID situation). Additionally, the mean age deviations for PELAGO and ECOCADIZ surveys in 2023 showed opposite signals meaning that there were some contradictory signals between surveys. The catchability for the surveys were still rather high, staying to around 3.2 for PELAGO, 2.4 for ECOCADIZ, and 4.4 for DEPM BOCADEVA, whilst it was around 0.75 for the recruitment index ECOCADIZRECLUTAS. These high catchability values should be further explored in future assessments as it is still a matter of concern.

The retrospective pattern did not exceed the bounds of the acceptable ranges suggested by Hurtado-Ferro et al. 2015 for small pelagic fish (acceptable range of Monh’s rho between -0.22 to 0.3). The larger retrospective pattern in SSB and F for the year 2020 could be due to reduced sampling coverage in the commercial fishery in that year (Covid). Generally, the retros are well within the limits (-0.11 for SSB and 0.26 for F).

Overall, the model achieved acceptable fitting and retrospective patterns, scaling upward the spawning stock biomasses in comparison with the initial SS runs and previous assessments with Gadget. The catchability for the surveys are still rather high and demanded further analysis and a final discussion within the group. Priors on survey catchability were tested in several sensitivity runs but ultimately were not adopted and not approved by the reviewers, mainly due to different opinions on the suitability of setting priors on the catchability of surveys and to a lack of time to properly explore those alternative runs further. This should be considered for future work. The final reference run passed all diagnostic tests (jittering and retros).

Biological reference points

The calculation of biological reference points followed ICES guidelines. The reference points were calculated following the guidelines for Type 6 stocks where the range of biomasses explored in the assessment was considered narrow. Thus, Bloss was taken as Bpa, instead of Blim. This assumption was made because it was noticed that if adopting the guidelines for stocks type 5 (which asks for setting Blim=Bloss), it would have implied Blim = 40%B0. Such a Blim would have been too large a fraction of B0, without any evidence of impaired recruitment over the biomass range estimated by the assessment. Therefore Blim was inferred from Bpa using the standard formula Blim = Bpa * exp(-1.645 * SigmaB), where sigmaB was taken at 0.2 (as a compromise between the default value for SPF of 0.3 and the reported value for SigmaB in the last year of the assessment, 0.1). Such SigmaB =0.2 also equals the default value suggested for most fish species in the ICES guidelines (ICES 2021) when no direct estimate of SigmaB is available from the assessment. There are no F reference points estimated for short-lived species.

Short-term projections

The short-term forecast followed the ICES guidelines and was approved by the group. The reviewers asked the stock assessment team to additionally report the SSB of the following year under the same F multiplier, and its risk to Blim under given recruitment assumptions.

Recommendations

- Further work on the potential improvements arising from setting priors to survey's catchability could be carried out in the future.
- Examine if revising the DEPM time series, i.e. including a robust estimator of egg mortality (see Citores et al., 2024), leads to an improvement of the fitting of the entire series and the overall fitting on the assessment.
- Further, an MSE should be completed as soon as possible to define Fcap that would ensure a risk below 0.05 to be below Blim in the long term to complement the basis for the catch projections (preferably before WGHANSA).

6.2.3 Anchovy in Division 9a West (Atlantic Iberian waters)

General conclusions

The assessment method of Anchovy 9a West was inter-benchmarked in 2023 and not part of this benchmark. We commented on the stock identification issue above. For the benchmark report see ICES, 2023.

6.2.4 Anchovy in Subarea 8 (Bay of Biscay)

General conclusions

The stock assessment of anchovy 8 presented to the working group makes appropriate use of available data sources and assumptions were well founded and represent the best available science. It provides an improvement over previous modelling approaches with CBBM. The calculation of biological reference points followed ICES guidelines and provided reasonable results which should be used for providing advice on the management of the stock. The short-term forecast was not finalized during the benchmark and the discussion was postponed to WGHANSA. The performance of the Harvest Control Rule currently applied to this fishery should be re-evaluated in the near future.

Background

Prior to this benchmark, the stock was assessed using a Bayesian two-stage biomass-based model (CBBM) (Ibaibarriaga et al. 2011) that relied on biomass estimates. The previously used CBBM was based on survey data and fishery inputs with age structure focused on ages 1 and 2+. It operated on a half-year time step.
The assessment team decided to move toward Stock Synthesis (SS3), which is an integrated statistical catch at age model, for the reasons of faster running speed (CBBM took some hours to finalize), and the wider scientific community working on this framework. SS3 also offers a large flexibility for modelling the stock and the fishery, and it can deal with larger age structures, ranging now from age 0 to a plus group at age 3 and older (age 3+).

One notable difference between the models is that CBBM operates in terms of biomass, while SS3 uses numbers. This shift in the modeling approach implied some changes in parametrization and in the data inputs. Comparisons were made between SS3 and CBBM outputs using the same input data until 2023 and it was considered as a backup solution for the assessment.

Data

The input data are on a semester level. Spawning is set to take place on the 15th of May, and recruitment settlement occurs on the 1st of July. The assessment model was fit to updated data previously used in the CBBM model using abundance data. Data inputs to the model included: 1) semiannual commercial fishery data (modelled as independent fleets by semester), 2) two acoustic surveys (PELGAS on adults and JUVENA on recruits), 3) one daily egg production method spring survey (BIOMAN), 4) time-varying weight-at-age data. A decreasing trend in weight at age across all ages both in surveys and commercial samples was apparent (e.g. Doray et al. 2018, Taboada et al. 2024). Previously used natural mortality rates were provisionally adopted for the initial runs with M1=0.8 and M2+=1.2. Age 0 natural mortality was set at M0=2.17 coming from Gislason (relative to M1 at 0.8). It was discussed within the group that there was no evidence of temporal trends in natural mortality and thus it was not considered necessary to undertake a sensitivity run with time-varying M. The JUVENA survey index was slightly revised, leading to minor changes in the index trend that had a negligible influence on SSB and F trends. The standard deviations reported for the surveys were taken as input (JUVENA –presumed 0.25, BIOMAN and PELGAS reported estimates). An additional SD was estimated for the surveys which is a procedure endorsed by the Reviewers as a common practice in this assessment model. The first runs were based on single blocks of survey catchability and availability (constant across ages 1 and older), and of the fisheries selectivity.

Model diagnostics and fit to data

The first runs resulted in residuals patterns of the mean age of acoustic PELGAS survey and of the BIOMAN index residuals, uncertainty of biomass estimates increased over the most recent years of the assessment and trends in biomass diverged from those estimated by the former CBBM model (by not showing a major increase since 2010). This led to exploring alternative models of the surveys' catchability, of the fishery selectivity and of natural mortality.

- **Catchability of the DEPM survey (BIOMAN)**: A strong residual pattern of the BIOMAN (DEPM) survey is reflected in a failure of the run test on residuals in the reference run and all other sensitivity runs carried out during the benchmark. No credible explanation was found for such residual pattern: The survey has been conducted with the same methodology since the beginning of the series, with an adaptive sampling to cover most of the spawning area which led the survey in the last decade to cover wider areas than at the beginning of the series. Globally the tendency in biomass recorded by the acoustic and the DEPM spring surveys are consistent. The potential for shift in time on the fraction of the entire biomass being covered by this survey was also considered, including examination of other concomitant surveys in spring (as PELACUS acoustic survey throughout the 8c subidvision) without finding a convincing reason for it. Finally, taking a power function for the catchability model of this survey was considered, however it was rejected by the group, including the reviewers, adopting instead the simpler linear catchability model. A power function for catchability was not recommended because of the lack of a mechanism which might explain such power behaviour, and because the survey was set up directly for the purpose of estimating anchovy biomass and has been carried out with a consistent methodology since the beginning of the time series.

- **Selectivity of the spring acoustic survey PELGAS targeting adults:** Sensitivity tests allowing selectivity at age to change overtime (two blocks, prior and post 2007) revealed that selectivity of age 1 was smaller before 2007 (=0.74) and reached full selectivity (=1) afterwards. Such testing was carried out given the failure of the run test on the mean age of the survey and to take into account that beginning in 2007, the survey was completed with accompanying commercial fishing boats which provided supplementary fishing hauls throughout the survey.

- **Catchability of acoustic survey JUVENA targeting juveniles:** The power function that was introduced in previous ICES assessments was removed as the new added stock-recruitment observations indicated high recruitment at moderate index values. Thus, the power function was very close to a linear model with the confidence intervals of the power parameter showing an insignificant difference from 0. This was discussed at length in the group but the decision was taken in agreement by the whole group following the reasoning above.

- **Natural mortality:** Significant discussion arose around the choice of M which was based on sensitivity runs conducted, scientific evidence and previous assessments. The initial run was based on the natural mortality values adopted in the previous benchmark: M1=0.8 and M2=M3=1.2. However, expanding the model up to age 3+ required an estimate of the natural mortality for age 3, not necessarily equal to M2. Uriarte et al. 2016 showed that Natural mortality for this anchovy population seemed to increase with age, assuming the two spring surveys on adults (Bioman and Pelgas) were unbiased in observing relative abundances by age. Actually, allowing the assessment to estimate the survey availability at age 3 and / or fishery selectivity at age 3 resulted in values consistently lower than 1, which could also be related to M at age 3 being bigger than at age 2. Using SS3 to estimate of M2+ conditional to M1=0.8 resulted in M2+=1.54. Alternatively, estimates of M3+ conditional to M1=0.8 and M2= 1.2 resulted in M3+ around 2.37-2.5. Both exercises resulted in a better fit in terms of AIC versus the original setting of the model, but with very similar values of the likelihood function between them. The second M vector by age could be preferred because there is quite firm evidence that age 3+ almost disappears from both the surveys and the fishery. For consistency with the U-shape resulting from the study of Uriarte et al. 2016 and with the former practice in the assessment of this population, the second vector of M at age was adopted. A final additional analysis was made based on a likelihood profile for M2 conditional to M1=0.8 and allowing estimation of M3+ simultaneously. Such exercise pointed towards a M2 around 0.9 but with a rather wide range of very similar likelihood values between 0.5 and 1.2. The group decided to stay at the M vector at age M0=2.17 M1=0.8, M2=1.2, M3=2.5 (finally 2.37), because it keeps the idea of a U-shape mortality (as suggested in Uriarte et al. 2016) and is still very close to the optimum. There is also a strong negative correlation between M2 and M3+ (so there is a single parameter for both compensating one another), so every option will show a very similar fitting. Reviewers endorsed the analysis and the decisions taken to fix the M at age vector.

- **Selectivity of the fisheries:** An analysis allowing a random walk-in fishery selectivity showed that particularly for the fishery in the second half of the year, there was a decrease in age-1 selectivity in recent years. This might be justified by the fact that the fishery during the second half of the year has changed substantially after the closure of the fishery, whereby the French fleet has gradually almost disappeared and the remaining Spanish fishery is taking place nowadays only along the North Spanish coast (implying a huge change in the center of gravity of the fleet). The fishery in the first half the year seemed to have changed less even though some changes have taken place such as fishing closer to the Spanish coast (and in western regions) than before the closure, mainly due to a higher availability of fish close to shore probably due to the higher abundance of anchovy in recent years. Therefore, allowing fishery selectivity at age to vary over time was considered reasonable, particularly prior and after the fishery closure. As such, time blocks and random walks on ages 1 and 3 fishery selectivity were considered (age 2 selectivity was fixed at 1). It was initially decided to create selectivity blocks with the second block starting in 2010, however, a random walk in selectivity was ultimately selected as the preferred parameterization because it provided more flexibility to the model to accommodate changes in selectivity.

- **Effective sample size for the fishery age composition:** Applying the Francis method as suggested in SS3 led to a decrease of the sample size for the fishery (mainly that of the 2nd half of the year) and then for the PELGAS but increased that of the DEPM. A single application of the Francis method made RMSE decrease from 60.5% to 7%. The group agreed that it was acceptable to apply a single iteration of Francis Method. Reweighting could be checked every year, but preferably should be fixed and just checked within the annual assessment routine. WGHANSA should be free to change the effective sample size if judged necessary by the group.

The run incorporating a model with natural mortality of M3+ estimated (then fixed for subsequent assessment updates), Juvena as a power function (next it was fixed to a linear function) and with two blocks for acoustics (availability at age 1) and for the fishery selectivity (being estimated for all ages except for age 2 where sel2=1) (Bioman had a single block with fixed availability at all ages1+ =1), applied with single reweighting by the Francis's method, was selected as the best one for moving forward. The models showed rather good residuals (except for the run test on Bioman), runs converged, estimated parameters seemed fine without touching the bounding values, and catchability and selectivities values seemed fine. Furthermore, overall biomass trends and absolute values were rather consistent with those resulting from the CBBM output in 2023, based on the same input data.

- Retrospective pattern: The model exhibited a strong retrospective pattern, with a Mohn's Rho of 0.56 for biomass, -0.36 for recruitment and 0.3 for F, and the group decided that these retros were not acceptable. A strong retro also occurred in last year's ICES assessment with CBBM, however in previous years those retros were not as high and were within the acceptable range suggested by Hurtado-Ferro etal. (2015) for short-lived species (-0.22 - 0.3).
- A leave-one-out exercise on the input data series revealed the retro pattern was mainly caused by the age composition of the fishery catch data. After considering several alternatives it was decided that assuming random walks in ages 1 and 3 fishery selectivity was the preferred way of being flexible without entirely losing the information in the catch-at-age composition.
- A provisional final run was based on: Random walk for fishery selectivity ages 1 and 3 type of RW 3; No blocks for PELGAS (because of convergence issues with SS3); Age 1 for Pelgas acoustic (Fleet3) is estimated (at 1); the Natural mortality estimated at age 3 was taken as input value M3+=2.2; single Francis tuning was applied. This led to a Mohn's Rho of about 0.374 for biomass, -0.40 for Recruits and about 0.226 for F. The Mohn's Rho in the current assessment year was still above the acceptable range.

It was discussed whether the stock should be moved into category 3 given the poor retros. The group rejected such possibility because:

- The past series of Rhos were always smaller and the increased retros are likely due to the input data of the most recent assessment year. Both the last year assessment based on CBBM and the current SS3 assessment shared the same input data and showed the retro pattern whereby the strongest retro deviation occurs just with the first peel (i.e., in 2023) indicating that the retro pattern is mainly driven by the last data year.
- Staying on the former model (CBBM) is not going to solve the problem. The stock assessors performed explanatory runs with the CBBM and the retro is shared by both models.
- The problem with the retros for advice does not rely on the assessment alone but on the HCR as well, which is rather resilient to errors at high biomasses.

Final improvement after the WG: Inclusion of a stock recruitment relationship for the estimation of recruitment deviations:

- A final run based on the former one but including a stock recruitment relationship within the assessment was put forward for considerations as it stabilized the assessment and improved the retros a lot, either by inclusion of a Beverthon-Holt or a Ricker SRR function. The inclusion of the SRR model within the assessment is supported in literature (Maunder and Thorson, 2019; Punt, 2023). The selection of either the Beverthon-Holt or the Ricker SRR model were left to the best fitting of the model. The Ricker model showed a slightly better fit, which might be justified by some cannibalism. Inclusion of a SRR model for recruits and a random walk-in time for the selectivities (ages 1 and 3+) of the fishery fleets (plus a two-time block for Pelgas) led to a strong reduction of the retrospective pattern, ending up to a Mohn's Rho of 0.3 for biomass.
- Yet, a matter of concern was the strong negative pattern of recruitment residuals at large SSB values, which could not be explained. It was requested to make sure that estimates of biomass and recruits in the years 1984, 85 and 86 were being excluded from the fitting of the SRR, because they are not part of the historical assessment of the fishery: Ensuring that years prior to the start of the assessment (in 1987) do not affect the fitting of the SRR parameters was pursued by setting recruitment deviations before the first data year

(1984-1986) as early recruitment deviations instead of main deviations (so they are not enforced to sum to zero). The group considered it a valid addition to the assessment, though further research on the influence of these early recruitment deviations on the fitting of the SRR parameters would be of interest during the next inter-benchmark period. The group agreed that this was a better modelling of recruits than the simpler modelling just based on deviations from a common mean recruitment (in log scales) throughout the entire series.

- A time variant bias correction for recruitment estimates was not included, contrary to what is suggested in literature (Methot and Taylor 2011), this being due to the fact that recruitment estimates are well supported by the input data all throughout the entire series, including the last year estimate for which Juvena index is available. A constant bias correction was included instead for the Recruitment deviations estimates versus the SRR (Methot and Taylor 2011).
- The new proposal based on the inclusion of the Ricker SRR achieved a successful fitting to the data and diminish the retros to acceptable values (0.289 for SSB).

Biological reference points

- The larger range of SSB and recruitments covered by the assessment can imply a change in Blim: The perspective of the relationship between the stock and recruitment changed. Also, since the last calculation of reference points, several years with rather high recruitments were added to the time series.
- Formerly Blim was based on the mean of the SSB in years 1987 and 2009 with minimum estimated biomasses which produced substantial recruitments, resulting in 21000 t (approx.). From the current assessment, these years do not represent a similar situation (for instance when compared to the median), and making the same calculation would result now in Blim of 23500 t.
- The stock assessment team explored a range of different options for Blim. The documentation was shared before and after a follow-up meeting with the group. Consensus was not reached during the follow-up meeting but by email after the meeting. First, the group considered adopting the new WKNEWREF suggestion of the lowest SSB resulting in a recruitment above the historical median recruitment (Blim = 27409 t from the SSB in 1991). The stock assessment team also tested the retrospective robustness of different Blim definitions against a pattern of growing R on SSB as might be the case of this anchovy and proved to be poor.
- Finally, in order to escape from relying on single year SSB and Recruit estimates, the stock assessors and the group agreed on setting Blim on an empirical Blim accounting for uncertainty in recruitment estimates (3 points, excluding 2009): The average of the lowest three SSBs whose confidence intervals at 95% included or were above the median recruitment (discarding the year 2009 in which the fishery was closed and recruitment was assumed to be impaired), was calculated for Blim (= 26 600 t), which is the average of 1989, 1991 and 1996. Such definition was proved to be the most robust over a retrospective assessment and resulted in values being very close to other potential definitions handled by the group (the former one based on the lowest SSB resulting in a recruitment above median (in 1991) and the cumulative recruitment quantiles method (resulting in 25900 t). The reviewer team supports this decision.

Short-term projections

The short-term forecast was, due to time issues, not set up during the benchmark and was postponed to WKHANSA. It was agreed however that the recruitment bias correction in the forecast year will be included, because the recruitment in the management year is actually an estimate of the assessment informed by the recruitment survey JUVENA and, furthermore, in this way consistency is assured also between the most recent year recruitment estimate and those needed for the forecast of the assessment until a year ahead of the management year (i.e., for the assumption on the recruitment at age 0 happening during the management year).

Recommendations

- The fixed effective sample size obtained for the surveys by the Francis iterative procedure will be kept constant for in subsequent assessments, though a regular checking of what effective sample sizes will result by surveys in future by the same procedure is to be made to verify no major changes in the relative weighting of survey age composition is happening between benchmarks.
- The drivers of the strong residual patterns in the BIOMAN survey should be further explored.
- The retrospective pattern in biomass and fishing mortality estimates should be carefully monitored in the following years, as it might not have been fully solved during the benchmark. If it becomes persistent, it may be indicative of some model mis-specification requiring further exploratory analysis.
- The negative pattern of recruitment residuals at large SSB values, coincident with the last series of the assessment, may be indicative of requiring some better SRR modeling. This might be linked to the modelling of the early biomass and recruitment series prior to the start of the main assessment period. Further analysis on these issues might be convenient to check if the assessment overall fitting and retros might be improved.
- Stochastic Catch forecast was not covered during the benchmark and would require further analysis at WGHANSA and ADG levels within ICES.
- The changes in Blim (but also some changes in natural mortality, SRR and other parameters), would require re-evaluation of the performance of the Harvest Control Rule currently applied to this fishery, in relation particularly to risks to Blim, but also to other performance indicators. As long as the recent high level of biomass is kept in the near future, inducing that the catch advice is being capped by the upper catch limit of the rule, there might be no major practical implications on applying the rule as it is (to the risks of falling below Blim). In any case the review of the performance of the rule should be addressed as soon as possible, to address the potential changes it may require to comply with the objectives of the management plan.

6.3 References

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Annex 1: List of Participants

Data Meeting, 5-7 March (online)

Name	Institute	Country (of institute)
Afra Egan	Marine Institute	Ireland
Andrés Uriarte	Independent Expert	
Fernando Ramos	Centro Oceanográfico de Cádiz (IEO, CSIC)	Spain
Guillermo Boyra	AZTI	Spain
Jeroen van der Kooij	CEFAS	UK
Kiersten Curti	NOAA	USA
Laura Wise	Portuguese Institute for the Sea and the Atmosphere-IPMA	Portugal
Leire Citores	AZTI	Spain
Leire Ibaibarriaga	AZTI	Spain
Lionel Pawlowski	IFREMER	France
Margarita Rincón Hidalgo	Centro Oceanográfico de Cádiz (IEO, CSIC)	Spain
Maria Jose Zúñiga	Centro Oceanográfico de Cádiz (IEO, CSIC)	Spain
Maria Santos	AZTI	Spain
Maxime Olmos	IFREMER	France
Natalia Diaz Arce	AZTI	Spain
Ryan Dunne	ICES	Other
Sarah Millar	ICES	Other
Stefanie Haase	Thünen Institute of Baltic Sea Fish-eries	Germany
Susana Garrido	Portuguese Institute for the Sea and the Atmosphere-IPMA	Portugal

Assessment Meeting, 23-27 September (Nantes, France and online)

Name	Institute	Country (of institute)	Participation
Afra Egan	Marine Institute	Ireland	In person
Andrés Uriarte	Independent Expert	Spain	In person
Fernando Ramos	Centro Oceanográfico de Cádiz (IEO, CSIC)	Spain	In person
Kiersten Curti	NOAA	USA	In person
Laura Wise	Portuguese Institute for the Sea and the Atmosphere-IPMA	Portugal	online
Leire Citores	AZTI	Spain	In person
Leire Ibaibarriaga	AZTI	Spain	In person
Lionel Pawlowski	IFREMER	France	In person
Margarita Rincón Hidalgo	Centro Oceanográfico de Cádiz (IEO, CSIC)	Spain	In person
Maria Jose Zúñiga	Centro Oceanográfico de Cádiz (IEO, CSIC)	Spain	In person
Amanda Perez-Perera	DG MARE	Other	Online
Sarah Millar	ICES	Other	Online
Stefanie Haase	Thünen Institute of Baltic Sea Fisheries	Germany	In person
Susana Garrido	Portuguese Institute for the Sea and the Atmosphere-IPMA	Portugal	In person

Annex 2: Resolutions

WKBANSP – Benchmark workshop on Anchovy Stocks

A **Benchmark workshop on Anchovy stock** (WKBANSP]), chaired by Afra Egan, and Kiersten Curti, and attended by invited external experts [Andres Uriarte, Stefanie Hass], will be established and meet 5-7 March, online, for the data workshop, and 23-27 September, Nantes, France for the assessment methods workshop. WKBANSP will:

a) As part of the data workshop:
   1. Consider the quality of data proposed for use in the assessment;
   2. Consider stock identity and migration issues;
   3. Make a proposal to the benchmark on the use and treatment of data for each assessment, including discards, surveys, life history, etc.
      i. Note: stakeholders are also invited to contribute data in advance of the data evaluation workshop (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality.

b) In preparation for the assessment methods workshop:
   1. Produce working documents to be reviewed during the assessment methods workshop at least 14 days prior to the meeting.

c) As part of the assessment methods workshop, agree to and thoroughly document the most appropriate, data, methods, and assumptions for:
   1. Obtaining population abundance and exploitation level estimates (conducting the stock assessment);
   2. Estimating fisheries and biomass reference points that are in line with ICES guidelines (see latest technical guidelines on reference points);
      i. Note: If additional time is needed to conduct the work and agree to reference points, an additional reference point workshop could be scheduled.
   3. Conducting the short-term forecast.

d) As part of the assessment methods workshop, a full suite of diagnostics (regarding e.g. data, retrospective behaviour, model fit, predictive power etc.) should be examined to evaluate the appropriateness of any model developed and proposed for use in generating advice.

e) If no analytical assessment method can be agreed upon, then an alternative method (the former method, or following the ICES data-limited stock approach see WKLIFE XI [1] should be put forward by the benchmark;

f) Update the stock annex; and

g) Develop recommendations for future improvements in the assessment methodology and data collection.

WKBANSP will report by 31 October 2024 for the attention of ACOM.

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[1] ICES. 2023. Eleventh Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE XI). ICES Scientific Reports. 5:21. 74 pp. https://doi.org/10.17895/ices.pub.22140260

Recurrent advice subject to benchmark	
ane.27.8	Anchovy (*Engraulis encrasicolus*) in Subarea 8 (Bay of Biscay)
ane.27.9a	Anchovy (*Engraulis encrasicolus*) in Division 9.a (Atlantic Iberian waters)

Annex 3: Working Documents

The following working documents from the benchmark assessment workshop (WKBANSP) are annexed below:

Working documents presented WKBANSP

Working documents: Anchovy in 27.9.aW (Western Iberian waters)

- Garrido S, Naiara Rodríguez-Ezpeleta, Natalia Díaz, Ana Machado, Tatsuya Sakamoto, Fernando Ramos, Margarita Rincón, Ana Moreno, M Paz Jiménez, Maria Santos, Pablo Carrera, Silvia Rodriguez-Climent, Diana Feijó, Leire Ibabarriaga, Leire Citores, Guillermo Boyra, Erwan Duhamel (2024) Population structure of the European Anchovy (*Engraulis Encrasicolus*) In ICES Division 9a. Working document presented to the ICES Stock Identification Methods Working Group (SIMWG) and ICES Benchmark workshop on anchovy species (WKBANSP).
- Susana Garrido, Laura Wise, Margarita Rincón, Fernando Ramos, Pablo Carrera, Ana Moreno. Investigation of consistency of acoustic surveys targeting anchovy off Western Iberia (JUVESAR/IBERAS, PELACUS, PELAGO). Working document presented to the: ICES Workshop on Anchovy stocks (WKBANSP). 23-27 September 2024.

Working documents: Anchovy in 27.9.aS (Gulf of Cadiz)

- Ramos et al. 2024 WD. Ane.27.9a stock (Anchovy in ICES Division 9a). Southern component (Anchovy in ICES Subdivision 9a South): Fishery, Biological and Surveys data. Data availability and trends.
- Zúñiga et al 2024 WD: Data consistency analysis of survey age-length data available for the Southern component of anchovy 9a stock
- Zúñiga et al 2024 WD: Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).
- Rincón et al 2024 WD: Growth and natural Mortality parameters estimation for anchovy 9a South, 2024
- Rincón 2024 WD: Comparison of Gadget implementations with the same data input as the age-based SS3 model plus length distributions.
- Zúñiga et al 2024 WD: **S1.0_4FLEETS** -Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)
- Zúñiga et al 2024 WD: **S1.0_InitCond_SigmaR** -Assessment for WKBANSP 2024 using age-structured data in SS3. Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).
- Zúñiga et al 2024 WD: **Scenario S1.0_InitCond_sigmaR_AdjIndexRec**: Assessment for WKBANSP 2024 using age-structured data in SS3: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)
- Zúñiga et al 2024 WD: Reference points and short-term forecast for WKBANSP 2024: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).

Working documents: Anchovy in 27.8 (Bay of Biscay)

- Santos, M., Citores, L. and Ibaibarriaga, L. Anchovy DEPM in the Bay of Biscay: BIOMAN survey 1987-2023.
- Citores, L and Ibaibarriaga, L. 2024 WD. Reference point for anchovy in the Bay of Biscay.
- Citores, L and Ibaibarriaga, L. 2024 WD. Updates on the assessment model for anchovy in the Bay of Biscay.

Working document presented to the:

ICES Workshop on Anchovy stocks (WKBANSP). 23-27 September 2024.

Investigation of consistency of acoustic surveys targeting anchovy off Western Iberia (JUVESAR/IBERAS, PELACUS, PELAGO)

By

SUSANA GARRIDO, LAURA WISE, MARGARITA RINCÓN, FERNANDO RAMOS, PABLO CARRERA, ANA MORENO

1. ABSTRACT

The present WD evaluates the consistency of the survey series conducted off the Iberian Peninsula targeting anchovy, both within-consistency and between-consistency. The goal is to analyse the consistency of the spring acoustic adult surveys used to derive the current survey index used in the assessment (PELACUS and PELACUS) and to investigate the consistency with the recruitment survey series (JUVESAR/IBERAS), carried out in the western Iberian coast during autumn, aiming at the acoustic estimation of sardine and anchovy juveniles. The JUVESAR survey was conducted by IPMA during the autumn in the part of the western Iberia considered to be a recruitment hotspot for both species in this coast (9aCN and part of 9aCS). This survey has been recently expanded (JUVESAR/IBERAS from 2018) to the entire western coast (9a N, 9aCN and 9aCS). There is low intra survey consistency for the spring acoustic surveys PELACUS, PELAGO but the survey index (abundance of anchovy resulting from the combination of both acoustic surveys) showed a significant correlation between Age 2 and 3. No significant correlation of recruitment surveys and spring acoustic surveys was found for the west component. Moreover, peak abundance years tracked by both the spring and recruitment surveys mainly correspond for fish of Age 1 or older. The lack of Age 0 fish in the recruitment survey suggests that the area covered by the survey is failing the total distribution of juveniles, that might be spread further offshore or possibly to the north, in the Cantabrian Sea, which should be further investigated.

2. INTRODUCTION

2.1. SPATIAL DISTRIBUTION OF SOUTHERN ANCHOVY STOCK

Off the Iberia, anchovy is mainly concentrated on the French shelf south of 47°N, close to the Gironde estuary (45°N) and in the Bay of Cadiz. These are recurrent high concentration areas or core habitats. Within the spatial limits of the southern Iberian anchovy stock there is one area considered as a secondary habitat at the north of Portugal (41°N), where anchovy abundance is occasionally high but where the species does not always occur (Fig. 3).

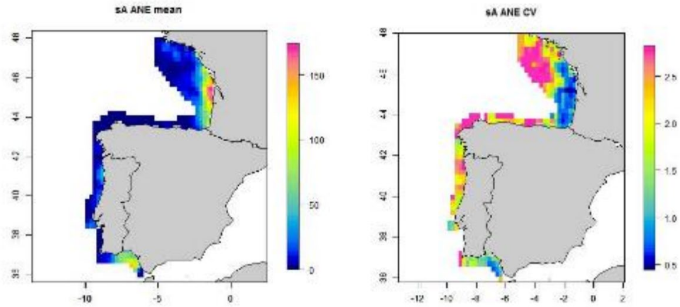

Figure 3. Distribution (gravity centres of spatial patches) of anchovy from spring acoustic surveys, time average (left) and CV (right). From the CCR document at http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/CRR%20332.pdf

2.2 ACOUSTIC SURVEYS

2.2.1 ADULT ACOUSTIC SURVEYS

2.2.1.1 PELACUS survey series

The PELACUS (PELagic ACoUStic in northwestern Spanish waters) acoustic survey series started in 1991 (previously, since 1984, an acoustic survey was carried out in the area, aimed at sardines and called SARACUS). It is conducted by the Instituto Español de Oceanografía (IEO) in the RV Cornide de Saavedra and covers the divisions 9.a North, 8.c West (western part), and 8.c East (eastern part). During 1994 to 1996 the survey took place in spring but covered mainly the shelf-break area from the Spanish-Portuguese border to Brittany. The acoustic estimate of sardine abundance and biomass was again the objective of the survey in 1995 (IBERSAR 95) and took place on RV “Noruega”. From 1997 to 2012, PELACUS was carried out on RV “Thalassa”. The Planning Group for Pelagic Acoustic Surveys in ICES Subareas 8 and 9 agreed that acoustic data would only be recorded during daylight, leaving the night-time available for physical, chemical, and plankton characterization of the water column. This recommendation was implemented in 1998. In 2000, the 120-kHz frequency began to be used to help discriminate between different fish species. In 2005, RV “Thalassa” was equipped with the new EK60 with a series of new transducers (18, 70, and 200 kHz). In 2013 the R/V used for PELACUS was substituted by the Spanish vessel Miguel Oliver (MO), built in 2007. In addition, the surveyed area was extended from the 200 m isobath to the 1000 m one to make available the bulk of the blue whiting distribution. Since 2007, top predator’s data have also been routinely collected, as well as floating litter and other human pressures such as fishing (e.g. number of boats, type, activity).

The survey design consists of a grid of parallel transects, eight nautical miles apart and perpendicular to the coastline, and covering the continental shelf up to a depth of 200 m. The starting point of each transect is located close to the coast (1–1.5 nautical miles from the shoreline), although the exact location can be modified due to adverse weather conditions or the presence of shallows. The end point of each transect can be also extended if shoals are detected in deeper waters.

Since the beginning of the time series, biological data (length, weight, sex, maturity, etc.) are registered for the assessment of sardines and all other target species. The Spanish spring acoustic survey series PELACUS is the only survey that samples yearly the waters off the subdivision 9aN and division 8c since 1984. These surveys are currently funded by DCF. This survey series provides the size composition (LFD) of the estimated population in numbers and biomass. Age composition is also available since 2008.

2.2.1.2 PELAGO survey series

The PELAGO survey covers the majority of the 9a Division, from subdivisions 9aCN to the Gulf of Cadiz, only excluding the 9aN subdivision. The PELAGO survey (spring Portuguese acoustic survey) series started in 1996 carried out by IPMA in RV Noruega, surveying the waters of the Portuguese continental shelf and those of the Spanish Gulf of Cadiz (subdivisions 9a.C-N, 9a.C-S and 9a S), between 20 and 200 m depth. Two surveys were carried out only in Portuguese waters in 1986 and 1988. There was no PELAGO survey in 2004 and 2012. In 2020 the PELAGO survey was carried out with the IEO RV Miguel Oliver (abundance and biomass estimations were considered comparable with previous years (Carrera et al. 2020). PELAGO is co-funded by DCF to provide biomass estimates of anchovy and sardine since the mid-2000's.

Acoustic surveying is undertaken along 71 transects perpendicular to the coast, covering the whole platform, and separated approximately 8 nm. Average survey speed is 8 knots and the acoustic signals were integrated over one nautical mile intervals. Echo integration is carried out with a scientific echo sounder Simrad EK500 (38 kHz transducer) until 2017, Simrad EK60 (38 kHz and 120 KHz transducers) between 2017 and 2019 and Simrad EK60 (18, 38, 70, 120, 200 kHz transducers) in 2020. Fishing hauls are carried out for species ground-truthing and fish size composition. Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) and age-structure of the estimated population in numbers and biomass for sardine and anchovy. The PELAGO time-series with estimates for anchovy in the western component of Division 9a dates back to 1999, with gaps in 2000, 2004 and 2012. Fish egg samples are collected underway every 3nm, with the CUFES system (water pumped from 3m from the surface, system fitted with a 335µm mesh size net), concurrently to the acoustic surveying along the trajectory of the acoustic transects. At night, when acoustics surveying was not running, CTD profiles for hydrography and zooplankton samples (Bongo 60) were collected, opportunistically, in some of the transects.

2.2.2 RECRUITMENT SURVEYS

2.2.2.1 JUVESAR

The JUVESAR autumn survey series was an acoustic survey restricted to the subdivisions 9aCN and 9aCS. This time-series started in 2013 and ended in 2017 to be incorporated into the IBERAS surveys, which extended the JUVESAR surveyed area since 2018. In 2014, due to bad weather, only a small area was covered. The work area ranged from Póvoa do Varzim in the subdivision 9a C-N and Cape Espichel in subdivision 9a C-S, from shoreline (12 m) to 60-100 m isobath over an adaptive grid with tracks spaced 4 or 8 nmi (4nm in the main sardine recruitment areas). The methodology was similar to that of the PELAGO surveys. Acoustic equipment consisted of a Simrad EK-500 scientific echosounder, operating at 38 and 120 kHz. The backscattering acoustic energy from marine organisms was measured continuously during daylight. Pelagic or bottom trawls were carried out whenever possible to help identify the species (and size classes) that reflect the acoustic energy. This series provides the size composition (LFD) and numbers and biomass for age 0 sardine and anchovy.

2.2.2.2 IBERAS

IBERAS survey is conducted by IEO and IPMA. IBERAS main objective is to get a recruitment index for both species in Atlantic waters of the Iberian Peninsula, aiming to improve the estimation of the strength of the recruitment of the Ibero-Atlantic sardine and the western component of the southern anchovy population. In 2018 the survey was undertaken in November. However, both the bad weather conditions, that limited the number of effective survey days, and the aggregation and distribution patterns of the fish, with rather isolated and big schools that made it difficult either to find and, specially, to improve the precision of the biomass estimates, led to change the period of the survey. Therefore, from 2019 the survey was shifted to September, at the same time of JUVENA, which in turn allows a synoptic coverage of the Iberian Peninsula at the end of summer, beginning of fall. The survey was carried out in R/V Ramon Margalef in 2018 and 2020, and in a similar vessel, Angeles Alvariño, in 2019.

The work area ranged from Finisterra cape (in 2020 from Estaca de Bares cape) until S. Vicente cape, from shoreline (20 m) to 100 m isobath over an adaptive grid with tracks distanced between 4-8 nmi on account the potential recruitment distribution area of both sardine and anchovy. Tracks were enlarged or shortened accordingly. This series provides the size composition (LFD) and age-structure of the estimated population in numbers and biomass for anchovy and sardine, of age 0 individuals.

The methodology was similar to that of the previous surveys and is summarised in ICES (2018). Acoustic equipment consisted of a Simrad EK-80 scientific echosounder, operating at 18, 38, 70, 120 and 200 kHz. The backscattering acoustic energy from marine organisms was measured continuously during daylight except in the northern area where some tracks were steamed at night. Pelagic trawls were carried out whenever possible to help identify the species (and size classes) that reflect the acoustic energy. During daylight hours, concurrently to acoustics, a trained observer recorded marine mammals, seabirds, floating litter and vessel presence and abundance. At night, when acoustics surveying was not running, CTD profiles for hydrography and zooplankton samples (Bongo 60 and Manta trawl nets) were collected, opportunistically, in some of the transects.

3 MATERIAL AND METHODS

3.1 Data availability

Table 3.1 shows the list of surveys series providing direct estimates of anchovy stocks and the corresponding subdivisions covered within its area of distribution. These surveys are coordinated and standardized (updated surveys protocols) since 2005, within the frame of the ICES Working Group on Acoustic and Egg Surveys for Sardine and Anchovy in subareas 7, 8 and 9 (WGACEGG).

Table 3.1 – Acoustic surveys providing direct estimates for anchovy in subdivision 9a west (9aN, 9aCN, 9aCS). **Surveys for which anchovy age data is available are represented in blue.**

Survey	PELACUS	PELAGO		SAR	JUVESAR	IBERAS
Institute (Country)	IEO (Spain)	IPMA (Portugal)		IPMA (Portugal)	IPMA (Portugal)	IEO (Spain)
Subdivisions	9a N	9a C-N, 9a C-S, 9a S		9a C-N, 9a C-S, 9a S	9a C-N, 9aCS (partial)	9a N 9a C-N to 9a C-S (partial)
Year/Quarter	Q2	Q1	Q2	Q4	Q4	Q4
1998		Mar		Nov		
1999		Mar				
2000		Mar		Nov		
2001		Mar		Nov		
2002		Mar				
2003		Feb		Nov		
2004			Jun			
2005			Apr	Nov		
2006			Apr	Nov		
2007			Apr	Nov		
2008	Apr		Apr	Nov		
2009	Apr		Apr			
2010	Apr		Apr			
2011	Apr		Apr			
2012	Apr					
2013	Mar		Apr		Nov	
2014	Mar		Apr		Nov	
2015	Mar		Apr		Dec	
2016	Mar		Apr		Dec	
2017	Mar		Apr		Dec	
2018	Mar		Apr			Nov
2019	Mar		Apr			Sep
2020			Apr			Sep
2021	Mar		Apr			Sep
2022	Mar		Apr			Sep
2023	Mar		Apr			Sep
2024	Mar		Apr			Sep

Due to a low abundance of anchovy in the beginning of the time series and the fact that not all anchovy otoliths of the acoustic surveys carried out in the beginning of the series are yet analysed, only age composition data for anchovy from 2008 are available for the PELACUS and PELACUS surveys series and from 2015 for the JUVESAR survey series. The 2020 PELACUS survey was not carried out due to COVID-19 restrictions.

3.2 Survey consistency

Two methods of examining survey consistency have been used for anchovy in 9a west: within-survey consistency and between-survey consistency. These methods mainly follow those adopted in the 2004 ICES Study Group on Assessment Methods Applicable to Assessment of Norwegian Spring-Spawning Herring and Blue Whiting Stocks (SGAMHBW; ICES, 2004; see also Payne et al., 2009).

3.2.1 Within-survey consistency

Na,y,s is the abundance index for age a, year y, and survey s. Within-survey consistency may be expressed as correlation coefficients calculated over years between the Na,y,s and Na+1,y+1,s. These correlation coefficients offer an indication of the ability of surveys to track year class strength effects. This has been done in the linear domain to allow for zeros as these are often present in the data, if correlation of log(N) was preferred, the log of (N+k) would need to be used, where k is a small constant depending on the scaling of N. A value of k of half of the min{N} might be preferred (ICES, 2004). In the current analyses k was set equal to 3 fish (min{N} = N1,2015=3 millions) In addition to the correlation coefficients, bi-variate plots were examined to check for linearity and the absence of a spuriously high correlation resulting from one or two outliers.

To visualize the correlation in the surveys, plots were made, where the numbers at age a are plotted versus the numbers at age a+1 in the series. The points are marked as the year class so it is possible to follow the year classes through the time series. A linear regression was made where the line is forced through the origin. The fitted line is shown.

Within-survey consistency is completed with survey-based catch curves for each of the year classes (i.e. cohorts) present in the assessed population and an analysis of survey's catchabilities at age. In the first case, natural logarithms of abundance indices (ln(N+k)) for successive ages composing the cohort are plotted and a regression line and model is fitted to the right descending limb of the curve. The abundance index for age 0 (not fully recruited to the adult population), was neither plotted nor fitted to the regression line for the purposes of graphical representation.

3.2.2 Between-survey consistency

The approach followed here differs from the described one in ICES (2004). In that report, the between-survey consistency for a given age was analysed by estimating the correlation between abundance indices for that age provided by two surveys, s1 and s2. Numbers at age 0 in the autumn recruitment surveys were compared to the numbers at age 1 in the following year in the spring PELACUS and PELAGO. An additional correlation analysis was also conducted between juvenile age 0 fish from the autumn survey and the estimate of the recruitment in the following year. A linear regression was made where the line was forced through the origin. The fitted line is shown in the plots.

4 RESULTS

4.1 ANCHOVY SURVEY CONSISTENCY – WESTERN COMPONENT

4.1.1 INTRA-SURVEY CONSISTENCY – ANCHOVY WEST

4.1.1.1 PELACUS INTRA-SURVEY CONSISTENCY – ANCHOVY WEST

Anchovy abundance estimated in PELACUS survey shows very low values in the beginning of the series and a peak in abundance in 2018 followed by a second peak during 2021 (Fig. 4.1.1.1.1).

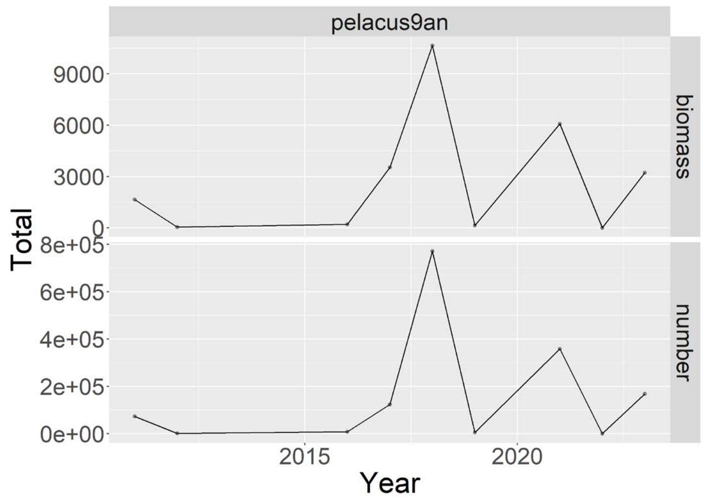

Figure 4.1.1.1.1 - ane.9awest stock component. PELACUS spring survey series. Time series of biomass (t; top panel) and abundance (millions; bottom panel) acoustic estimates.

There is no correlation of consecutive ages (Fig. 4.1.1.1.2) and poor cohort tracking (Fig. 5.1.1.1.3) for PELACUS for the western component of the anchovy (9aN), which corresponds to a small area, generally corresponding to 0 to 19% of the total biomass of anchovy in the western component.

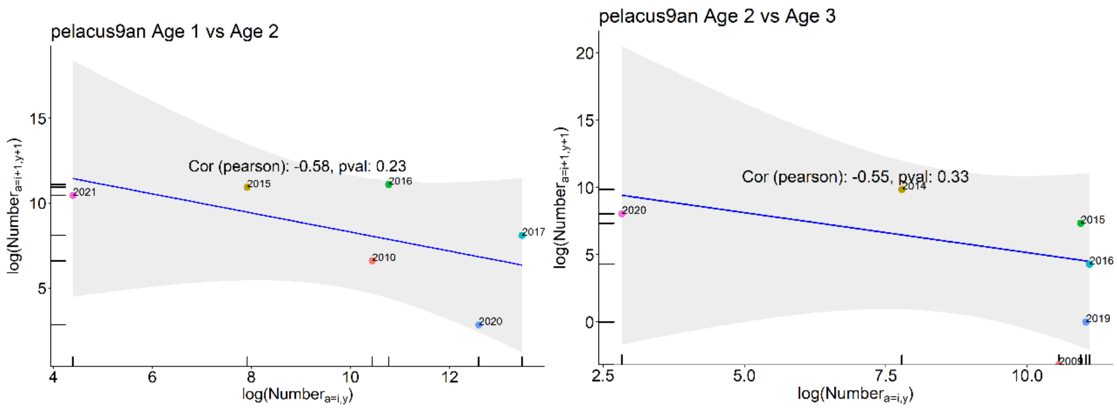

Figure 4.1.1.1.2 - ane.9awest stock component. PELACUS spring survey series. Correlation of consecutive ages (age x in year n with age x+1 in year n+1) for Age 0 and Age 1, left panel and Age 1 and Age 2, right panel.

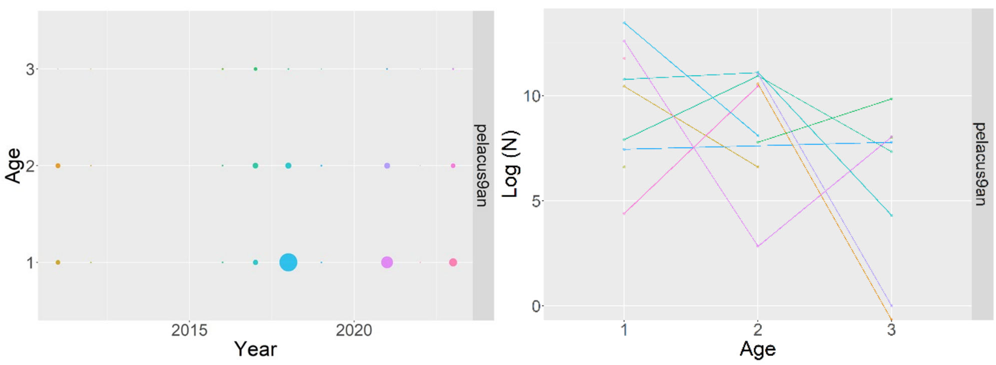

Figure 4.1.1.1.3 - Ane.9awest stock component. PELACUS spring survey series. Cohort tracking (Log number) by age.

4.1.1.2 PELAGO INTRA-SURVEY CONSISTENCY – ANCHOVY WEST

The presence and abundance of anchovy was low in the beginning of the PELAGO time series, except for a peak in 2011. In the last decade the abundance of anchovy registered in the PELAGO has been increasing as well as the frequency of occurrence of peaks in abundance. The highest peak in number was registered in 2018 followed by 2022 whereas the peak in abundance was 2022 followed by 2023 (Fig. 4.1.1.2.1).

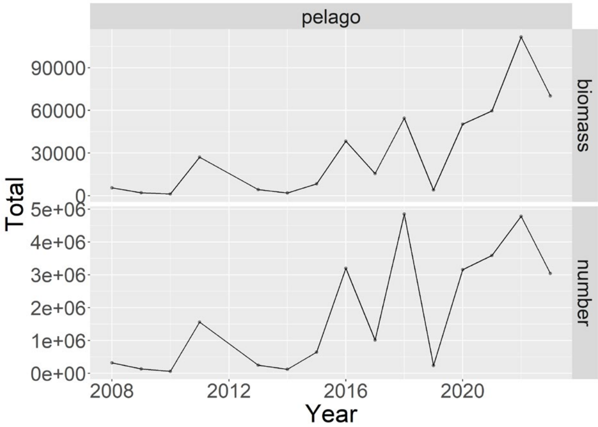

Figure 4.1.1.2.1 - ane.9awest stock component. PELAGO West component spring survey series. Time series of biomass (t; top panel) and abundance (millions; bottom panel) acoustic estimates.

There is no correlation of consecutive ages (Fig. 5.1.1.2.2) and poor cohort tracking (Fig. 5.1.1.2.3) for PELAGO for the western component of the anchovy (9aCN and 9aCS). The area covered by the PELAGO survey corresponds to >80% of the total anchovy biomass in the western Iberia.

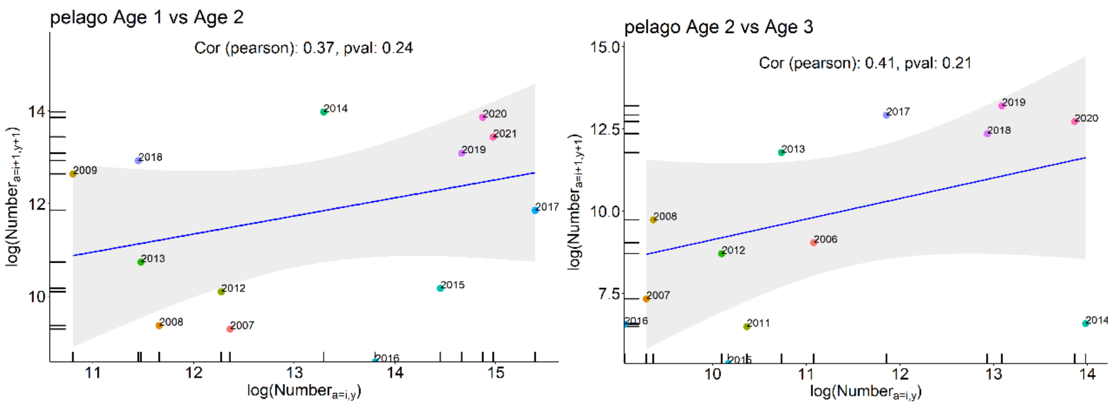

Figure 4.1.1.2.2 - ane.9awest stock component. PELAGO spring survey series. Correlation of consecutive ages (age x in year n with age x+1 in year n+1) for Age 0 and Age 1, left panel and Age 1 and Age 2, right panel.

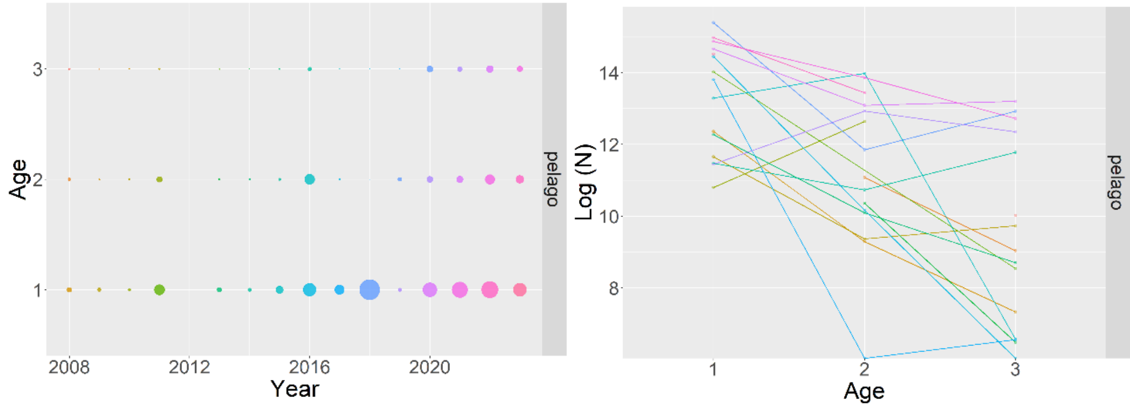

Figure 4.1.1.2.3 - ane.9awest stock component. PELAGO spring survey series. Cohort tracking (Log number) by age.

4.1.1.3 SURVEY INDEX INTRA CONSISTENCY - ANCHOVY WEST

Anchovy abundance in the western component of the Iberian stock increased significantly since 2016 with high interannual variability (Fig. 4.1.1.3.1). Peak number of anchovy in the western Iberia was registered in 2018 followed by 2022 and peak biomass occurred in 2022 followed by 2023 (Fig. 4.1.1.3.1).

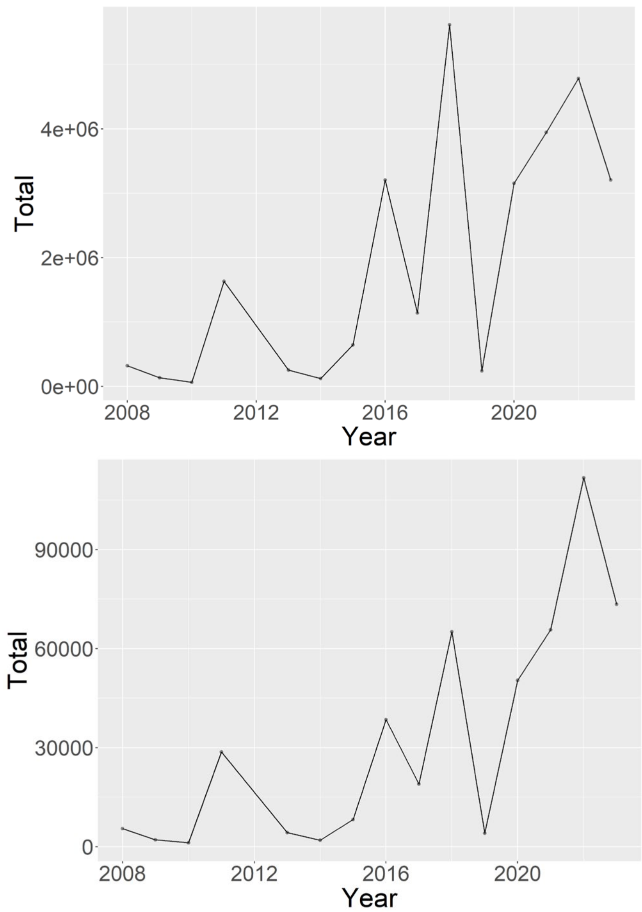

Figure 4.1.1.3.1 - ane.9awest stock component. Combined PELACUS 9a + PELAGO 9aCN and 9aCS spring survey series. Time series of biomass (t; top panel) and abundance (millions; bottom panel) acoustic estimates.

There is no significant correlation in the abundance of anchovy in the western component index obtained by the sum of the abundances registered in the PELACUS (9aN) and the PELAGO (9aCN + 9aCS) surveys series between ages 1 and 2, but there is a significant correlation between ages 2 and 3 (Fig. 4.1.1.3.2 and 4.1.1.3.3).

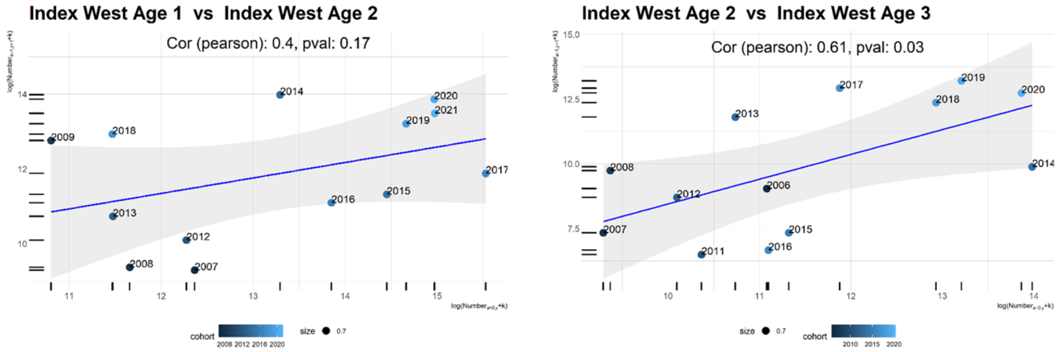

Figure 4.1.1.3.2 - ane.9awest stock component. Combined PELACUS 9a + PELAGO 9aCN and 9aCS spring survey series. Correlation of consecutive ages (age x in year n with age x+1 in year n+1) for Age 0 and Age 1, left panel and Age 1 and Age 2, right panel.

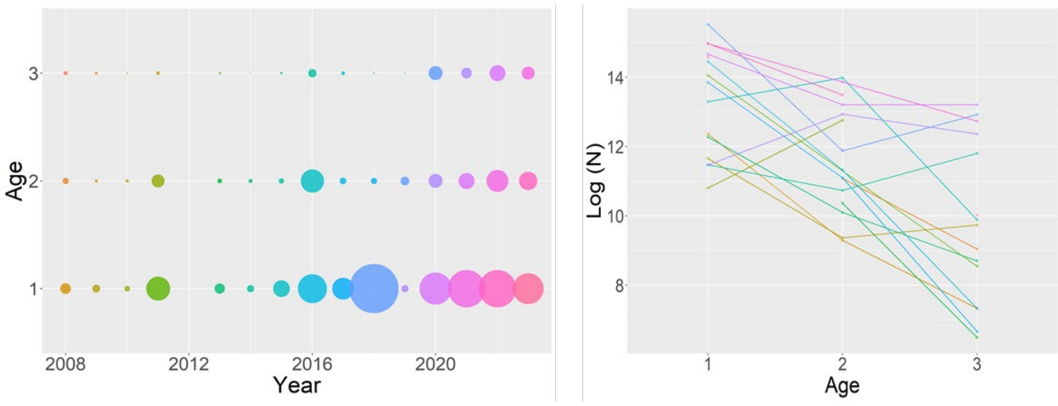

Figure 4.1.1.3.3 - ane.9awest stock component. Anchovy survey Index. Cohort tracking (Log number) by age.

4.1.1.4 JUVESAR AND IBERAS INTRA-SURVEY CONSISTENCY – ANCHOVY WEST

Considering the survey series JUVESAR and IBERAS pooled, starting from 2013, the number and biomass of anchovy peaked in 2018, being significantly lower in the other years.

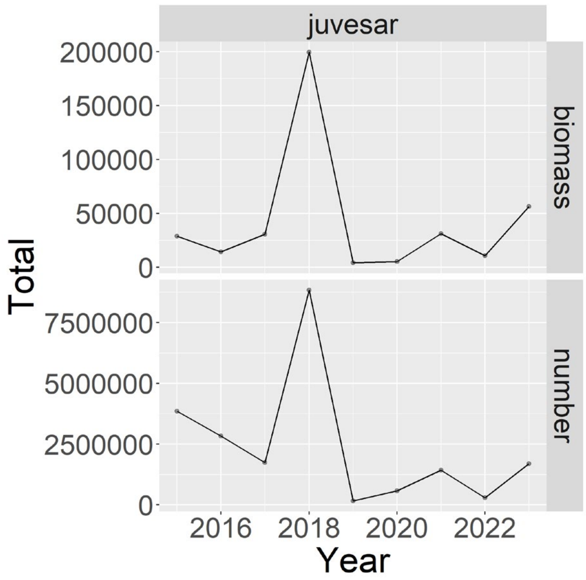

Figure 4.1.1.4.1 - Ane.9awest stock component. IBERAS component spring survey series. Time series of biomass (t; top panel) and abundance (millions; bottom panel) acoustic estimates.

Although the pooled survey series JUVESAR and IBERAS is still short, it has low intra-survey consistency of the recruitment surveys, given that the correlation between consecutive ages is not significant for ages 1 and 2 and ages 2 and 3, although it is significant for ages 2 and 3 (Fig. 5.1.1.4.2).

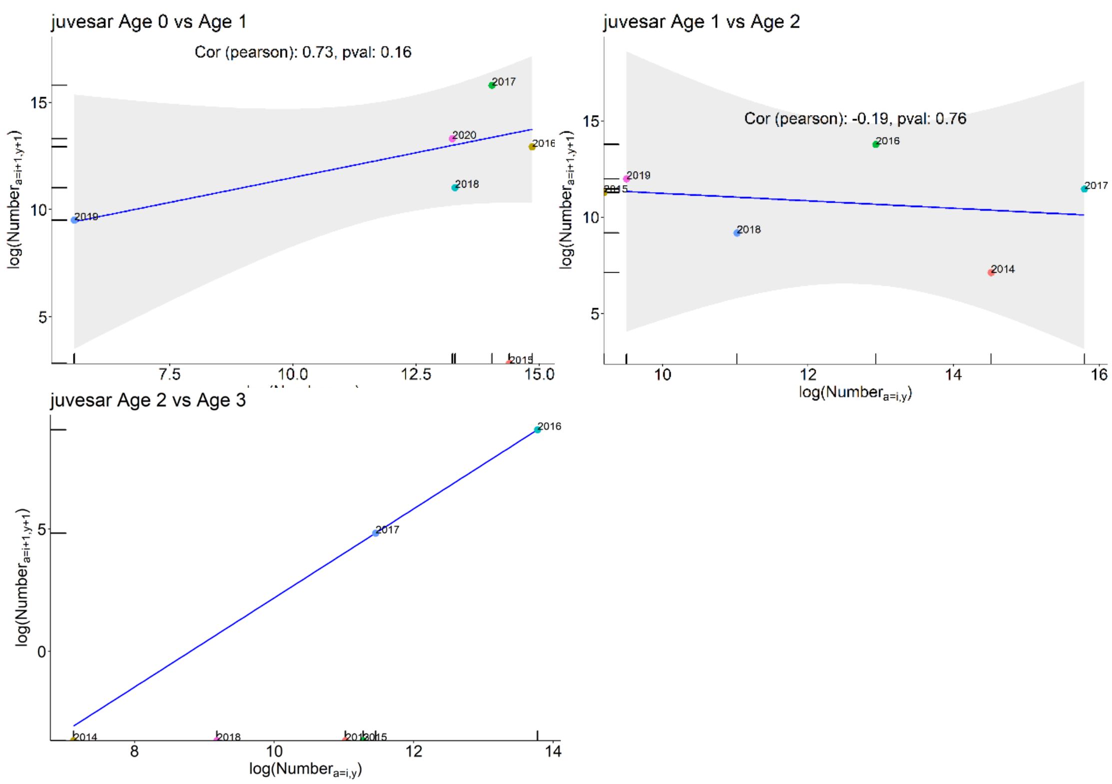

Figure 4.1.1.4.2 - Ane.9awest stock component. JUVESAR and IBERAS autumn survey series. Correlation of consecutive ages (age x in year n with age x+1 in year n+1) for Age 0 and Age 1, left panel and Age 1 and Age 2, right panel and Age 2 and Age 3, lower panel.

For 2018 and 2022, corresponding to the peak abundance years, the dominant year class is 1 year old, and the abundance of age 0 of the corresponding cohort is lower, suggesting that age 1 fish might have originated from an area not covered by the JUVESAR/IBERAS survey area.

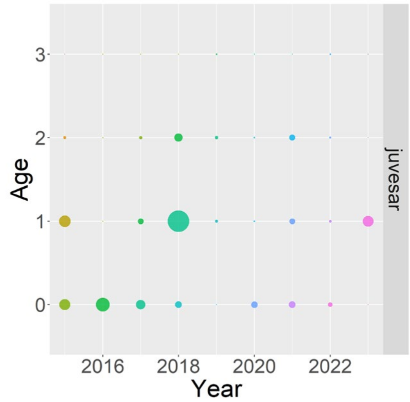

Figure 4.1.1.4.3 - ane.9awest stock component. PELAGO spring survey series. Cohort tracking (Log number) by age.

4.1.2 INTER-SURVEY CONSISTENCY – ANCHOVY WEST

4.1.2.1 PELACUS VS JUVESAR/IBERAS– ANCHOVY WEST

No relationship of Age 0 of recruitment surveys (JUVESAR and IBERAS) with Age 1 of the PELACUS in the following year (Fig. 4.1.2.1.1).

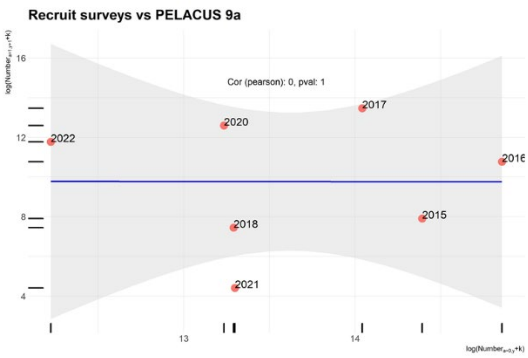

Figure 4.1.2.1.1 - Ane.9awest stock component. Correlation of anchovy abundance of at Age 0 for juvenile surveys (JUVESAR + IBERAS) and Age 1 in the PELACUS spring acoustic survey the following year.

4.1.2.2 PELAGO VS JUVESAR/IBERAS– ANCHOVY WEST

No significant correlation was found between the abundance of Age 0 estimated in the recruitment surveys with Age 1 of the PELAGO in the following year (Fig. 4.1.2.1.1).

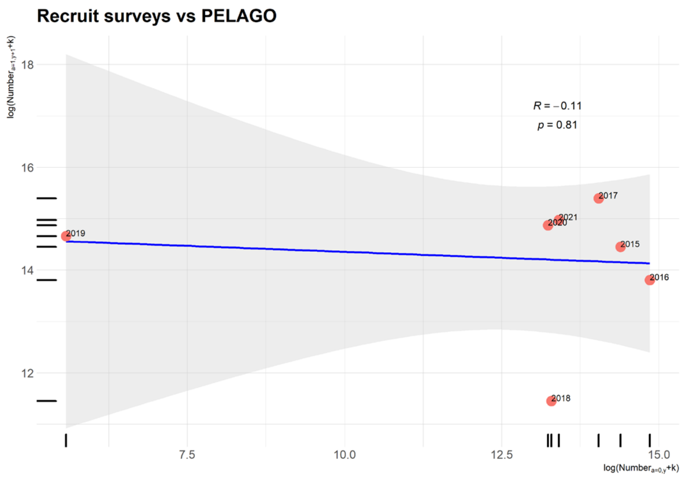

Figure 4.1.2.2.1 - ane.9awest stock component. Correlation of anchovy abundance of at Age 0 for juvenile surveys (JUVESAR and IBERAS) and Age 1 in the PELAGO spring acoustic survey the following year.

4.1.2.3 PELACUS+PELAGO VS JUVESAR/IBERAS – ANCHOVY WEST

No significant correlation was found between the abundance of Age 0 estimated in the recruitment surveys (JUVESAR and IBERAS) with Age 1 of the stock indicator (PELACUS+PELAGO) in the following year (Fig. 4.1.2.3.1).

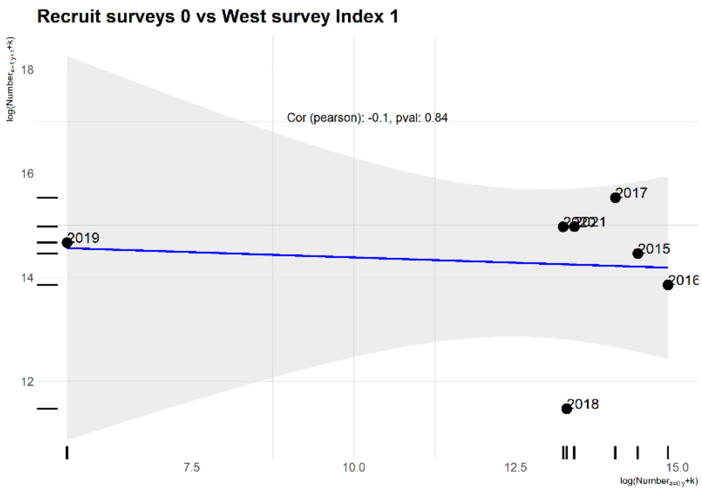

Figure 4.1.2.4.1 - ane.9awest stock component. Correlation of anchovy abundance of at Age 0 for juvenile surveys (JUVESAR and IBERAS) and Age 1 in the stock index (PELACUS+PELAGO spring acoustic surveys) the following year.

Given the high influence of the 2019 survey point in the regression analysis, the correlation was repeated without that year. No significant correlation was found between the abundance of Age 0 estimated in the recruitment surveys and Age 1 of the stock indicator in the following year without the 2019 datapoint (Fig. 4.1.2.3.2).

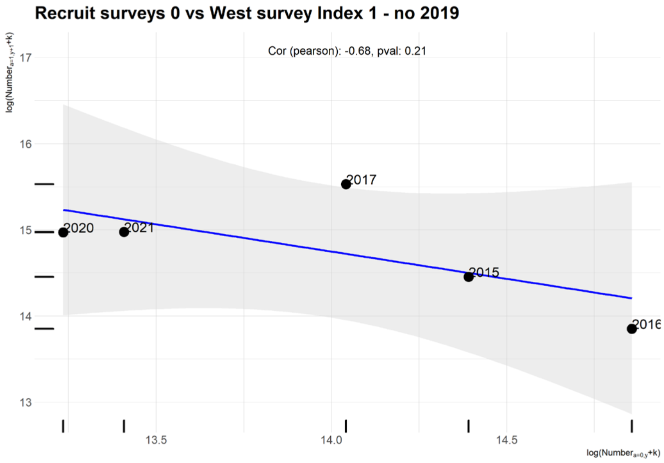

Figure 4.1.2.3.2 - ane.9awest stock component. Correlation of anchovy abundance of at Age 0 for juvenile surveys (JUVESAR and IBERAS) and Age 1 in the stock index (PELAUS+PELAGO spring acoustic surveys) the following year excluding the datapoint corresponding to the 2019 survey.

4.1.2.4 PELACUS 9a vs PELAGO West

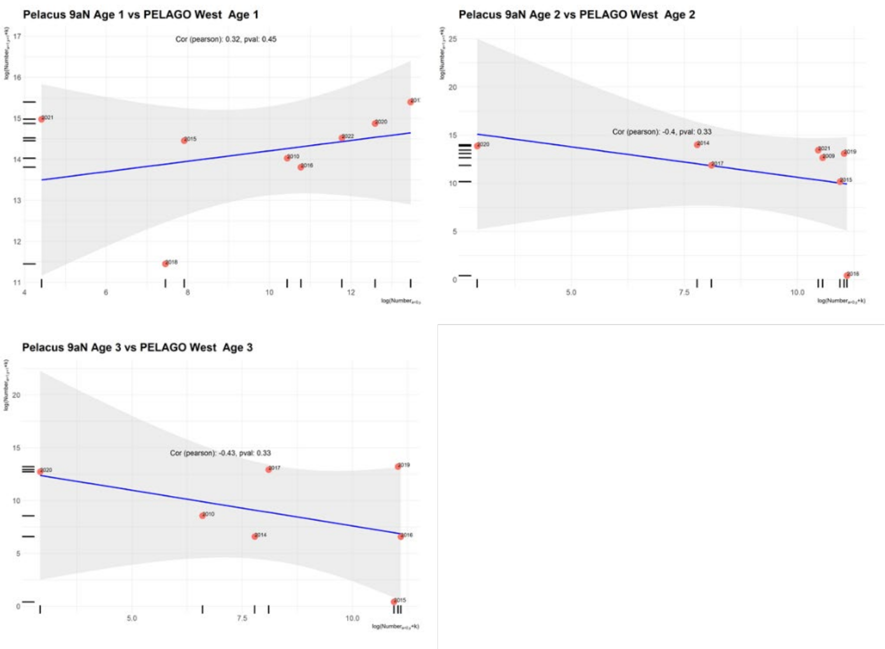

Figure 4.1.2.4.2 - ane.9awest stock component. Correlation of anchovy abundance of at Age between the spring acoustic surveys (PELACUS and PELAGO) thay cover complementary areas within the western component (9aN and 9aCN+9aCS, respectively).

5 CONCLUSIONS

The analysis of survey consistency for the western component of the 9a anchovy stock revealed that there is a low within survey consistency for the spring acoustic surveys PELACUS, PELAGO. However, when considering the combination of both surveys that constitute the survey index, there is a positive and significant correlation between Age 2 and 3. Correlation between age 1 and 2 is positive although not statistically significant. There is no correlation between the abundance of Age 0 anchovy estimated by the recruitment survey series (JUVESAR+IBERAS survey) and Age 1 anchovy determined the following year by the spring acoustic surveys. During the recruitment surveys it is reported that occasionally anchovy peak concentration is located at the outer limit of the transects in the area covered by the survey (until the 100 m bathymetric, smaller than the spring acoustic surveys that covers the area until the 200 m bathymetric), therefore the survey may, at least for some years, only partially cover the distribution area of anchovy in the western Iberian coast. On the other hand, the two years when anchovy abundance peaked (2018 and 2022), correspond to high numbers of Age 1 individuals, both for the spring acoustic survey and for the recruitment survey, and the latter failed on both occasions to capture Age 0 individuals the year before. Therefore, the absence of Age 0 fish in the recruitment survey indicates that the surveyed area may not adequately represent the full distribution of juveniles. These juveniles could be located further offshore or come from the north, in the Cantabrian Sea, a possibility that warrants further investigation.

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Working document presented to the:

ICES Stock Identification Methods Working Group (SIMWG) and

ICES Benchmark workshop on anchovy species (WKBANSP)

POPULATION STRUCTURE OF THE EUROPEAN ANCHOVY (*ENGRAULIS ENCRASICOLUS*) IN ICES DIVISION 9A

By

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ABSTRACT

The present WD summarises the state-of-the art and presents new information on the stock structure of anchovy in the Division 27.9.a (Atlantic Iberian waters). The stock status was first assessed after its first benchmark in February 2018 (WKPELA 2018, ICES, 2018a). Recognizing the different fisheries and populations dynamics of the west and south Iberian populations, WKPELA 2018 supported the separation of the stock into two different stock components for management purposes: The Western component – in ICES Subdivisions 9a.N, 9a.CN and 9a.CS, and the Southern component – in ICES Sub-division 9a.S, for which the advice is given separately. During the benchmark, it was advised that more information should be collected regarding the population structure of anchovy Iberian populations, namely genetic information, to decide if the two components should be managed as independent stocks. In this document state-of-the-art information of anchovy distribution and stock structure is provided namely i) information of the time series of surveys conducted in the area and also in the contiguous Cantabrian Sea occupied by the Bay of Biscay anchovy stock; ii) landing distribution; iii) heterogeneity of life-history traits; iv) synopsis of works published using morphometric and genetic analysis, v) new data of a comprehensive genomic study in the area of distribution, vi) new data of modelling of larval dispersal in Iberian waters and vii) new data of stable isotopic analysis of eye lenses. Results show that anchovy spatial distribution in Division 9a provided by surveys reveal a persistent discontinuity between the western and southern components of the stock for several life stages (eggs, juveniles and adults) and during different seasons of the year. Landings also show this discontinuity, with most Portuguese landings (>90%) occurring in Subdivision 9a.CN. Moreover, no correlation of anchovy catches was found between the Western and Southern components, further suggesting independent dynamics of the two components. On the contrary, a significant correlation exists between anchovy abundance at age in the western and northern Iberia, suggesting potential connectivity between the areas or a response to similar environmental drivers. A review of studies conducted in Portuguese estuaries shows the persistent occurrence of recruits in numerous estuaries throughout the years, mainly in the Subdivision 9a.CN. Past morphometric and genetic studies indicate a differentiation of the western and Cantabrian populations, as well as a separation with those from the Gulf of Cadiz, but these conclusions might be affected by the presence of two ecotypes (marine and coastal), which were not considered in these studies. New data of genomic analysis reveal a clear separation of populations of the western and southern components of the anchovy stock, and no separation of those from the west and northern Iberia. In addition, new data of larval dispersal modelling suggests that the years when anchovy abundance increased in the west coast of the Iberia (2016 onwards) were preceded by strong and persistent western currents from the Bay of Biscay and high egg abundance in that area, suggesting a potential mechanism by which anchovy started to occur in high numbers in the western Iberia from that year. On the contrary, the larval dispersal model shows it is very unlikely that eggs dispersed from the Gulf of Cadiz reach the northwestern coast in any relevant numbers. Finally, new data of stable isotopic composition of the eye lenses of juvenile and adult anchovy collected during different years off the Iberia show a clear difference of the populations from the western and southern Iberia, suggesting a separation between the two areas. On the contrary, the isotope values of anchovies collected from the western and southern Iberia are overlapped, suggesting either that there is high connectivity between the two areas or insufficient contrast of baseline isotope values between the two areas. In conclusion, the information presented in this WD leads the authors to consider the anchovy populations inhabiting the southern and western Iberian regions and their exploited populations are clearly separated with independent dynamics and therefore, should be considered as separate stocks for management. As shown in the document, the current management based on a combined TAC for both components is causing the southern component to be overexploited above advised catches, which may be in

part causing the observed decrease of anchovy abundance in the area during recent years. Finally, several pieces of evidence point to a potential connectivity of the western and northern populations that should be further explored in the future.

1-INTRODUCTION

The European anchovy, *Engraulis encrasicolus*, is a small pelagic coastal marine fish distributed from the North Sea to Southeast Africa, including the entire Mediterranean basin. This species supports important fisheries and economic activities for the countries bordering the Iberian Peninsula and Mediterranean Sea (Uriarte *et al*., 1996; Lleonart and Maynou, 2002). Due to its market value, production, and wide distribution in several Northeast Atlantic (ices and Mediterranean countries, anchovy is a major shared resource in the region. For management purposes, the European anchovy is separated in two distinct stock units in the Northeast Atlantic, one distributed in the Bay of Biscay (ICES Subarea 8) and the other distributed in ICES Division 9a (Portuguese coast and Spanish waters of the Gulf of Cadiz). Further north this species is not assessed. However, these stock limits were essentially based on administrative considerations.

In 2015 a review on the sub-stock structure of the European anchovy in the Bay of Biscay and Iberian-Atlantic waters was provided by Ramos (2015) to the ICES Stock Identification Methods Working Group (SIMWG). The evidence presented in that document suggested the existence of a stable population in the Gulf of Cadiz that seemed to be relatively independent of the remaining populations in Division 9a. At that time, the ICES SIMWG (ICES, 2015) considered that there was evidence to support a self-sustained population of anchovy located in the Gulf of Cadiz (ICES Subdivision 9a South, 9aS), but there was a lack of information regarding the origin of European anchovy in ICES Subdivisions 9a North (9aN), 9a Central-North (9aCN) and 9a Central-South (9aCS) (Fig. 1.1).

In 2018, at the time the stock was benchmarked (WKPELA 2018), an updated review of anchovy stock structure was provided (Garrido et al. 2018), including new information of the potential connectivity of anchovy population of the 9a West subdivisions with the South Iberian population. Data on spatial distribution of surveys and landings identified a discontinuity of anchovy distribution in the southwestern Iberia, separating the western and southern populations. Different dynamics of western and southern populations were identified. A summary of studies on genetics and morphometry was presented, pointing to a differentiation of western and southern anchovy populations. This evidence led WKPELA to support considering two different components of the stock (western and southern components) for which the advice should be given separately, but the evidence was not consensually considered sufficient to modify the current stock structure. At that time, new studies on genetics and otolith microchemistry, aimed at elucidating the identity and structure of anchovy populations in the western component were still in progress. WKPELA suggested presenting both the available evidence and the resulting new evidence from these undergoing studies to the ICES Stock Identification Methods Working Group for future consideration. During 2022 an updated version of the Stock structure Working Document was submitted to SIMWG (Garrido et. al. 2022). The group considered that the results of the genomic analysis that was ongoing at that time should be completed in order for the group to make a decision.

In the present WD we i) compile and summarise the information presented previously on the stock structure of anchovy, ii) update the analysis of the historical dynamics of landings and surveys, iii) present new evidence, particularly the genomic, larval dispersal modelling and stable isotopic analysis, that point to independent dynamics of western and southern Iberian anchovy populations.

2 - SPATIAL DISTRIBUTION OF ANCHOVY IN DIVISION 27.9.a

The distribution of anchovy in Division 9.a (Fig. 1.1) was investigated by using all the available information of scientific surveys carried out regularly in the 9a area, and covering several life-stages (eggs, juveniles and adults) and seasons of the year (spring, summer, fall). It also included some relevant information of the distribution of anchovy resulting from surveys in the contiguous area of northern Iberia (Subarea 8), occupied by the Bay of Biscay anchovy. In what follows, the historical data of the distribution of the species is presented.

Figure 1.1. ICES Statistical Divisions and Subdivisions in Southern Europe. Western component of anchovy stock distributes in the area identified in blue as 9.a. West (comprising Sub-divisions 9aN, 9aCN, 9aCS). Southern component of anchovy stock distributes in the area identified in blue as 9.a. South (comprising sub-divisions 27.9.a.S (Portugal) and 27.9.a.S (Spain)).

3 - HISTORIC DYNAMICS OF SURVEY DATA

3.1. SPRING ACOUSTIC SURVEYS

There are 3 spring acoustic surveys that cover the the anchovy stocks distribution in the North East Atlantic: PELGAS in the Bay of Biscay, PELACUS in western Galician waters and the Cantabrian Sea, and PELAGO, covering the area from western Portugal and the Gulf of Cadiz (Fig. 3.1.1, ICES WGACEGG 2024). According to the estimates provided by the spring acoustic surveys carried out in the Atlantic Iberian waters from 2014 to 2023, adult anchovy core distribution areas in springtime are, by decreasing order of importance: coastal areas in Southern Bay of

Biscay (Gironde and Landes coast, ~46°N), the Gulf of Cadiz (~37°N), and in the north western Portuguese coast, North of Cape Mondego (~40°N). There is a gap in the distribution of adult anchovy in the western side of the Cantabrian Sea and in the southwestern Portuguese coast.

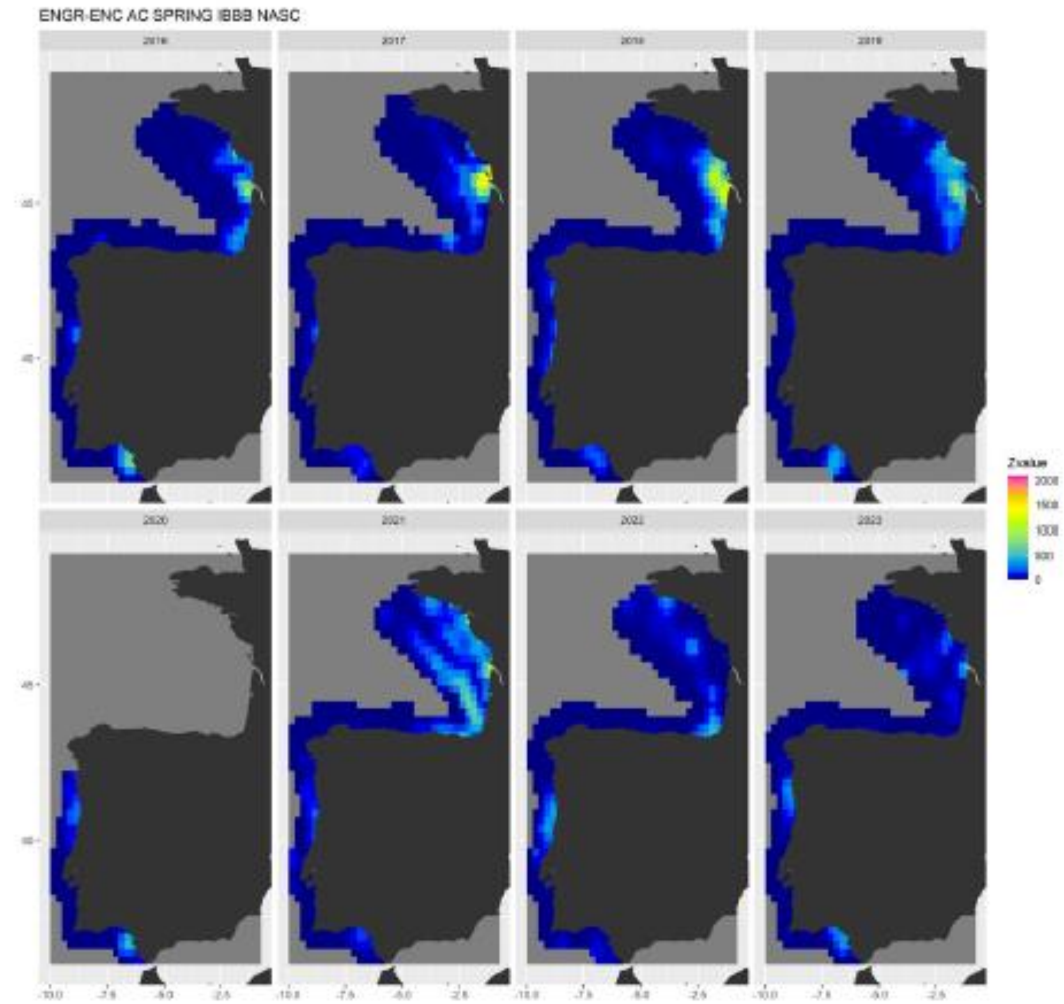
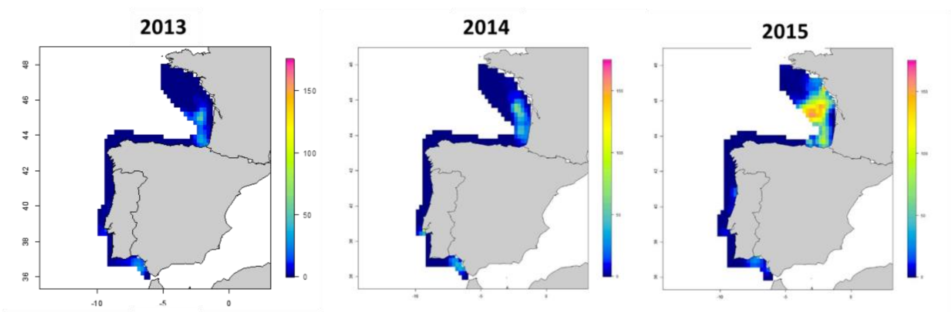


Figure 3.1.1 Mean acoustic density (NASC, m².NM-²) of anchovy in surveys PELGAS, PELACUS and PELAGO 2016 to 2023. Source: ICES WGACEGG 2024 report.

Anchovy egg distribution estimated during the spring acoustic surveys from 2013 to 2023 is similar to that of the adults, being higher in the Bay of Biscay, followed by the Gulf of Cadiz and the north western coast of Portugal (Fig. 3.1.2). However, it should be noted that peak spawning for anchovies in Division 9a generally occurs two months after these surveys.



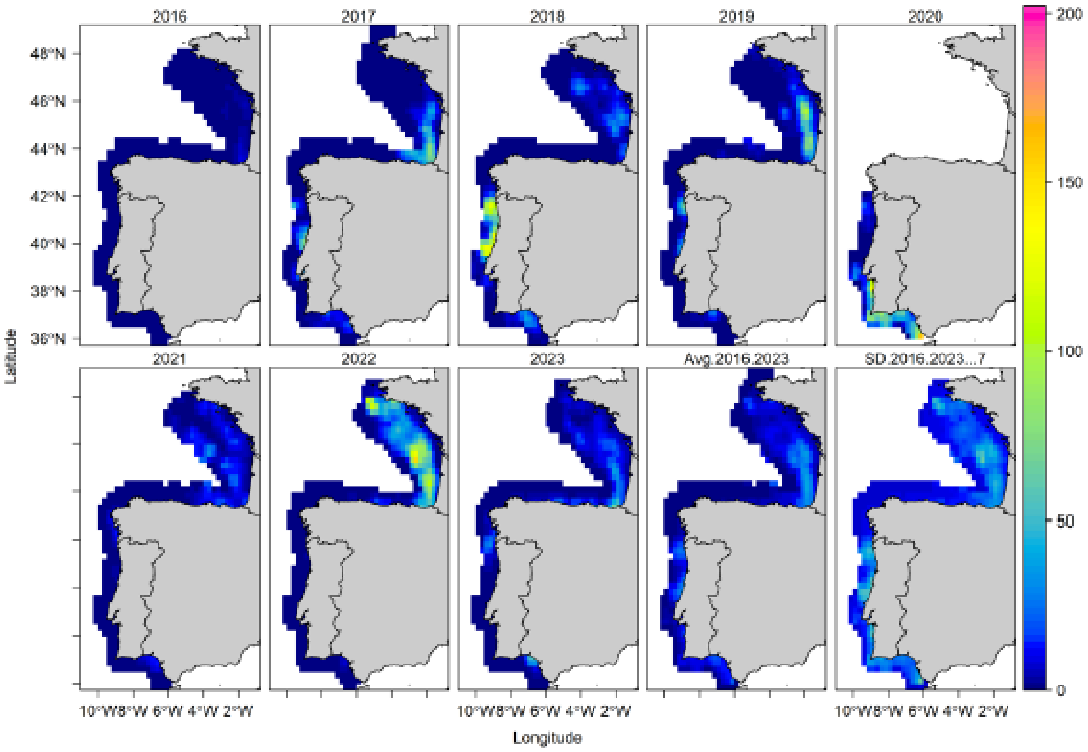


Figure 3.1.2. Anchovy egg density (eggs.m^{-3}) distribution derived from CUFES sampling during the spring acoustic surveys, PELGAS (IFREMER), PELACUS (IEO) and PELAGO (IPMA) for the period 2013-2023. Source: ICES WGACEGG 2017 (2013 to 2015) and 2024 Reports (2016 to 2023).

3.1.1 – PELAGO SURVEY SERIES

The PELAGO survey covers most of 9a Division, from subdivisions 9a.CN to the Gulf of Cadiz, only excluding the 9a.N Subdivision, that accounts, on average, 2.9 ± 4.14% of anchovy abundance in Division 9a and 5.7 ± 4.75% of anchovy in the western component (data of spring acoustic surveys from 2007 to 2023). Acoustic surveying is undertaken along 71 transects perpendicular to the coast, covering the whole platform, and separated approximately 6 (south) or 8 nm (west). Fishing hauls are carried out for species ground-truthing and fish size composition. Zooplankton samples are collected underway every 3 nm, with the CUFES system (water pumped from 3m from the surface, system fitted with a 335 µm mesh size net), concurrently to the acoustic surveying along the trajectory of the acoustic transects. As described above, detailed observation of the PELAGO results (Fig. 3.1.1.1) allows the identification of two main centres of anchovy distribution, in Cadiz and in the north western Portuguese coast.

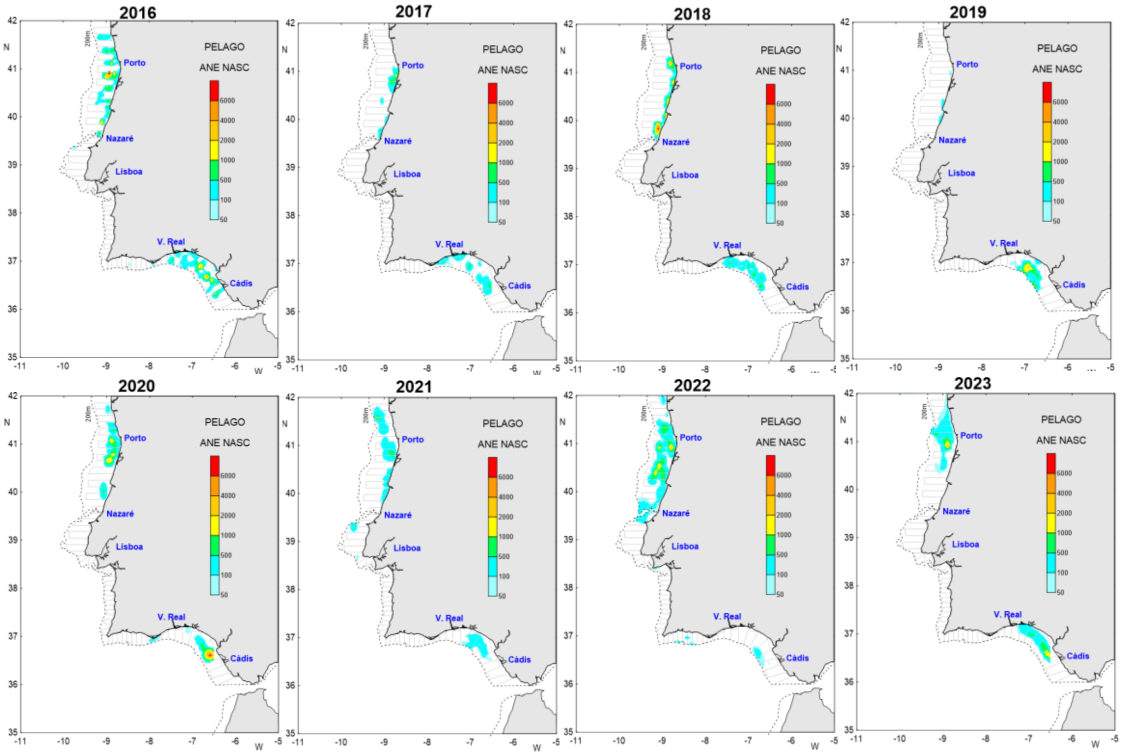


Figure 3.1.1.1 – Acoustic density (NASC, m².nm-²) of anchovy in PELAGO survey series from 2016 to 2023.

Egg distribution assessed in the PELAGO survey (conducted from March to May, depending of the year, which is near or at the beginning of anchovy spawning season) shows a recurrent concentration of eggs in the Gulf of Cadiz and in the area from Cape Carvoeiro to Cape Espichel (North-western Portugal) (Fig 3.1.1.2). Occasionally, some eggs are detected off River Mira (south of Cape Sines) in the southwestern coast. The major egg densities in the western Iberia occur more often in the central region off Ria de Aveiro – River Mondego area. Anchovy egg distribution is highly variable between years. During years of high abundance, the southern coast appears almost entirely occupied, with observations from the inner Cadiz Bay to Cape S. Vicente, while during low abundance periods the distribution is retracted to the Spanish waters. Likewise, in the west coast during years of higher abundances anchovy eggs may be observed in a larger area occupying the northwestern and the north part of the southwestern Portuguese coast (e.g. in 2017) while during low density periods may only be observed in the core areas. It is worth noting that the spawning period for anchovy in the area covered by the PELAGO survey is from May to July. Unplanned delays that occurred in the 2016 and 2017 surveys have contributed to the higher anchovy egg abundances observed since the survey was conducted. In fact, 2017 was the year with the record high anchovy egg abundances during the PELAGO survey series and the following year (2018) the third highest peak on anchovy abundance was registered. The highest egg densities were observed on the northwest coast and in good agreement with the detection of anchovy, where high fish abundances were also registered during the previous spring.

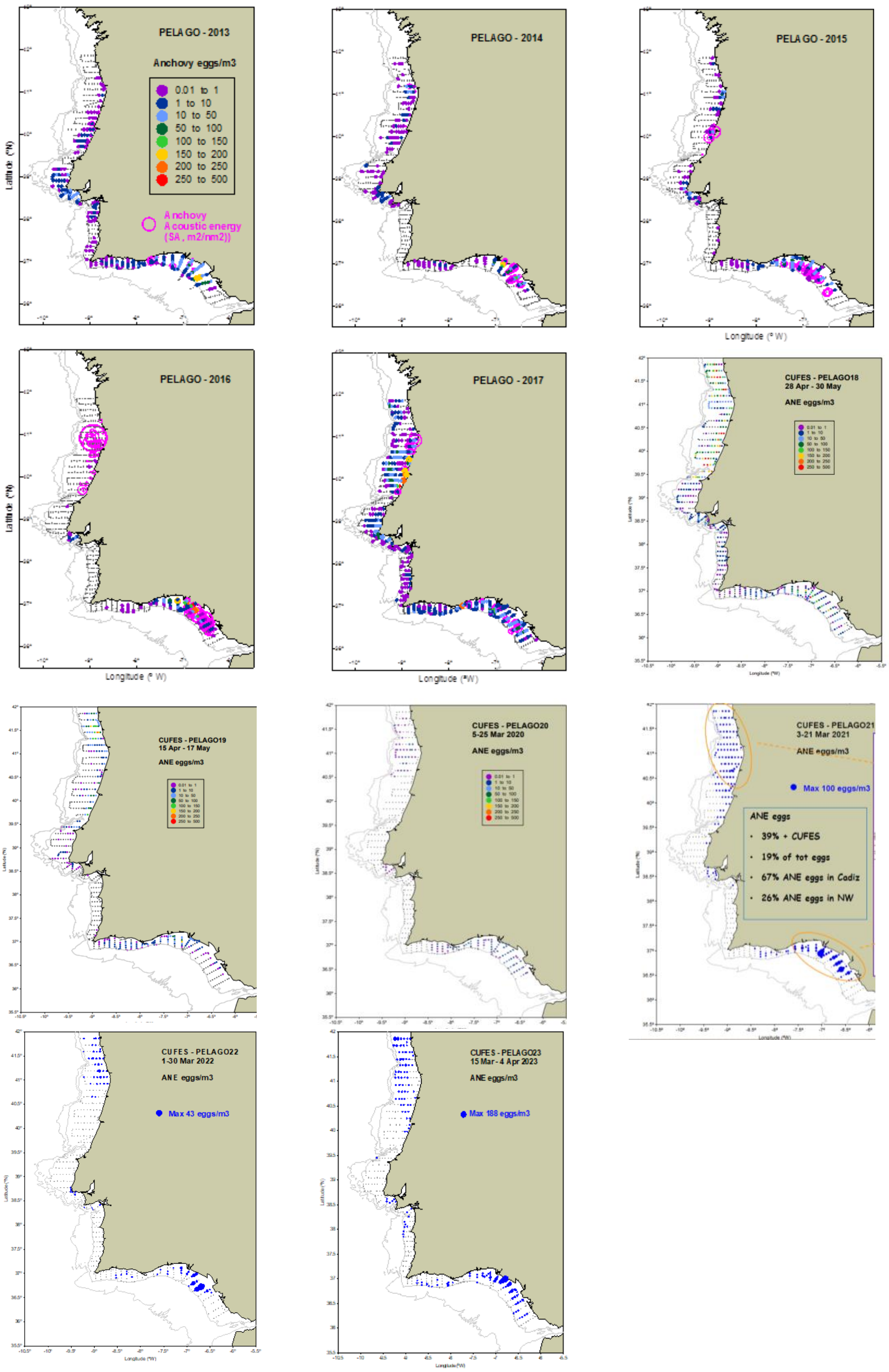


Figure 3.1.1.2 - Anchovy egg density (eggs/m^3), from CUFES sampling, and acoustic energy (SA m^2/nm^2) distributions, during the acoustic surveys of the PELAGO series (IPMA) for the period 2013-2023. Egg distributions are represented by density classes according to the colour scale depicted. Acoustic energy of adult anchovy is shown in pink circles with areas proportional to SA in maps from 2013-2017. Source: ICES WGACEGG.

The PELAGO survey series has data of anchovy abundance and distribution since 1998. In the beginning of the survey series, the majority of anchovy in the 9a Division was in the southern component, mainly in the Spanish waters. From 2011 onwards, no clear trend was found in anchovy abundance in the southern component, but a sharp increase was observed in western Iberia, with peak abundances registered in 2022 followed by 2023 (Fig. 3.1.1.3).

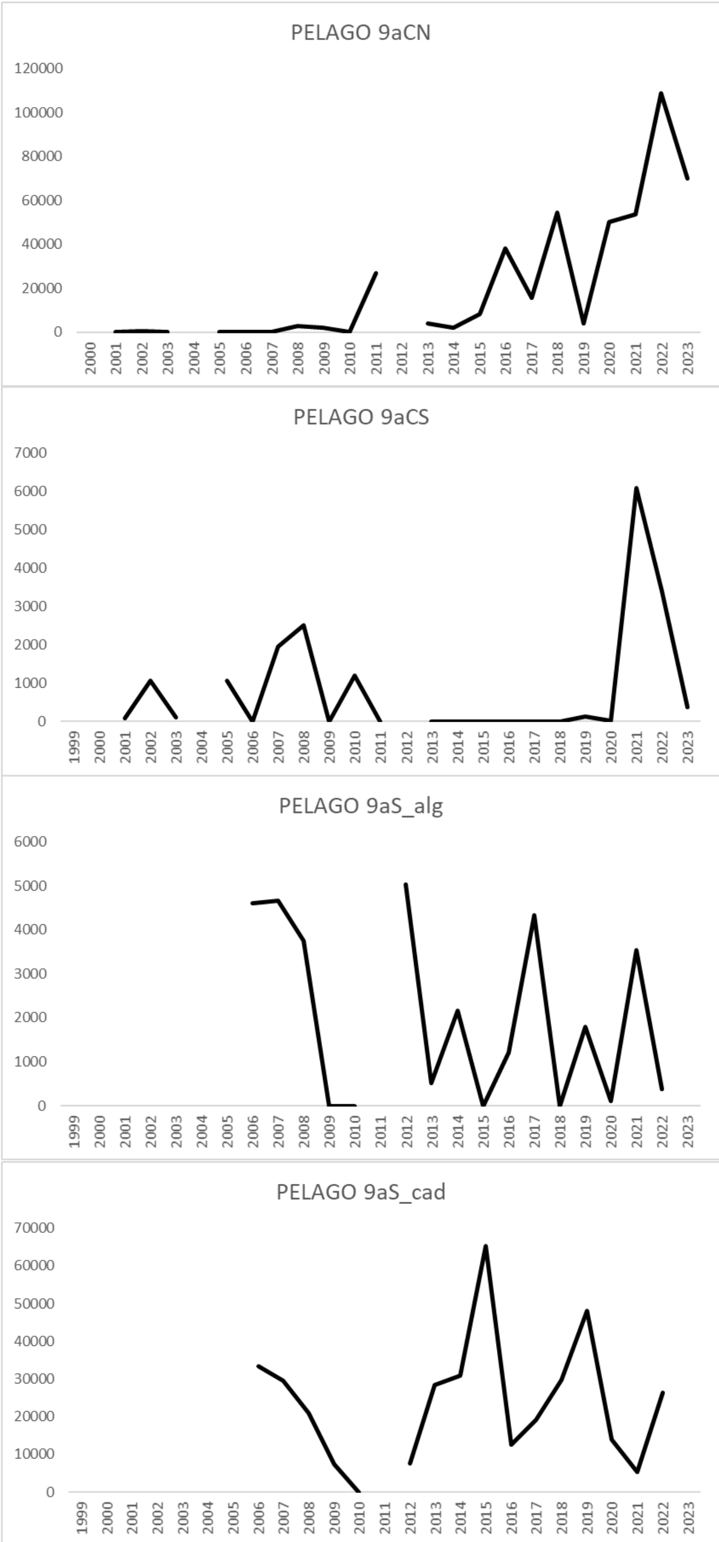


Figure 3.1.1.3 - Anchovy in Division 9.a. Western and Southern components. PELAGO survey series (spring Portuguese acoustic survey in Subdivisions 9.a Central-North, 9.a Central-South, 9.a South-algarve and 9.a South-Cadiz. Subdivisions 9.a Central-North to 9.a South). Regional acoustic estimates of anchovy biomass (t). Note the different scale of the y-axis.

Focusing on the western Iberia, in the beginning of the PELAGO survey series, when anchovy abundance was very low in the western Portuguese coast (Fig. 3.1.1.4), the species was largely found in the northern part of the southwestern Iberia, near Lisbon – 9aCS (or OCS). Since 2011, when the abundance of anchovy started to sharply increase until present levels, anchovy was absent from the southwestern area during 10 surveys, from 2011 to 2018, and its biomass was very low in the remaining 5 surveys, carried out from 2019 to 2023, being 3, 0.02, 9.3., 3.0 and 0.5 % of the total biomass in the western Portuguese coast, respectively.

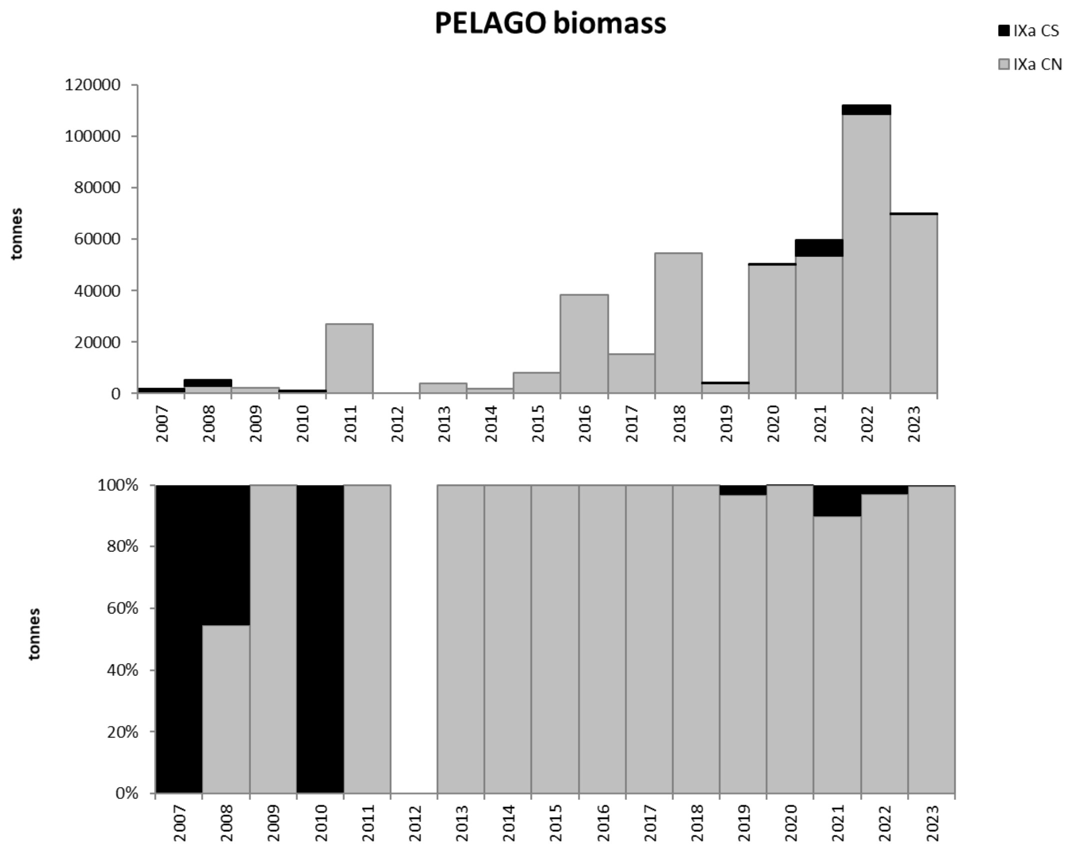


Figure 3.1.1.4 - Anchovy in Division 9.a. Western component. Subdivisions 9.a Central-North to 9.a Central-South. PELAGO survey series. Historical series of regional acoustic estimates of anchovy biomass (t).

3.1.2 – PELACUS SURVEY SERIES

The Spanish PELACUS is an acoustic-trawl survey which objective is to achieve a biomass estimates by echointegration of the main pelagic fish distributed in the Spanish Cantabrian and NW waters (sardine, anchovy, horse mackerel, mackerel, blue whiting, bogue, boarfish and chub mackerel). The time-series started in 1984. Over the years, the survey was carried out with different research vessels and incorporated further elements to sample the whole pelagic community in the Spanish Cantabrian and NW waters.

From its start until 1997 PELACUS was carried out in R/V *Cornide de Saavedra*; from 1997 to 2012 was carried on board R/V *Thalassa* and since then it is routinely conducted on board R/V *Miguel Oliver*. The surveyed area, which until 2012 only covered from shoreline (*e.g.* 30 m depth to the 200 m isobath) was also extended up to the 1000 m one in order to make available the bulk of the blue whiting distribution. An inter-calibration survey was done in April 2014 off Garonne mouth (*i.e.* at the spawning area and season). No significant changes in both fish availability (acoustic) or in fish accessibility, catchability or selectivity (trawl) were detected, and therefore similar performance for both vessels was assumed.

Since 2000, the survey uses a Continuous Underwater Fish Egg Sampler (CUFES) to collect sub-surface eggs (both from sardine and anchovy) and a new frequency (120 kHz) started to be used to help discriminate between different fish species. In 2007, presence, abundance and behaviour of top-predators (marine mammals and seabirds) and information on floating litter (type, number and position) and on other human pressures such as fishing (number of boats, type, activity, etc.) started to be routinely collected. In 2007, new frequencies (18,70 and 200 kHz) were incorporated. Since 2014, the pelagic ecosystem characterization has been complemented with records on subsurface microplastics obtained from opportunistic manta trawl hauls.

Sampling grid consists of parallel acoustic transects separated 10 nmi, between 20 and 1000 m depth, and with random start in each of the geographical strata, which correspond to the ICES subareas. During the acoustic survey, trawl catches are done opportunistically to ground-truth the observed echotraces, and to obtain individual biological data (length, weight, sex, maturity, etc.) needed to produce length-weight and age-length relationships used for the assessment of the target species. Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

The time series of PELACUS data (Fig. 3.1.2.1, 3.1.2.2, 3.1.2.3) shows that: In **2016** two main areas of anchovy distribution were found, one around Cape Peñas and other in the inner part of the Bay of Biscay. At the mouth of Rias in the 9aN sub-division, some schools were also observed, although in a very small quantity, thus, irrelevant in terms of biomass estimated. Egg distribution obtained from CUFES agreed with this distribution. In **2017** the bulk of the distribution corresponding to the Bay of Biscay stock was located in French waters but extending southwards and westwards along the Spanish coast with a large stock size. For the 9a stock, an outburst was in the northwestern coast (Rias Baixas-Spanish 9aN), where anchovy was found on the shelf and inside the rias. In the same way, and despite the peak of the spawning season taking place later (i.e. may), the egg distribution was also wide, with the highest concentration located in the 8b sub-division. In **2018**, anchovy shows a westwards trend with an important increase in the overall backscattering energy. During this year, almost all anchovy occurred in Galician waters, mainly in 9a where the distribution and aggregation patterns were similar to those observed in the Bay of Biscay. The bulk of the distribution was located in 9aN in shallower waters. Anchovy eggs were only collected in the western part. The presence of anchovy eggs close to the 200 m contour depth in 8cW, match with the few adults observed in the fishing stations in this area. For the first time in the PELACUS time series (started in 1991) important anchovy aggregations have been observed in 9aN. The aggregation and distribution pattern observed this year was very similar to the one observed around the Garonne area, with continuous anchovy schools mostly occurring in medium-low waters, well above the seafloor. During **2019** anchovy had a very scarce presence in 9aN and the observed anchovy biomass was very low. Regarding egg distribution, in 9aN 41.51% of the stations were positive (44 of 106), with a mean density on positive stations of 5.57 egg/m^3. The relatively high number of eggs is probably due to the presence of old fish (age 2 and 3). In **2020** due to the covid-19 pandemic the PELACUS survey was not carried out. In **2021**, anchovy occurred throughout the whole surveyed area, with the bulk of distribution located at the inner part of the Bay of Biscay where the 90% of the total biomass was found. In general, anchovy had a very scarce presence in 9aN. Nevertheless, there is a continuity of anchovy presence from the 9aN to the 8cW, although density in the former subdivision was very low. In **2022** the presence of anchovy was very scarce, only 2 tonnes were estimated in the 9aN area. It was a good recruitment year with 51% of the biomass corresponding to recruits, but those were found in 8c area. In **2023** anchovy occurred throughout the surveyed area, with the bulk of the distribution located at the inner part of the Bay of Biscay and the North of West Galician coast (9aN). In total 3.2 thousand tonnes, corresponding to 168 million fish were assessed in 9aN.

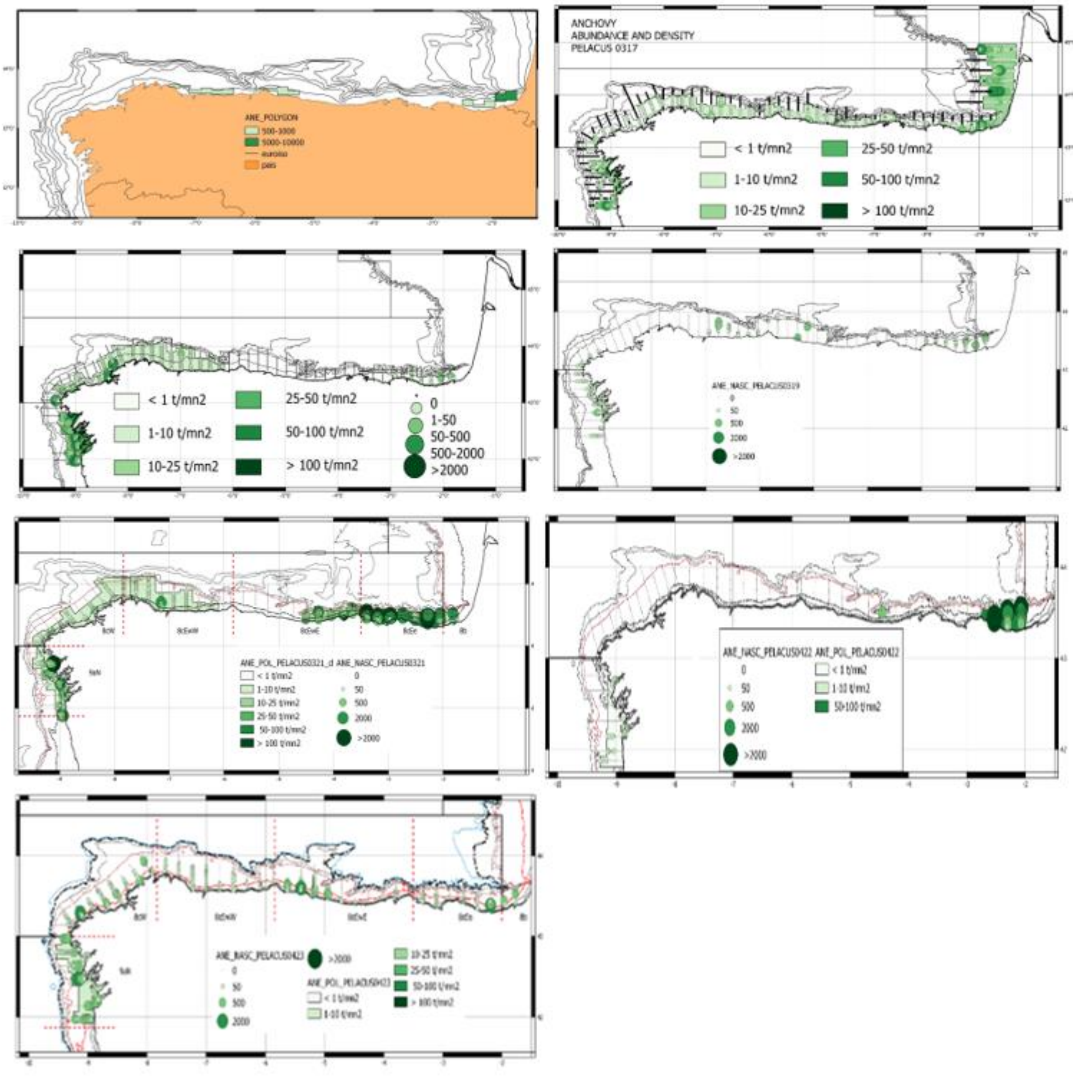


Figure 3.1.2.1 - Acoustic density (NASC m^2 nmi^2) of anchovy in PELACUS survey series from 2016 to 2023.

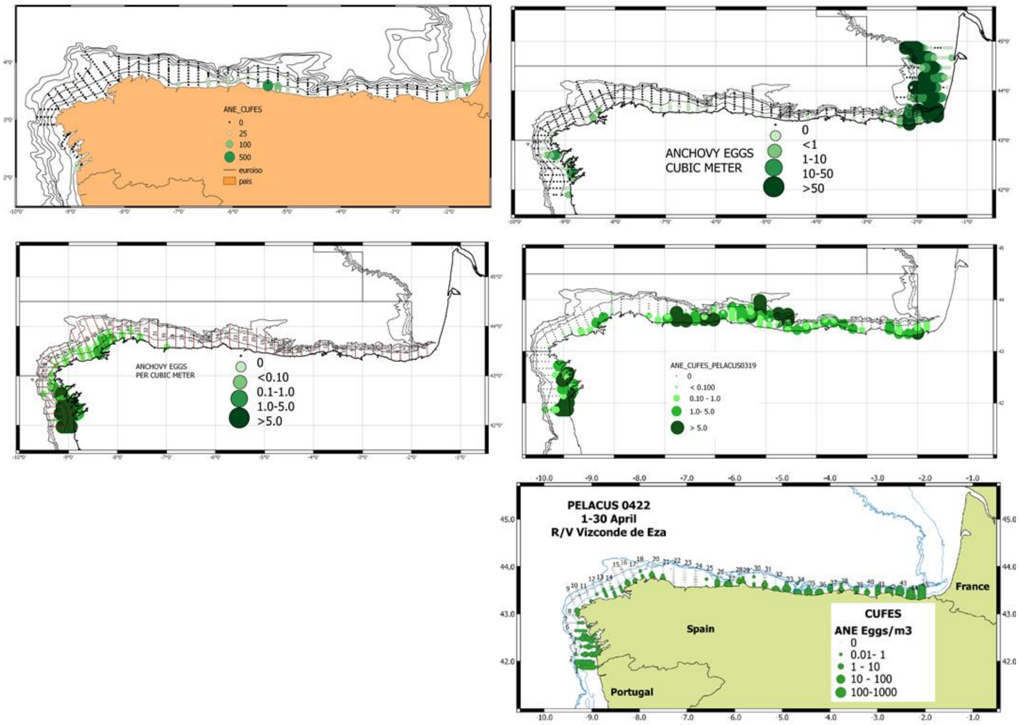


Figure 3.1.2.2 - Anchovy egg density (eggs m3) from CUFES sampling during acoustic surveys of the PELACUS series (IEO) for the period 2016-2019. Egg distributions are represented by density classes according to the colour scale depicted.

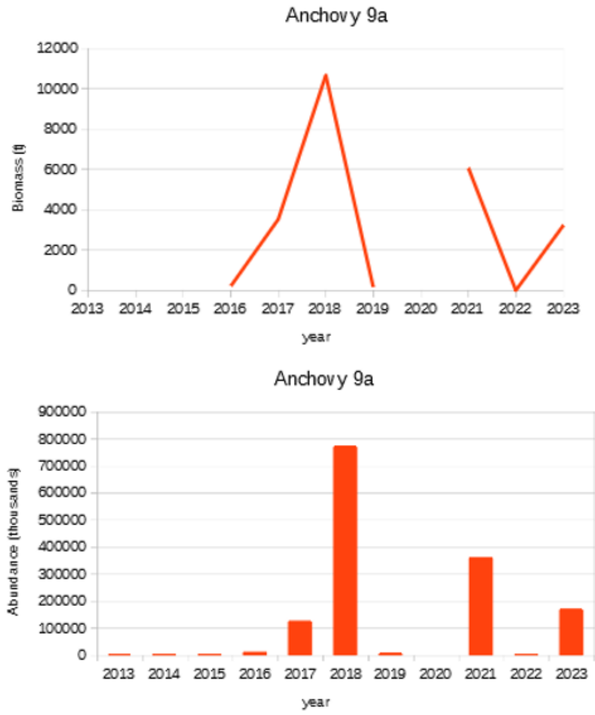


Figure 3.1.2.3 - Anchovy in Division 9a from PELACUS survey series in Biomass (top) and Abundance (bottom).

3.2 SUMMER SURVEYS

3.2.1 – BOCADEVA

The Daily Egg Production Method (DEPM) to estimate the Anchovy Spawning Stock Biomass (SSB) in the Gulf of Cádiz (ICES, Subdivision 9aS, Portuguese and Spanish waters, ane.27.9a) is conducted since 2005 by IEO (Spain). The target population is sampled on a triennial basis. To obtain spawning stock biomass of Anchovy, the BOCADEVA survey is directed at egg abundance and spawning area estimation for daily egg production determination and at adult sampling for daily fecundity calculation. Timing for surveying is the peak spawning period of the targeted species; accordingly, the survey is carried out in summer (July/August) in the Gulf of Cadiz. All surveys covered under the auspices of ICES WGACEGG (Working Group on Acoustic and Egg Surveys for small pelagic fish in NE Atlantic) are considered ecosystem surveys and data collection is not limited to the target species alone. The surveyed area extended from the Strait of Gibraltar to Cape San Vicente (Spanish and Portuguese waters in the Gulf of Cadiz). Plankton samples, along a grid of 21 transects perpendicular to the coast are obtained for the spawning area delimitation and density estimation of the daily egg production. The survey objectives also include characterising oceanographic and meteorological conditions in the study area during the survey. Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

The main objective of the BOCADEVA is to estimate the SSB of anchovies in the Gulf of Cádiz (ICES 9aS), based on the application of the DEPM. Specific objectives are: i) To estimate the extension of anchovy Spawning area in the Gulf of Cadiz; ii) To estimate the Daily egg production (P0) and total egg production (Ptotal) of Anchovy in the Gulf of Cadiz, iii) To determine the egg distribution area and density of other commercial species; iv) To characterise oceanographic and meteorological conditions in the study area during the survey. This survey is internationally coordinated and standardised in the ICES WGACEGG and follows the standardised protocols of Spanish and Portuguese DEPM surveys. Such protocols are discussed and updated in both SGSBSA (2001-2004) and WGACEGG groups.

3.2.1.1. Sampling and processing

Egg Sampling

The sampling egg is carried out in the East - West direction using a PairoVET net in fixed stations as the main sampler. The sampling grid is established on the continental shelf following a systematic sampling scheme, with the 21 transects being perpendicular to the coast and equally spaced 8 nm. Egg samples are taken every 3 nm in the inner shelf (ICES, 2003). The inshore limit of transects is determined by bottom depth (as close to the shore as possible), while the offshore extension is decided adaptively depending on the results of the CUFES sample.

Vertical sampling (PairoVET)

Vertical hauls are carried out with a PairoVET sampler equipped with nets of 150 µm of mesh size. Hauls are carried out up to a maximum depth of 100 m or of 5 m above the bottom in shallower depths, (speed of about 1 m/s). Flowmeters are used to calculate the volume of filtered water during each haul. Egg samples are analysed onboard. A preliminary identification and counting of anchovy eggs and larvae, as well as other commercial species is carried out. Samples are sorted, counted and preserved in a 4 % buffered formaldehyde solution. Anchovy eggs are classified in 11 developmental stages, according to the key proposed by Moser and Ahlstrom (1985).

Continuous sampling (CUFES)

During the CUFES sampling (Checkley et al., 2000) the volume of filtered water (600 l/min, approximately) is also integrated each 3 nm (at a fixed depth of 5 m). The CUFES collector was arranged with a 335 µm net. Anchovy eggs were classified in three stages: No-Embryo (I-III), Early Embryo (IV-VI) and Late Embryo (VII-XI).

Adult sampling

For the adult component of the population, fishing hauls are carried out for the estimation of adult parameters (sex ratio, female weight, batch fecundity and spawning fraction) within the mature component of the anchovy population. Surveying for adults takes place quasi-simultaneously with ichthyoplankton sampling. Fishing hauls should be distributed over the surveyed region according to fish abundance distribution. The number of samples and their spatial distribution is thus organised to ensure good and homogeneous coverage of the survey area and an adequate representation of population demography and distribution. Fishing hauls are conducted by pelagic trawling, following the detection of species schools by echosounder. Except for searching anchovy females with hydrated gonads, fishing stations were mostly conducted during daylight hours and carried out over isobath, once echotraces supposedly belonging to anchovy were detected by echo-sounder. In recent years, adult Anchovy samples for DEPM were obtained during ECOCADIZ survey. For the estimation of spawning fraction (S), a minimum of 30 mature, non-hydrated females per sample is sought, so a minimum of 60 random anchovies are sampled, adding batches of 10 random individuals to the sampling until the goal is achieved or a maximum of 120 anchovies are sampled. Sex-ratio (R), along with other parameters used in the DEPM is also obtained from this random sampling. When hydrated females (HF) appeared, an additional sampling was done in order to obtain a minimum of 150 HF for the whole area. These females were sampled as described above. Gonads from both hydrated and non-hydrated females were preserved in 4% buffered formaldehyde.

Hydrography

The oceanographic conditions of the prospected area are necessary to characterise the spawning area and to estimate egg production. Vertical CTD profiles are taken in each station to obtain temperature, salinity, fluorescence and oxygen of the water column. Also, a continuous sampling of sea surface temperature and salinity was carried out.

3.2.1.2. Historical series

Information about daily egg production, eggs mortality rate, spawning area extension, adult parameters and the final anchovy Spawning Stock Biomass of the Gulf of Cadiz (Spanish and Portuguese waters) estimation is provide to ICES Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA) and ICES Working Group on Acoustic and Egg Surveys for small pelagic fish in Northeast Atlantic (WGACEGG). Detailed and aggregated data are available to the scientific community. Estimates are provided to WGACEGG and WGHANSA both graphically and in a tabulated way in their reports. Furthermore, additional working documents containing more detailed information are also presented in these WGs. WGACEEG is generating a common database from surveys under its scope (IFREMER, IPIMAR, AZTI and IEO). At a national scale, survey data are stored in the SIRENO database. For the time being it has never been used to respond to specific management needs, nevertheless, given this survey is usually conducted during the anchovy peak spawning time, an anchovy SSB estimate is obtained, which may be used for direct stock monitoring. No duplication with other surveys. The Portuguese DEPM survey covers the same area as BOCADEVA (Algarve + Gulf of Cadiz), but takes place in a different season (January-February), and with a different target species (sardine).

The historical values of DEPM parameters and final SSB (2005, 2008, 2011, 2014, 2017, 2020 and 2023) are shown in Table 3.2.1.2.1, and Figure 3.2.1.2.1 and 3.2.1.2.2. On the other hand, the historical series of SSB, both acoustic (ECOCADIZ and PELAGO series) and DEPM (BOCADEVA series) surveys are shown in Table 3.2.1.2.2 and Figure 3.2.1.2.3.

Finally, Figure 3.2.1.2.4 shows the maps of abundance distribution of anchovy eggs density (eggs/m2) by PairoVET along the historical series. The highest densities of anchovy eggs along the series were concentrated in the coastal area between the Bay of Cádiz and Cape Sta. Maria, mainly in Spanish waters. In 2023, exceptionally, a high density of Anchovy eggs was found in the Algarve (Portugal).

Table 3.2.1.2.1 - Anchovy SSB in the Gulf of Cadiz by DEPM. Historical series.

Year	2005	2008	2011	2014	2017	2020	2023
Eggs							
P_0 (eggs/m^2/day) (CV)	50.8(0.80) / 224.5(0.69)	184(0.44) / 348(0.35)	276 (0.32)	313.5 (0.34)	145.8 (0.55)	523.4 (0.38)	181.9 (0.54)
Z (day^{-1}) (CV)	-0.039(0.75)	-1.43(0.29)	-0.29 (1.14)	-0.33 (1.19)	-0.16	-1.11 (0.44)	-0.1228 (0.45)
P_{total} (eggs/day) (x10^{12}) (CV)	0.07(0.76) / 1.06(0.65)	0.31(0.44) / 1.80(0.35)	1.87 (0.36)	1.95 (0.34)	0.74 (0.55)	5.26 (0.38)	1.03 (0.54)
Surveyed area (km2)	11982	13029	13107	14595	15556	16223	13261
Positive area (Km^2)	6139	6863	6770	6214	5080	10058	5662
Adults							
Female Weight (g) (CV)	25.2(0.03) / 16.7(0.04)	23.67 (0.06)	15.2 (0.11)	18.22 (0.08)	16.14 (0.17)	16.63 (0.13)	17.64 (0.25)
Batch Fecundity(CV)	13820(0.05) / 11160(0.05)	13.778 (0.07)	7486 (0.12)	7502 (0.08)	7507 (0.17)	8212 (0.14)	9515 (0.144)
Sex Ratio (CV)	0.53(0.01) / 0.54(0.01)	0.528 (0.005)	0.531 (0.007)	0.54 (0.008)	0.53 (0.009)	0.54 (0.009)	0.519 (0.02)
Spawning Fraction (CV)	0.26(0.07) / 0.21(0.07)	0.218 (0.065)	0.276 (0.036)	0.276(1)	0.234 (0.06)	0.241(2)	0.248(2)
SSB							
Spawning Biomass – tons (CV)	**14673**	**31527(0.32)**	**32757 (0.40)**	**31569 (0.30)**	**12392 (0.61)**	**81466 (0.43)**	**15138 (0.62)**

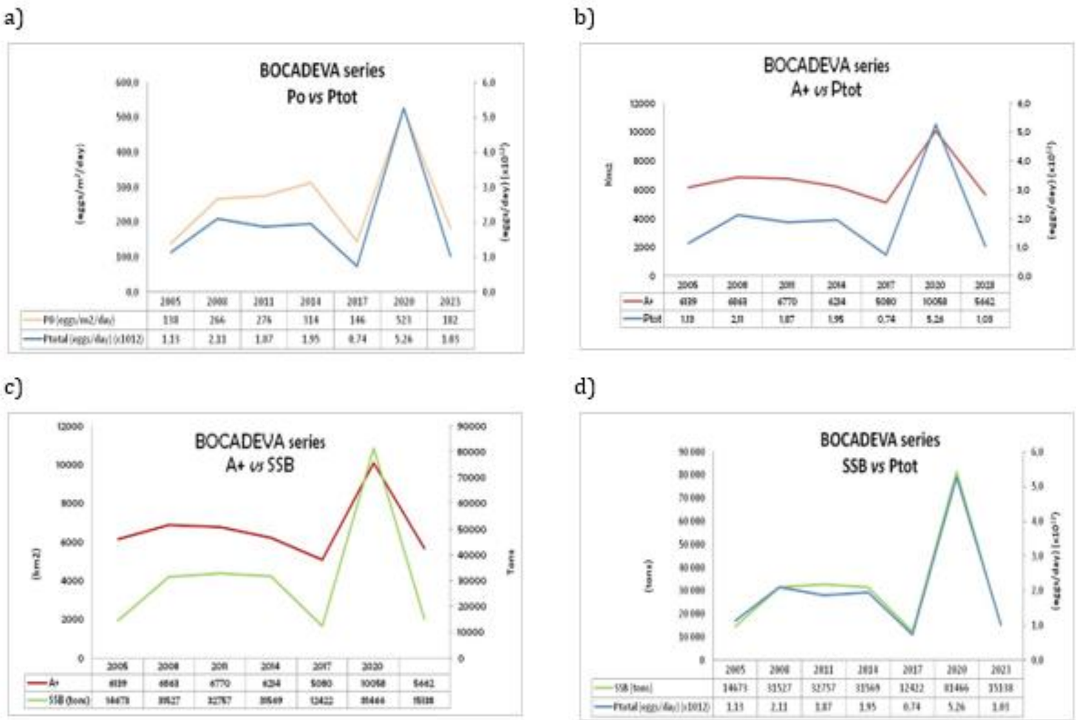


Figure 3.2.1.2.1. Historical values by DEPM (BOCADEVA series) of a) Daily Production (P0) vs Total Production (Ptot); b) Positive area (A+) vs Total Production (Ptot); c) Positive area (A+) vs Spawning Stock Biomass (SSB); d) Total Production (Ptot) vs Spawning Stock Biomass (SSB).

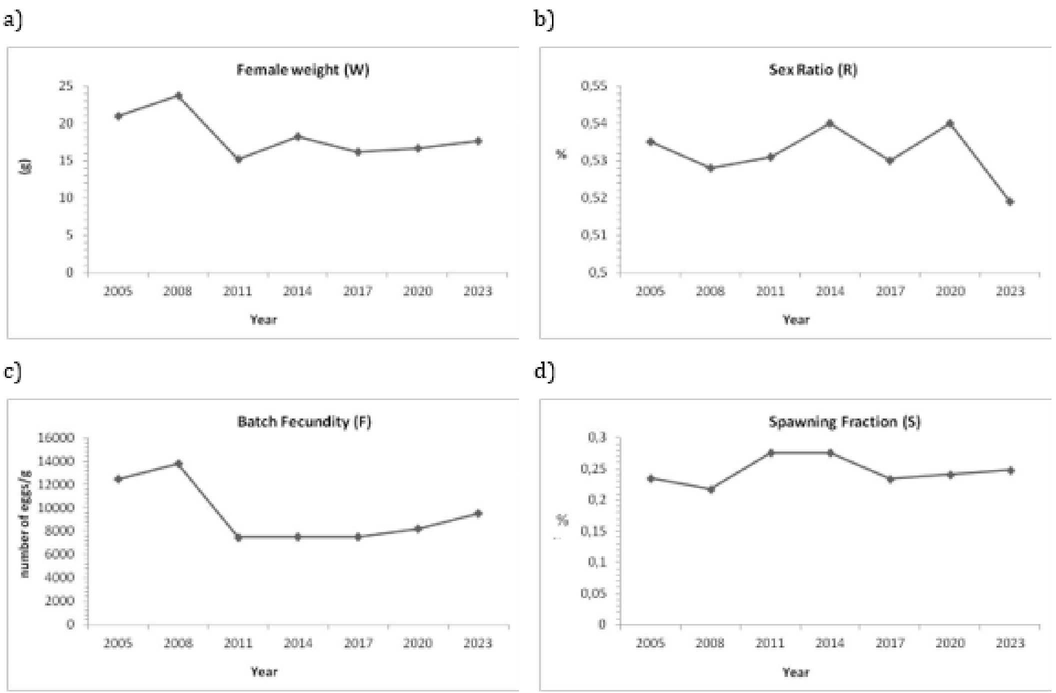


Figure 3.2.1.2.2 Historical values by DEPM (BOCADEVA series) of a) Female weight; b) Sex Ratio; c) Batch Fecundity; d) Spawning fraction.

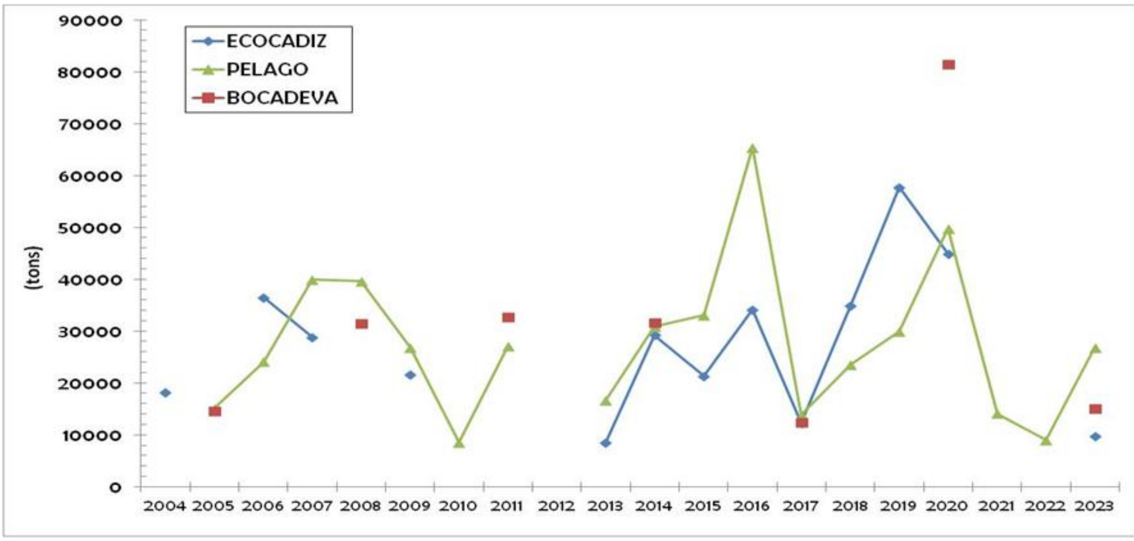


Figure 3.2.1.2.3 - Historical series of biomass (in tons), both acoustic (ECOCADIZ and PELAGO series) and DEPM (BOCADEVA series) surveys.

Table 3.2.1.2.2. Historical values of biomass (in tons) estimates by acoustic (ECOCADIZ and PELAGO series) and DEPM (BOCADEVA series) surveys (*only Spanish waters in 2010).

Year	ECOCADIZ (Acoustic)	PELAGO (Acoustic)	BOCADEVA (DEPM)
2004	18177	-	-
2005	-	15103	14673
2006	36521	24082	-
2007	28882	39965	-

2008	-	39667	31527
2009	21580	26834	-
2010	12339*	8583	-
2011	-	27050	32757
2012	-	-	-
2013	8487	16655	-
2014	29219	30864	31569
2015	21305	33100	-
2016	34184	65345	-
2017	12229	13797	12392
2018	34908	23473	-
2019	57700	29876	-
2020	44877	49787	81466
2021	-	14065	-
2022	-	8972	-
2023	9714	26785	15138

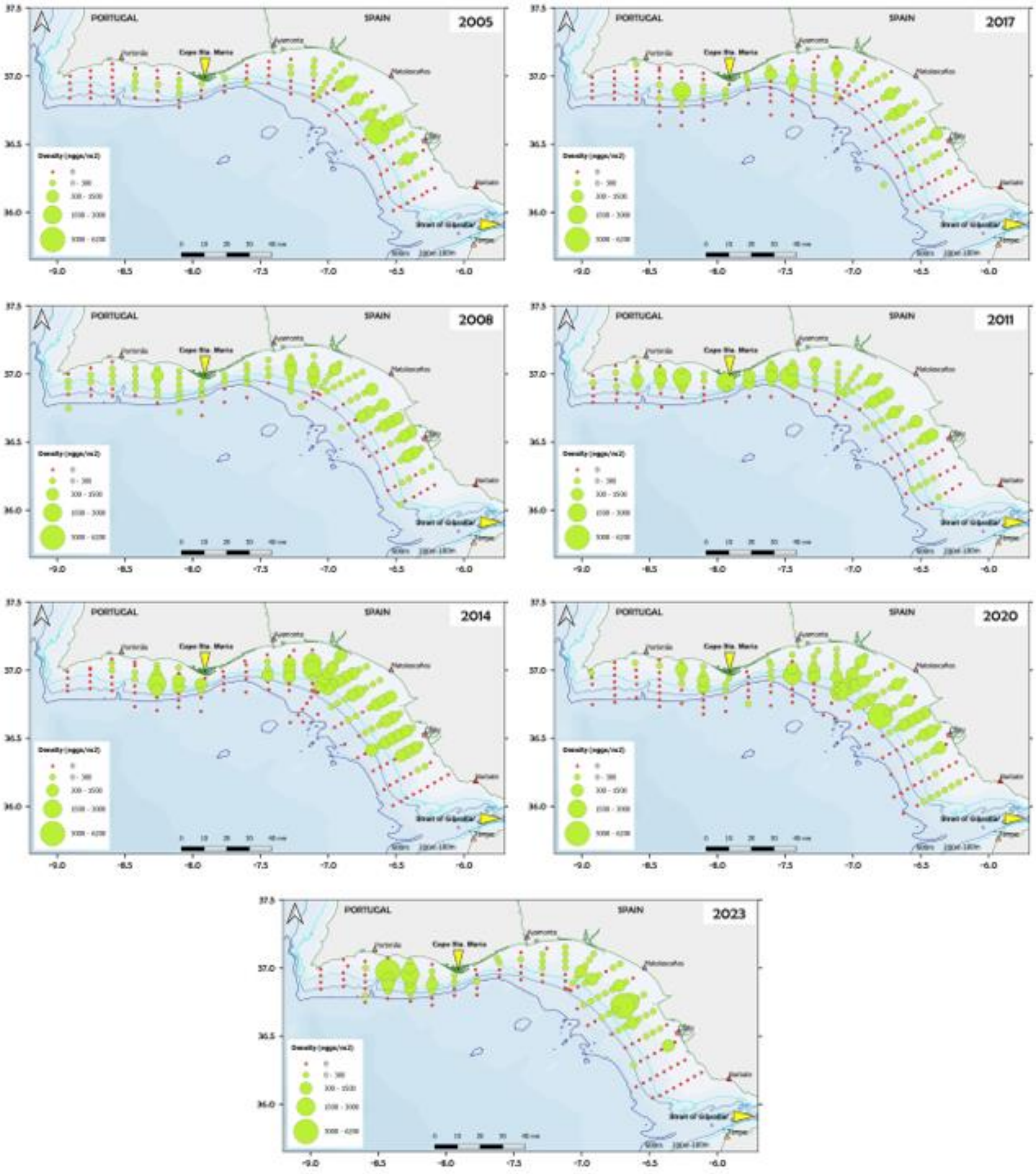


Figure 3.2.1.2.4 - BOCADEVA series. Abundance distribution of Anchovy eggs density (eggs/m2) by PairoVET. Historical series.

3.2.2 – ECOCADIZ SURVEY

The *ECOCADIZ* Spanish survey series is an integrated pelagic community survey series conducted by IEO in the Spanish and Portuguese shelf waters (20 – 200 m depth) of the Gulf of Cadiz (GoC). These acoustic-trawl surveys have been financed by UE-DCF. They were firstly conducted with the RV *Cornide de Saavedra* (2004-2013) and with the RV *Miguel Oliver* (2014-2020) afterwards. Survey dates were initially planned to be coincident with the GoC anchovy peak spawning (late spring-early summer), but these dates were progressively delayed until late July-early August because ship-time availability and prioritisation of other surveys. Such a delay in the survey dates should be taken into consideration when interpreting the acoustic estimates in the temporal (inter-annual) and spatial contexts. Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

The series started in 2004, but with gaps in 2005, 2008 and 2011 because the available ship-time had to be invested in the conduction of the anchovy DEPM triennial survey *BOCADEVA* (see **section 3.2.1**). Since 2014 both surveys are conducted almost synchronously, with the DEPM-ichthyo-plankton component being sampled by the RV *Ramón Margalef* during the *BOCADEVA* surveys and with the *ECOCADIZ* surveys providing adult anchovy samples. The 2009 and 2010 *ECOCADIZ* surveys suffered a shortage of the days at sea (10 and 7 days, respectively) in relation to the duration usually scheduled (ca. 14 days) because of financial problems, which culminated with the cancellation of the 2012 survey. More recently, the 2021 survey was neither conducted because of a serious RV breakdown, nor the 2022 survey because of a cessation of this surveys series. However, acoustic estimates were again available in 2023 during a combined *ad hoc* DEPM/acoustic-trawl survey (*ECOBOCADEVA 0723*) conducted on board the RV *Ramón Margalef*. However, no *ECOCADIZ* survey has been scheduled in 2024 and subsequent years.

Acoustic surveying during *ECOCADIZ* is undertaken in a multi-frequency fashion at a 10 knots speed along 21 transects perpendicular to the coast, covering the whole GoC shelf, and separated 8 nm. Fishing hauls are carried out for species ground-truthing and fish size composition. The time-series' average coverage index of valid fishing hauls/EDSU (*Elementary Distance Sampling Unit*, 1 nm; Simmonds & MacLennan, 2005) is 0.07 hauls/EDSU (ca.23 hauls per survey), one of the highest indices reached in acoustic-trawl surveys of similar characteristics conducted in ICES waters (Doray *et al*., 2021). Egg samples are collected underway every 3 nm, with the CUFES system (water pumped from 3 m from the surface, system fitted with a 335 µm mesh size net; Checkley *et al*., 1997), concurrently to the acoustic surveying along the trajectory of the acoustic transects. Equipment, sampling protocols and estimation methods are described in Doray *et al*. (2021).

Anchovy, together with sardine and chub mackerel (*Scomber colias*), is one of the species with the highest acoustic energy contributions (*i.e. Nautical Area Scattering Coefficient*, NASC, values) to the total acoustic energy recorded in summer for the GoC small pelagic fish assemblage. The species is also one of the most frequent ones and with higher yields in the fishing hauls. The lowest anchovy NASC values were recorded in 2013-2014, 2017 and 2023, and the highest ones in 2016 and 2018-2020. As mentioned above, no information on the NASC values in summer 2021 and 2022 are available since no survey was conducted in those years, hence it is not possible to identify if the most recent low value recorded in summer 2023 is the result of either a progressive decreasing trend during those previous years or a sudden drop. Nevertheless, as it will be presented below, autumn surveys in the last 4 years confirm that the GoC anchovy population levels have been progressively decreasing down to the historical minimum recorded in 2023.

The mapping of the estimated acoustic densities allocated to GoC anchovy indicates a wide geographic distribution of the species over the GoC, with higher densities being in the mid-outer shelf waters (75-125 m depth) between Cape Santa Maria and Bay of Cadiz, and density hotspots over the shelf waters between the Guadiana and Guadalquivir river mouths (**Figure 3.2.2.1**). Anchovy exhibits a persistent spatial pattern in the GoC in summer, with the smallest and youngest fish concentrated in the shallow waters in front of the Guadalquivir mouth and surrounding waters (coinciding with the main recruitment area in the GoC) and the largest ones in the Algarve waters.

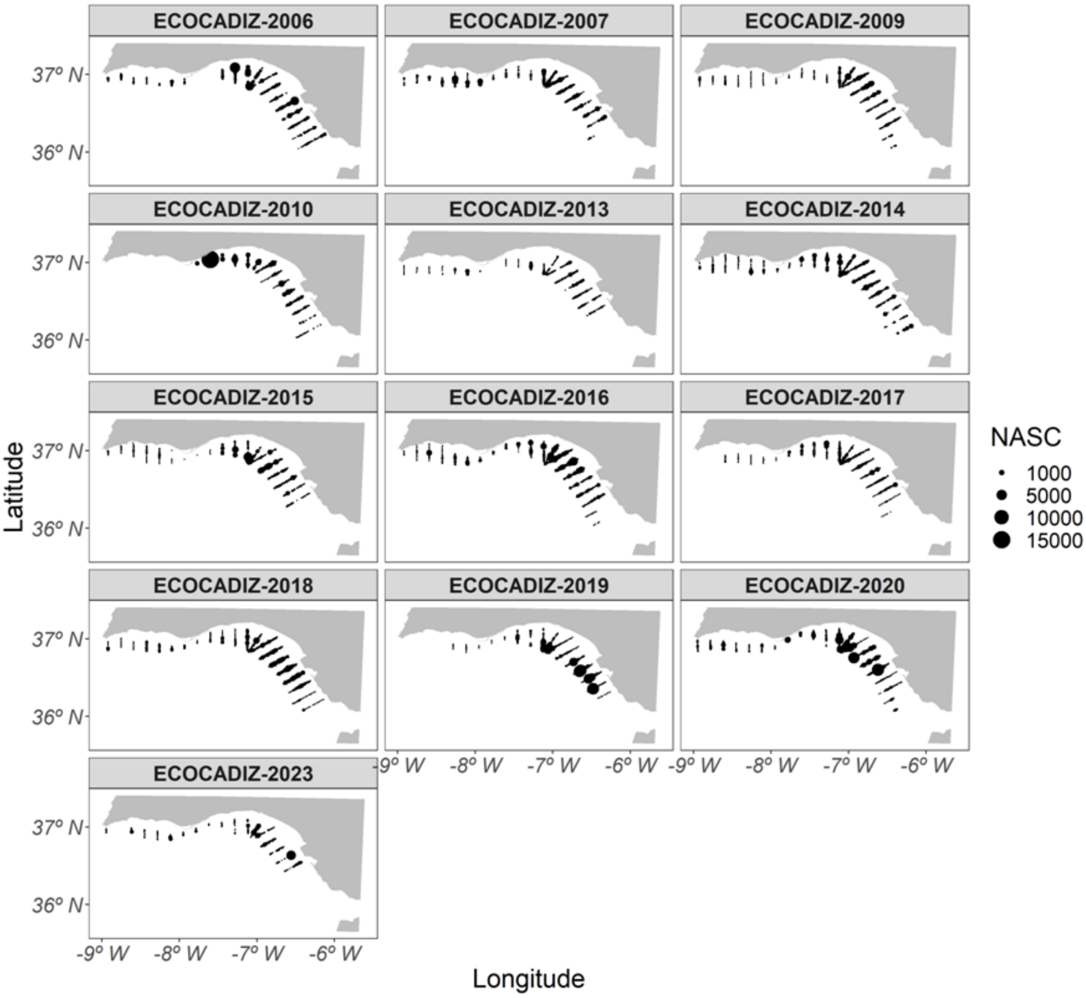
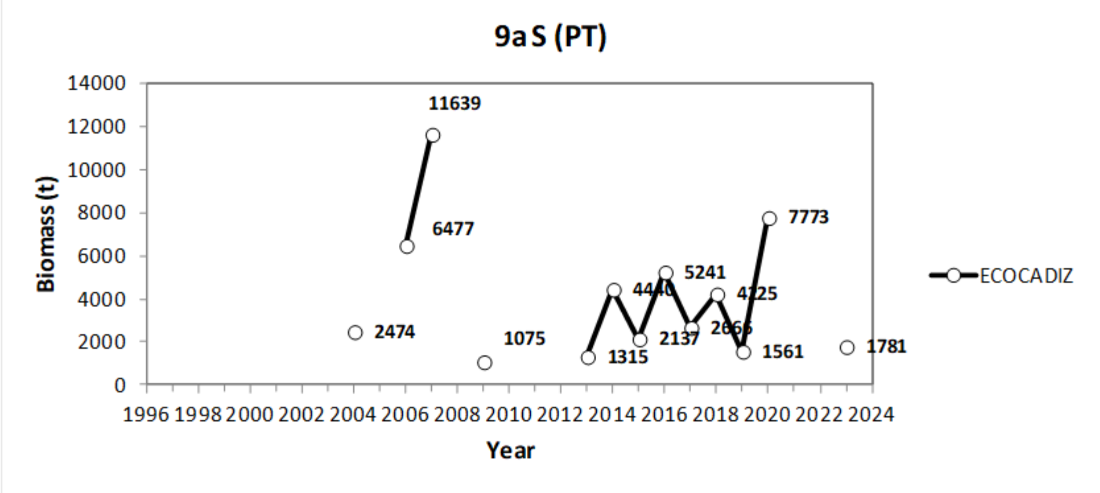
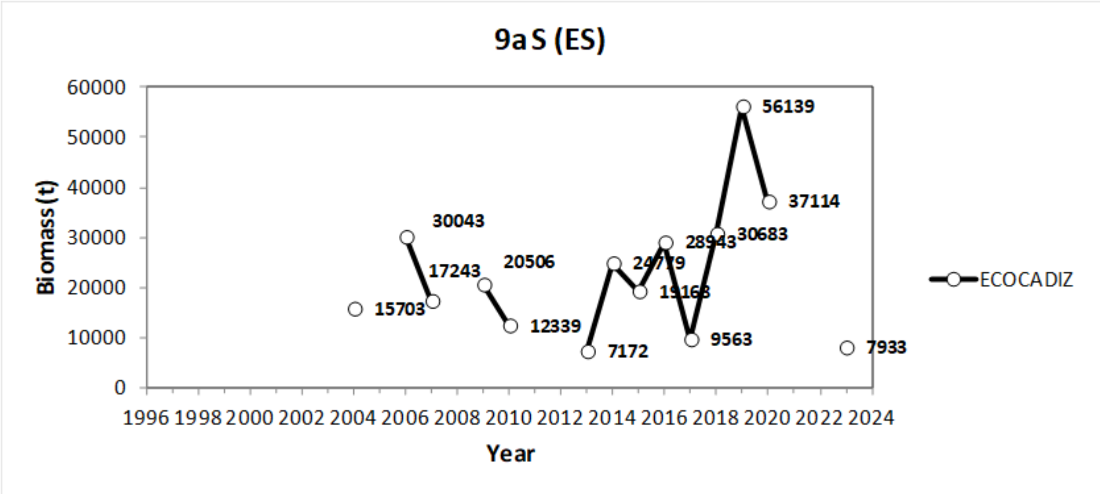


Figure 3.2.2.1 Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Mapping of the distribution of NASC allocated to anchovy. The 2010 survey only surveyed the whole Spanish waters and the 3 easternmost transects off Portuguese waters (sources: IEO, ICES WGACEGG, ICES WGHANSA).

Figures 3.2.2.1 and **3.2.2.2** show the time series of biomass estimates. The estimated abundances (not shown) oscillated between 609 (2013) and 5485 (2019) million fish (time-series average: 2538 million fish). The range of biomass estimates oscillates between 8487 t (2013) and 57 700 t (2019), (time-series average: 27 447 t). Spanish waters, excepting in 2007 when the population was more evenly distributed, usually concentrate more than 80% of the total estimated population biomass. Trends in abundance and biomass are quite similar to the ones described for the *PELAGO* spring surveys series. Summer acoustic biomass estimates were also at the same magnitude that those estimated by the DEMP survey *BOCADEVA* when both surveys were conducted at the same year (as it is the case since 2014), with the exception of the huge estimate from the 2020 DEPM survey (81 466 t *vs* 44 887 t estimated by *ECOCADIZ* and 49 787 t estimated in spring by *PELAGO*). The most recent summer estimates also show a strong drop in the population levels after the historical maximum recorded in 2019.





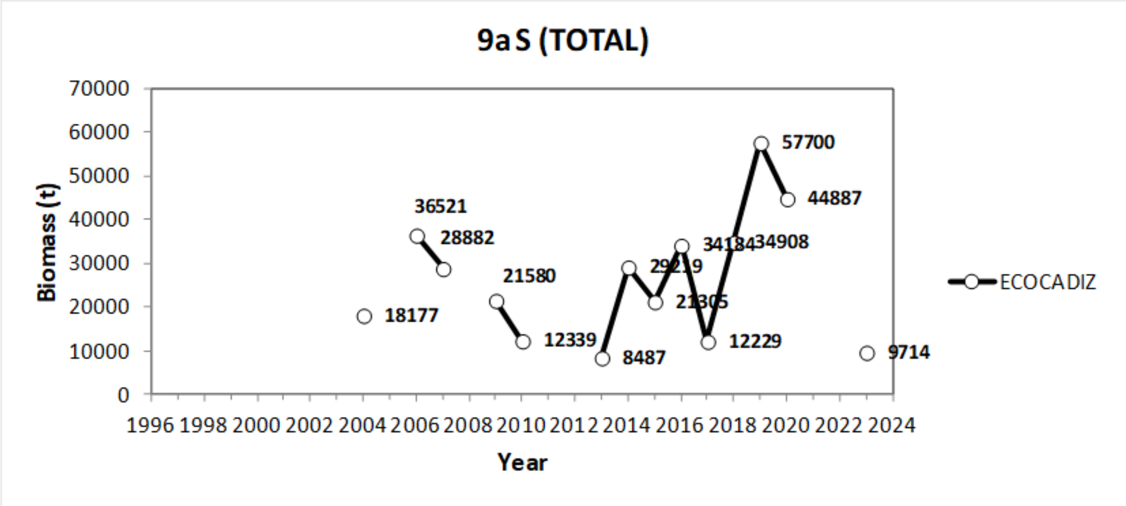
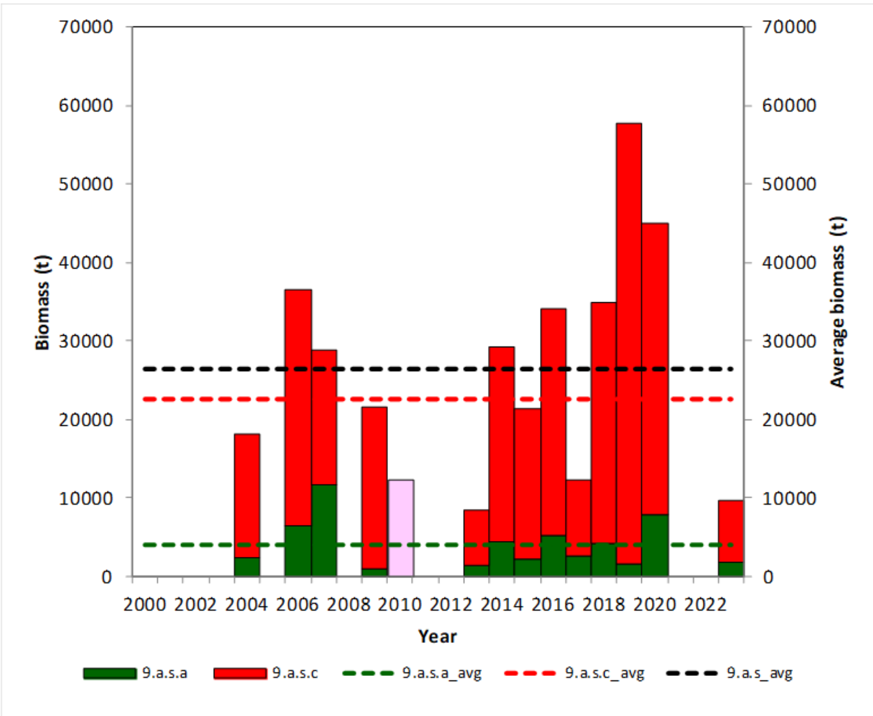


Figure 3.2.2.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Historical series of regional acoustic estimates of anchovy biomass (t). The 2010 survey only surveyed the whole Spanish waters and the 3 easternmost transects off Portuguese waters. Note the different scale of the y-axis (sources: IEO, ICES WGACEGG, ICES WGHANSA).



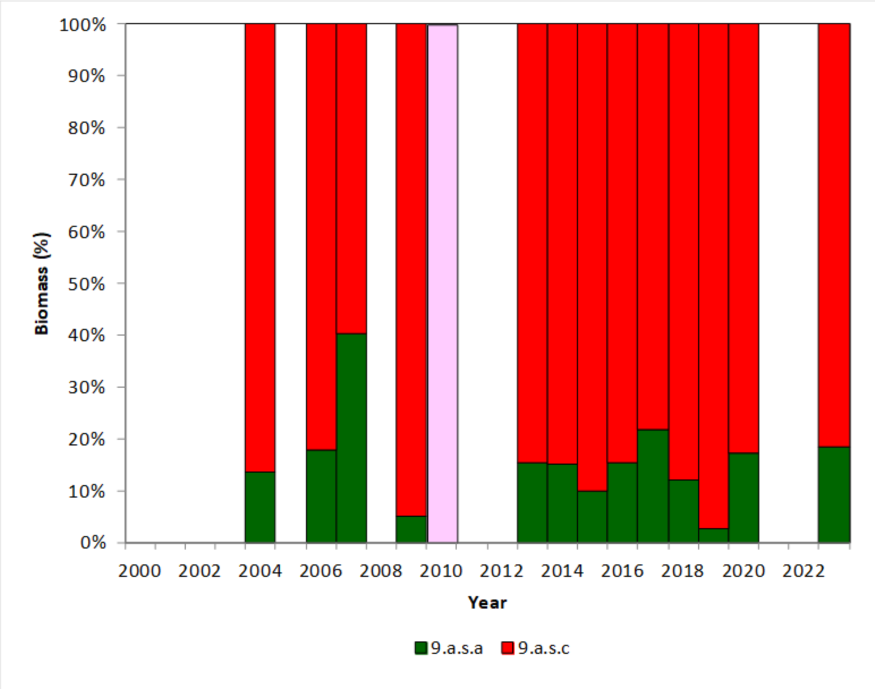


Figure 3.2.2.2. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Top: historical series of regional acoustic estimates of anchovy biomass (t) with indication of the respective time-series averages (9.a.s.a: Portuguese waters; 9.a.s.c: Spanish waters; dotted lines indicate the respective historical regional average estimates). Bottom: relative importance of the regional biomass estimates. Pink colour denotes the incomplete coverage in the 2010 survey, when the whole Spanish waters and only the 3 easternmost Portuguese transects were surveyed (sources: IEO, ICES WGACEGG, ICES WGHANSA).

3.3 AUTUMN ACOUSTIC SURVEYS

According to the estimates provided by the autumn acoustic surveys from 2018 to 2023 targeting sardine and anchovy recruitment (CSHAS, PELTIC, JUVENA, IBERAS and ECOCADIZ-RECLUTAS surveys, Fig. 3.3.1), the core distribution areas of juvenile and adult anchovy are similar to those detected in the spring-time. Anchovy biomass is concentrated along the coastal areas of the Bay of Biscay, in the Gulf of Cadiz and in the north western Portuguese coast. As for spring surveys, there is a gap in the distribution of anchovy in the southwestern Portuguese coast.

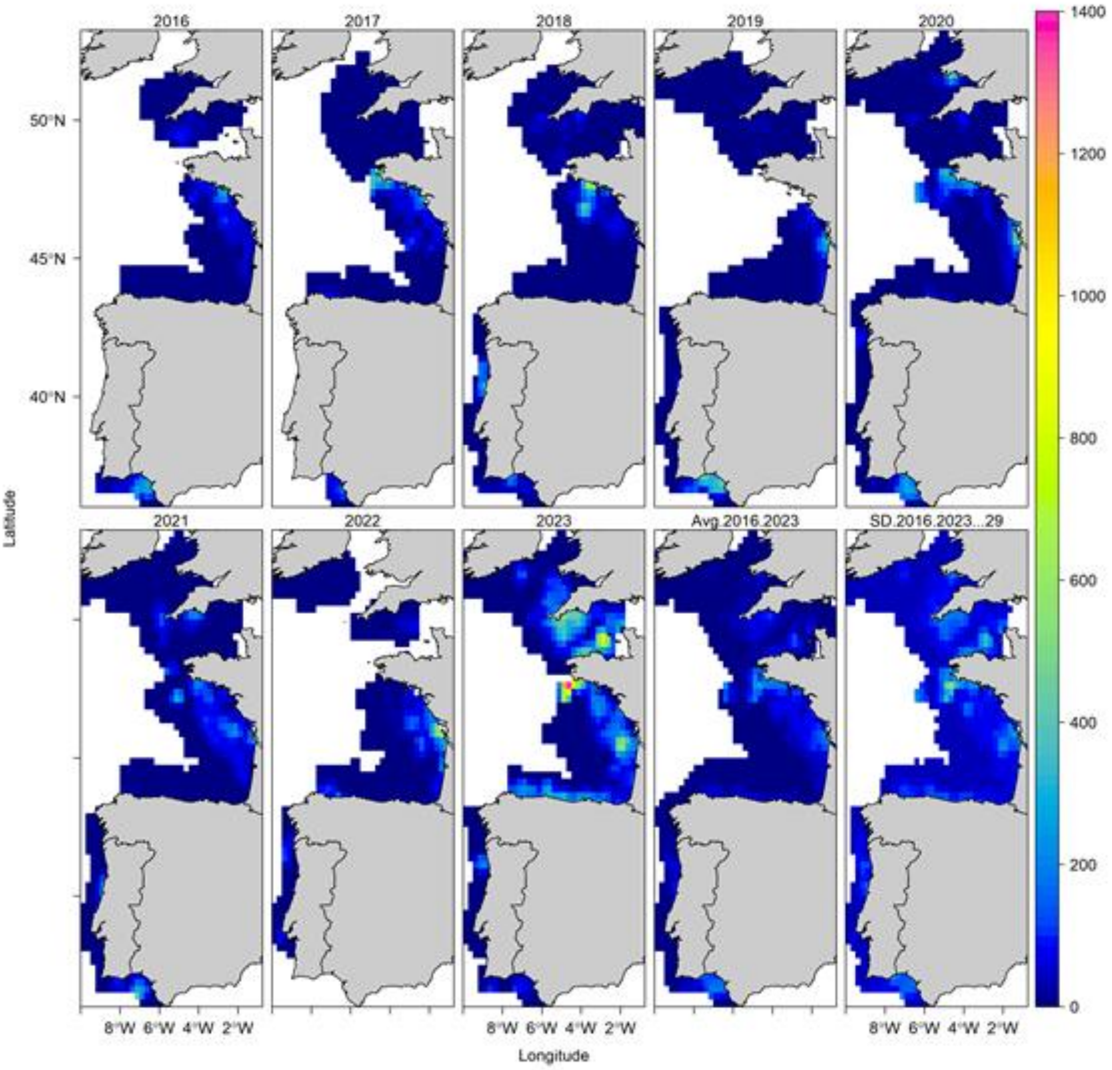


Figure 3.3.1. Adult anchovy mean acoustic density (NASC, $m^2.nm^{-2}$) maps derived from the CSHAS, PELTIC, JUVENA, IBERAS and ECOCADIZ-R Autumn surveys for the period 2016-2023, 0.25° map cells. Source: ICES WGACEGG 2024 report.

3.3.1 – IBERAS SURVEY

Until 2017, an acoustic survey series carried out during autumn to estimate sardine and anchovy recruitment strength was limited to the north western Portuguese coast, 9aCN until Lisbon, at the northern part of the 9aCS (JUVESAR survey series). From 2018 onwards, the surveyed area was extended to the whole Iberian western coast, including Sub-divisions 9aN, 9aCN and 9aCS (IBERAS survey series). Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

During the IBERAS survey series, anchovy abundance was generally low except for 2018 and 2023. For all years, most fish was found in the 9aCN area, with the exception of 2020 and 2023 when most fish was found in the 9aN area. Regarding the 9aCS area, fish were nearly absent for most years (abundance below 0.2% of western component during 2018, 2020, 2021, 2022, 2023) except for the lowest abundance year (2019) when 29% of the fish were located at the northern part of the 9aCS area near Lisbon. A persistent gap with no anchovy present occurs at the southern part of the 9aCS area (Fig. 3.3.1.1, 3.3.1.2).

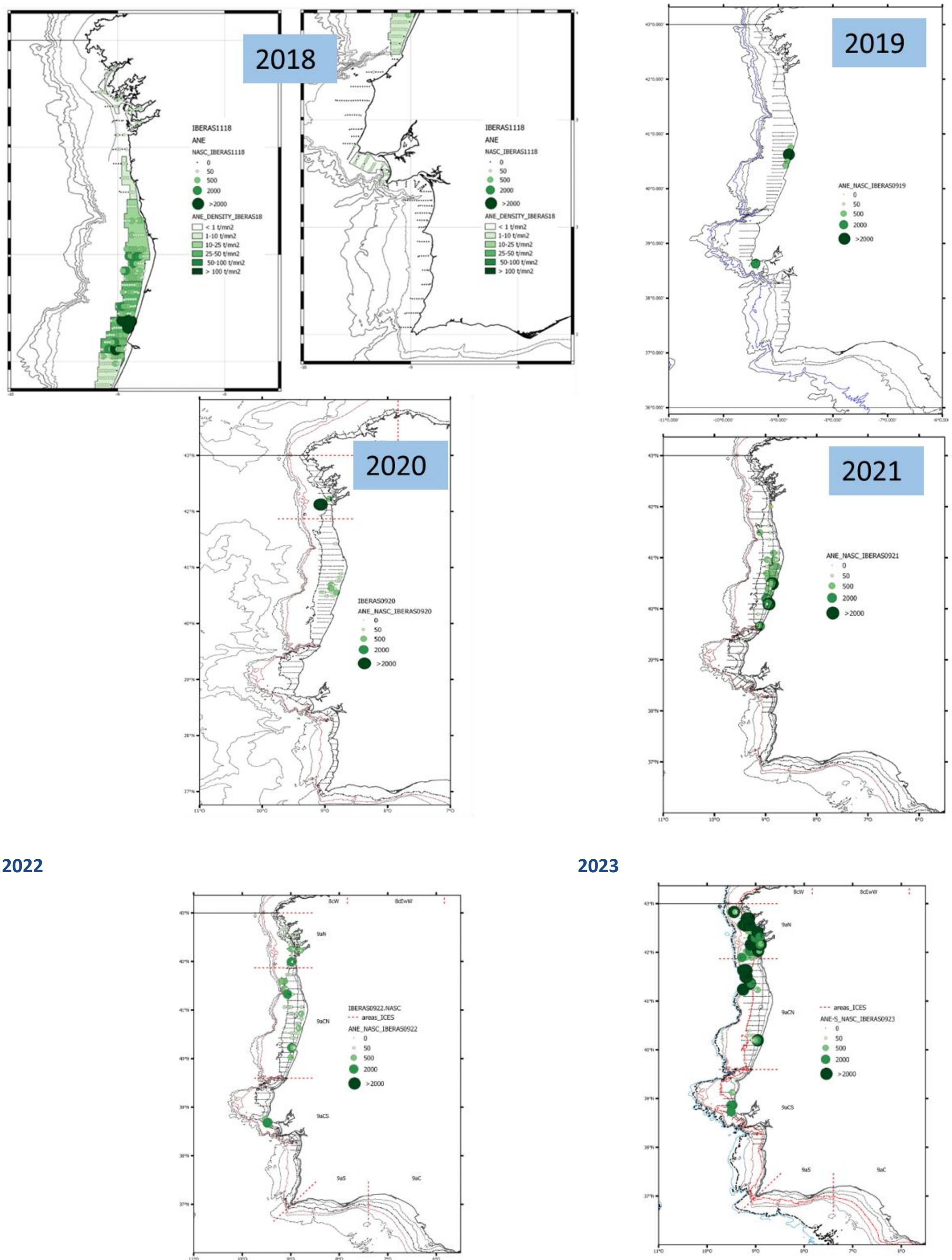


Figure 3.3.1.1 - Map of anchovy in the IBERAS survey series from 2018 to 2021 (allocated NASC at 38 kHz).

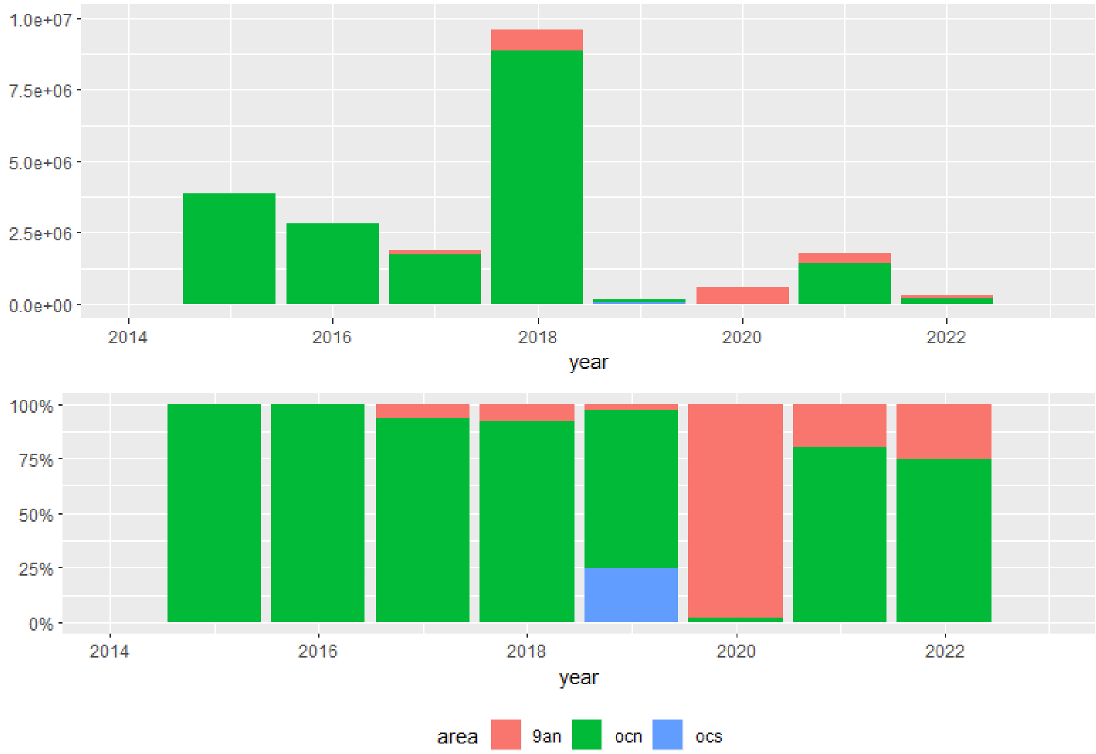


Figure 3.3.1.2 – Biomass of anchovy in the IBERAS survey series from 2018 to 2023, by sub-division (subdivisions 9.a North, 9.a Central-North and 9.a Central-South, total biomass in the upper panel and proportion in the lower panel).

3.3.2 – ECOCADIZ-RECLUTAS SURVEY

The abundance of the anchovy and sardine recruits in the Gulf of Cadiz started to be acoustically assessed by the IEO in autumn 2009. However, that survey was considered a pilot experience due to a series of events that drastically reduced the ship-time and the area covered (Ramos *et al.*, 2010). This autumn survey was conducted again in 2012 as *ECOCADIZ-RECLUTAS 1112*; it was financed by the Spanish Fisheries Secretariat and planned and conducted by the IEO to obtain an autumn estimate of GoC anchovy biomass and abundance. That survey was carried out onboard R/V *Emma Bardán*, but restricted to the Spanish waters only. *ECOCADIZ-RECLUTAS 2014-10* re-started the series two years later, with the surveys being conducted with the R/V *Ramón Margalef* (the 2022 survey was conducted on board R/V *Ángeles Alvariño*, twin vessel of the former) and covering both the GoC Portuguese and Spanish waters as the agreed standard sampling scheme and sampling methods (identical to the ones described for the *ECOCADIZ* summer survey series, but in these autumn surveys no ichthyo-plankton sampling by CUFES is performed; Doray *et al.*, 2021). Since 2014 on, the series should therefore be considered as the standard one. The 2017 survey is not included in the series since it suffered from an unexpected breakdown of the research vessel, leading to an earlier survey's ending and an incomplete coverage of the survey area (only the seven easternmost transects were sampled). The time-series' average coverage index of valid fishing hauls/EDSU is 0.06 hauls/EDSU (ca.20 hauls per survey). The surveys are usually conducted during the 3 last weeks in October, although some deviations to this schedule occurred in 2016 and 2021 (they finished in the first week in November), and in 2020 and 2023 (they started earlier, in late September). The series is also suffering from a progressive reduction in its duration (from 21-20 days to the current 16-15 days). Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

The general objective of these surveys is the acoustic assessment by vertical echo-integration and mapping of the abundance and biomass of recruits of small pelagic species (especially anchovy, sardine and chub mackerel), as well as the mapping of both the oceanographic and biological conditions featuring the recruitment areas of these species in Division 9a. The long-term objective of the surveys is to assess the strength of the incoming recruitment to the fishery of these species the following year.

The highest total NASC values allocated to anchovy were recorded in the 2015-2016 and 2019-2021 periods, and the lowest ones in 2014, 2018 and 2023. Although widely distributed, GoC anchovy mainly occurred in autumn in the mid-outer shelf between Isla Cristina and the Bay of Cádiz, with the hotspots being located in front of the Guadalquivir river mouth (**Figure 3.3.2.1**). The lowest anchovy NASC values were recorded in 2014, 2018 and 2023.

The size and age composition of anchovy throughout the surveyed area confirms the usual pattern exhibited by the species during the survey season, with the largest (and oldest) fish being distributed in the westernmost waters and the smallest (and youngest) ones concentrated in the surroundings of the Guadalquivir river mouth and adjacent shallow waters. **Figures 3.3.2.2** and **3.3.2.3** show the time series of biomass estimates. The estimated abundances (not shown) oscillated between 816 (2023) and 5518 (2019) million fish (time-series average: 2686 million fish). The range of biomass estimates oscillates between 8113 t (2014) and 48 398 t (2019), (time-series average: 21 276 t). Spanish waters, excepting in 2018 when 60% of the population biomass was distributed in Algarve waters, usually concentrate more than 80% of this total estimated biomass. **Figure 3.3.2.4** shows the time-series of estimates for the whole population and age-0 fish. The anchovy population inhabiting the GoC during autumn 2023 was the lowest of the time series and it showed a large decrease in abundance (55%) and in biomass (38%) when compared to last year's estimates. The current estimates are well below than the time-series average. The observed recent strong decreasing trend for the whole population seemed to continue in 2023.

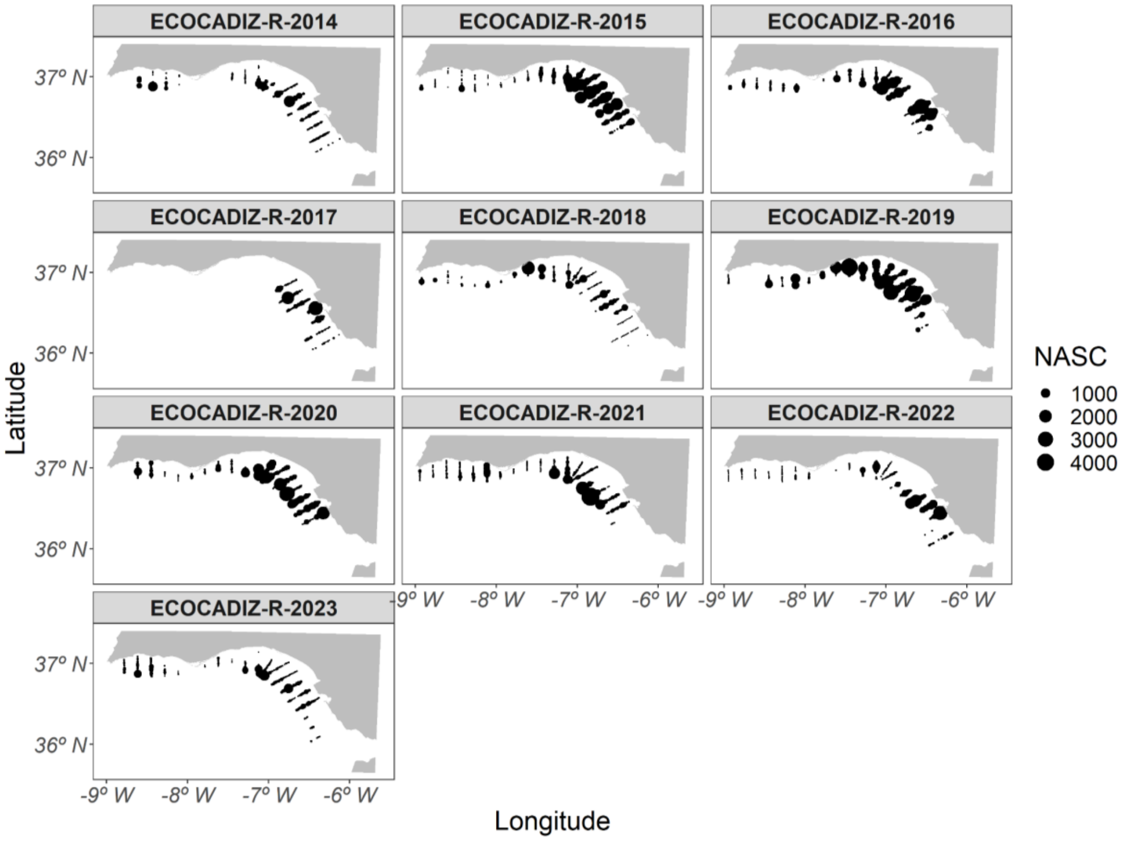
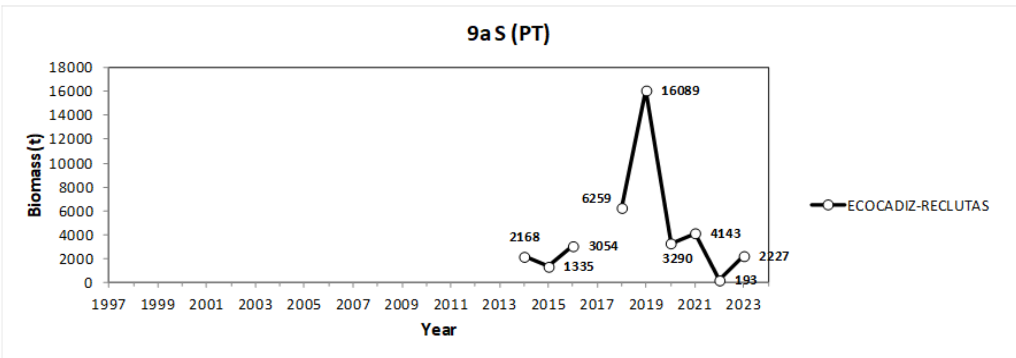


Figure 3.3.2.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Mapping of the distribution of NASC allocated to anchovy. The 2012 survey only surveyed the Spanish waters and has not been included in the figure (sources: IEO, ICES WGACEGG, ICES WGHANSA).



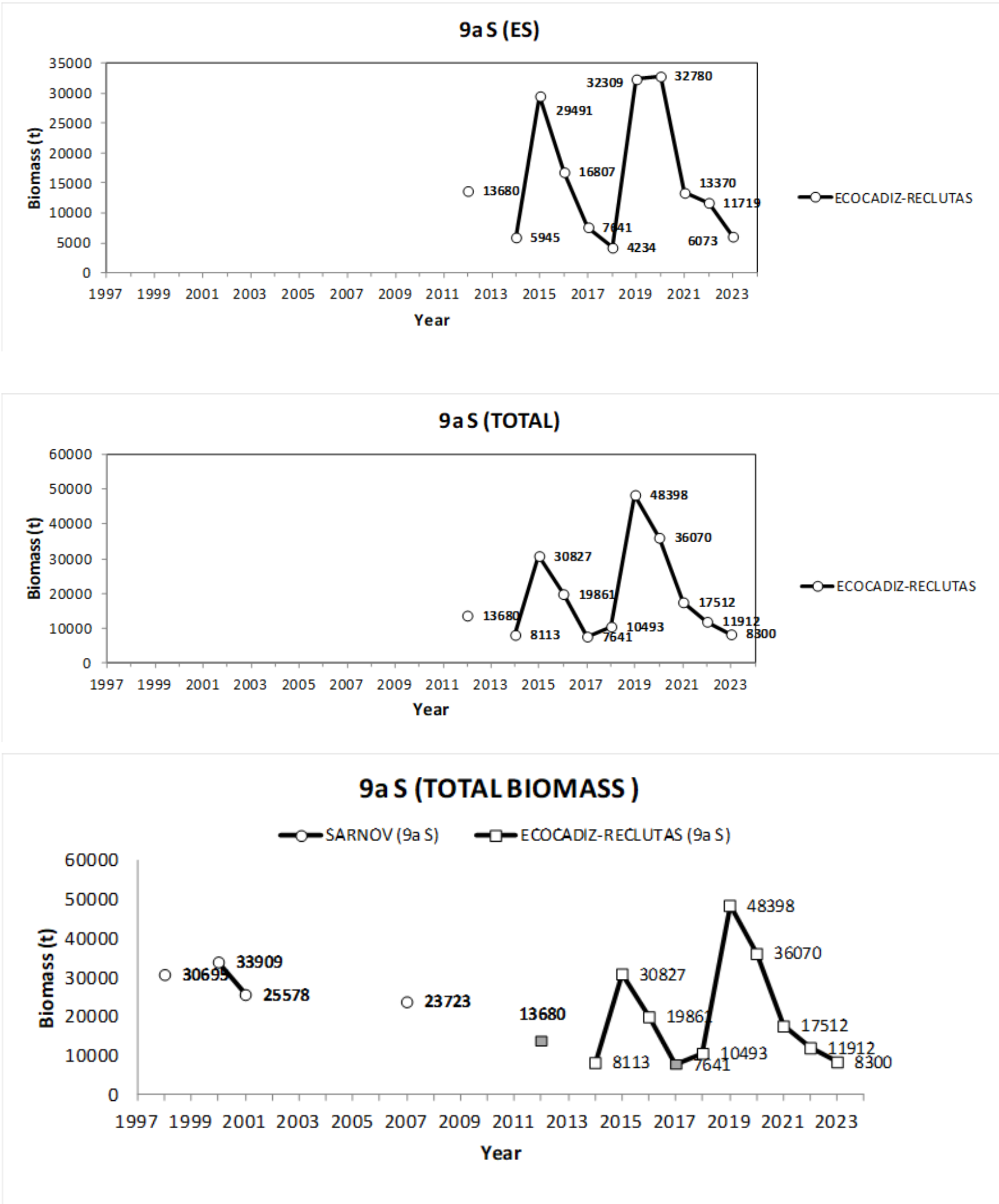
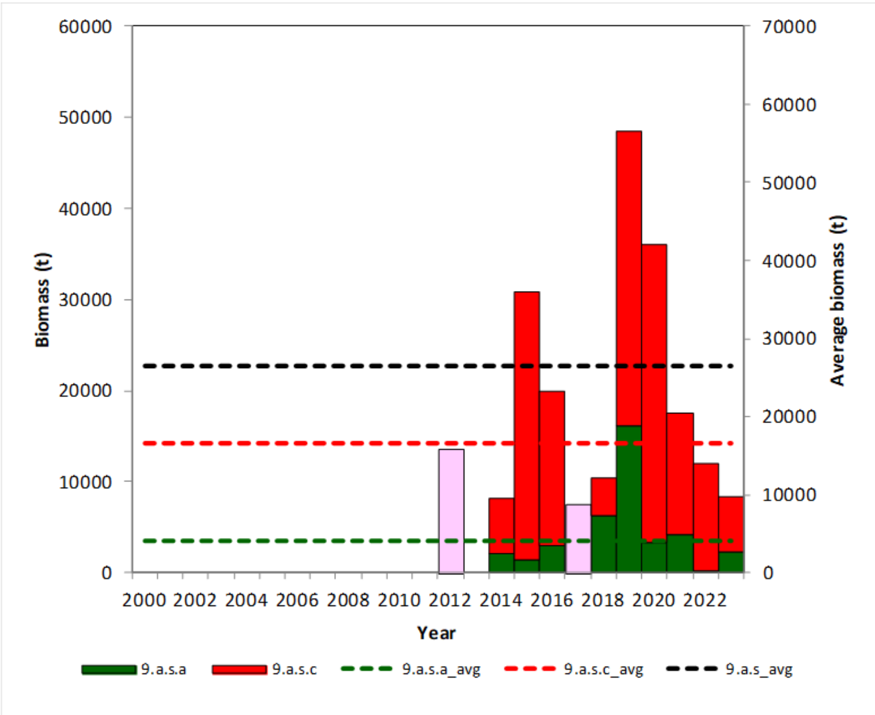


Figure 3.3.2.2. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Historical series of regional acoustic estimates of anchovy biomass (t). The 2012 and 2017 surveys only surveyed the Spanish waters either the whole (2012) or only a part (2017) of these waters. The figure shown in the bottom includes the *SARNOV* autumn Portuguese surveys. Note the different scale of the y-axis (sources: IEO, ICES WGACEGG, ICES WGHANSA).



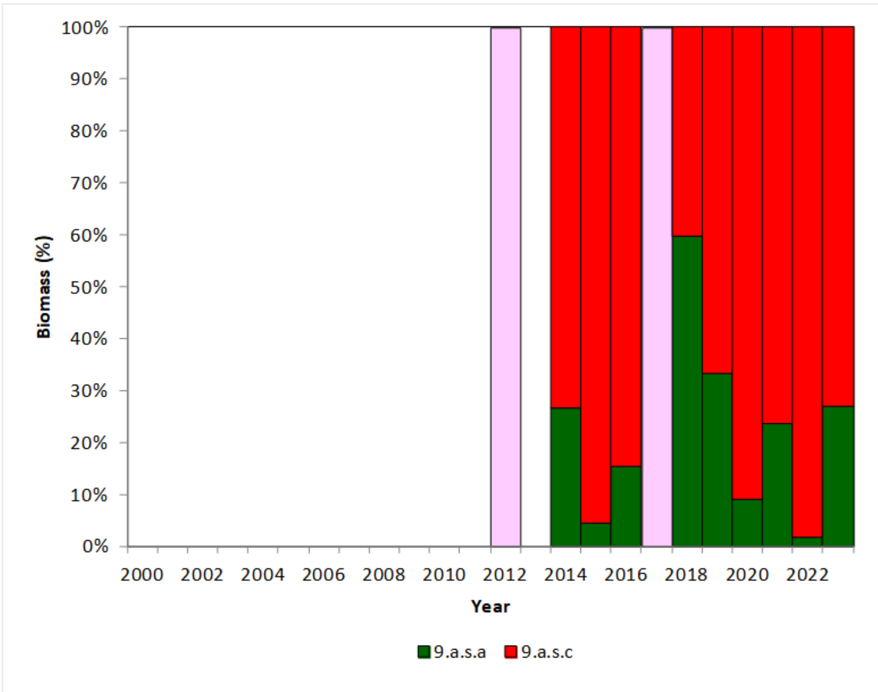


Figure 3.3.2.3. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Top: historical series of regional acoustic estimates of anchovy biomass (t) with indication of the respective time-series averages (9.a.s.a: Portuguese waters; 9.a.s.c: Spanish waters; dotted lines indicate the respective historical regional average estimates). Bottom: relative importance of the regional biomass estimates. Pink colour denotes the incomplete coverage in the 2012 and 2017 surveys, when only the whole or only a part of the Spanish waters were surveyed (sources: IEO, ICES WGACEGG, ICES WGHANSA).

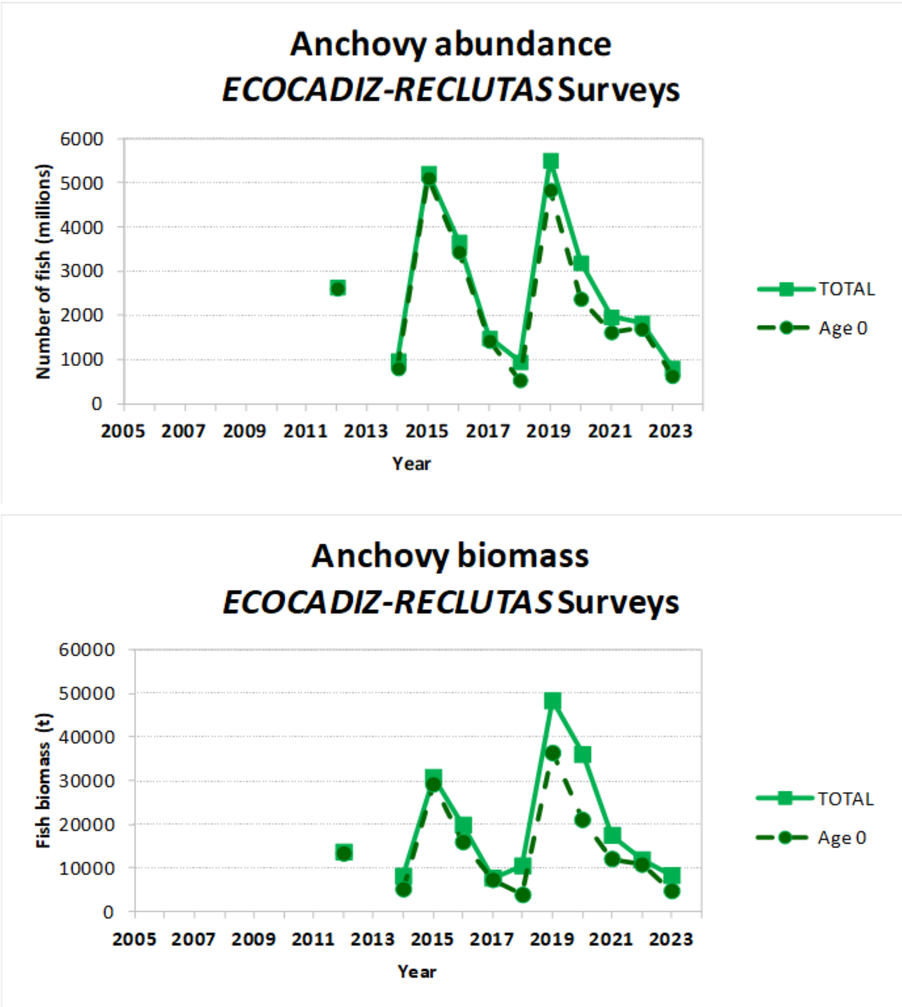


Figure 3.3.2.4. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Historical series of regional acoustic estimates of anchovy total and age-0 abundance (top; in million fish) and biomass (bottom, in t). The 2012 and 2017 surveys only surveyed the Spanish waters either the whole (2012) or only a part (2017) of these waters. Note the different scale of the y-axis (sources: IEO, ICES WGACEGG, ICES WGHANSA).

3.4 - OTHER RELEVANT SURVEY SERIES IN THE CANTABRIAN/ BISCAY

3.4.1 – SAREVA

The SAREVA survey series covers the Galician and Cantabrian waters and is carried out by the *Instituto Español de Oceanografía (IEO)* with the objective of evaluating the sardine stock through the Daily Egg Production Method (DEPM). The series began in 1988 but was interrupted for almost 10 years. Current surveys started in 1997 and have been carried out triennially since 1999. After 2002, the surveys have been conducted within the framework of ICES, with co-financing from the EU. Spanish SAREVA survey is carried out coordinated with the Portuguese

DEPM survey that covers the remaining area of distribution of the stock (Portuguese western and southern coasts and Gulf of Cadiz). Although the survey targets sardine, abundance of eggs, juveniles and adults of anchovy are also estimated. Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

The SAREVA survey series was carried out in March/April in 2017, 2021 and 2023, which corresponds to the beginning or close to the beginning of anchovy spawning season. Although this survey does not target anchovy eggs, these are identified, and the abundance is estimated for the area covered by the survey. Anchovy egg distribution in the SAREVA surveys from 2017 shows that eggs are persistently concentrated in the easternmost area of northern Iberia and also in the northwestern coast of Iberia and westernmost area of northern Iberian waters (Fig. 3.4.1.1). For 2017 and 2021 there is a gap of distribution in the middle of the Cantabrian Sea, off Asturias, while for 2023 the distribution of eggs is continuous throughout the Cantabrian Sea and northwestern Iberian coast.

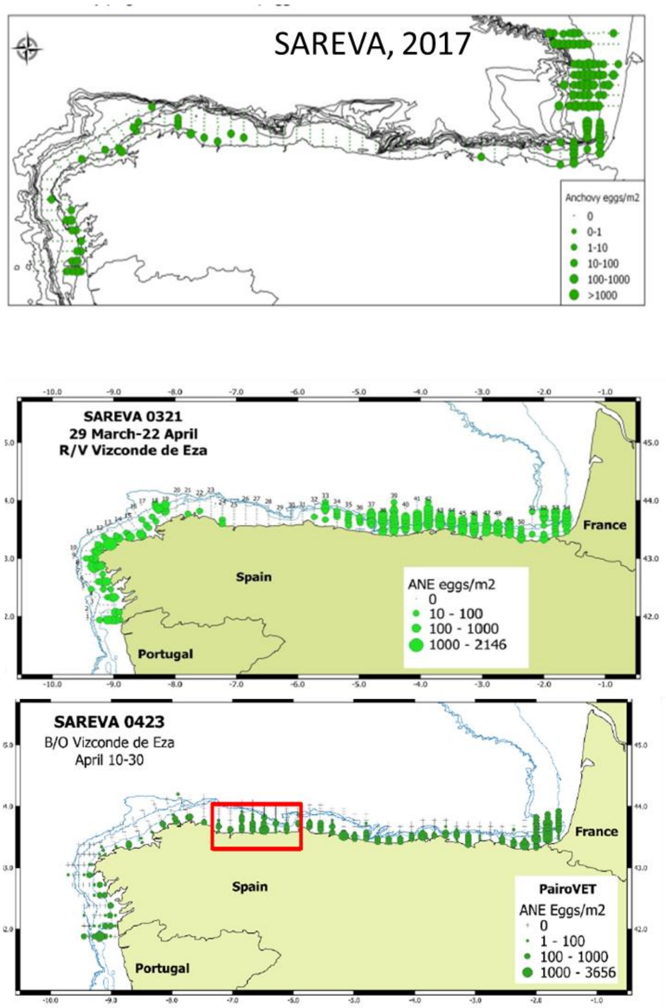
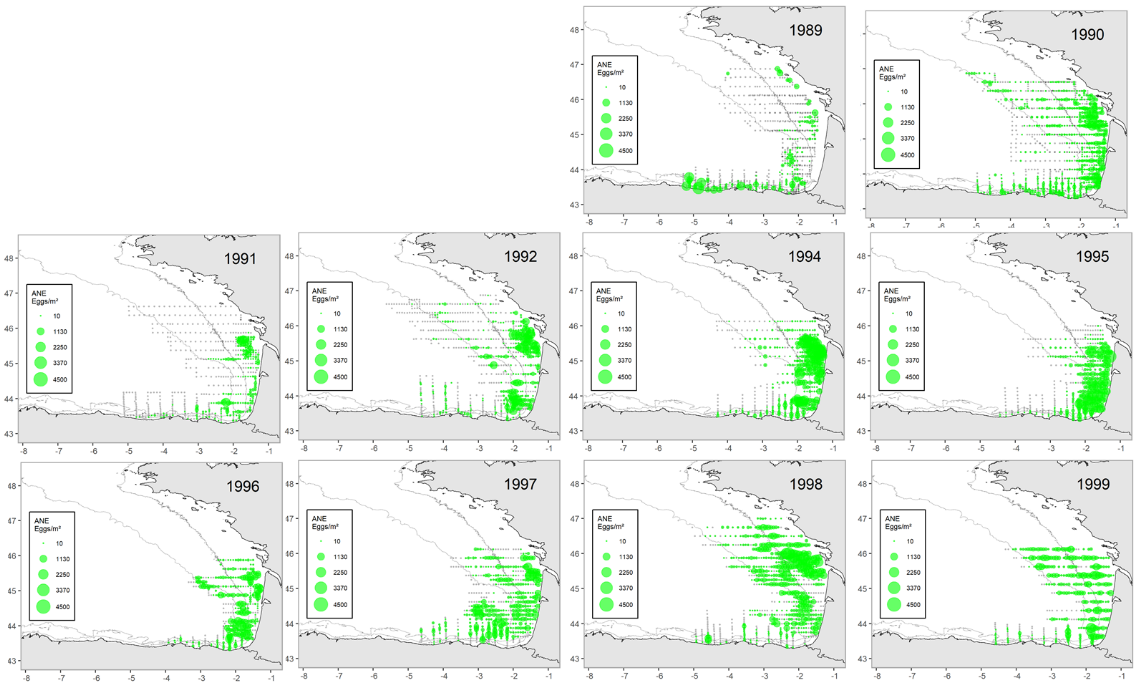


Figure 3.4.1.1 - Density of anchovy eggs estimated in the SAREVA survey series for 2017, 2021 and 2023.

3.4.2 – BIOMAN

The BIOMAN survey series began in 1987, aiming to improve the direct monitoring and assessment of the Bay of Biscay anchovy population. The main objective is the estimation of the spawning-stock biomass of the Bay of Biscay anchovy by applying the daily egg production method (DEPM; Lasker, 1985). In addition, the survey aimed to improve the knowledge on the spawning environment and reproductive biology of anchovy (Santos et al. 2018). Presently, BIOMAN incorporates other objectives within the European Marine Strategy Framework Directive as hydrographic characterization, acoustic estimates, stomach content of fish species, zooplankton distribution, genetics of fish and microchemistry of otoliths. The survey is funded by the Department of Fisheries of the Basque Government within Spain and by the EC since 2002. Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

The survey takes place during the anchovy spawning season (May) and covers the main bulk of the population in the Bay of Biscay. The spatial distribution observed during the BIOMAN survey (Fig. 3.4.2.1) shows a very large increase of anchovy eggs since 2014, with corresponding increase of anchovy biomass estimates in the survey (Fig. 3.4.2.2). A strong relationship between the spawning area and the SSB has been previously reported for this stock (Somarakis et al. 2004). The western expansion of the distribution range since 2014 coincides with the highest SSB estimates and with the years when it started to increase the abundance in the western Iberia (see section 4, Figure 4.1). The expansion further west than in previous years can increase the potential transport of eggs to the western Iberia (see section 6.3.3).



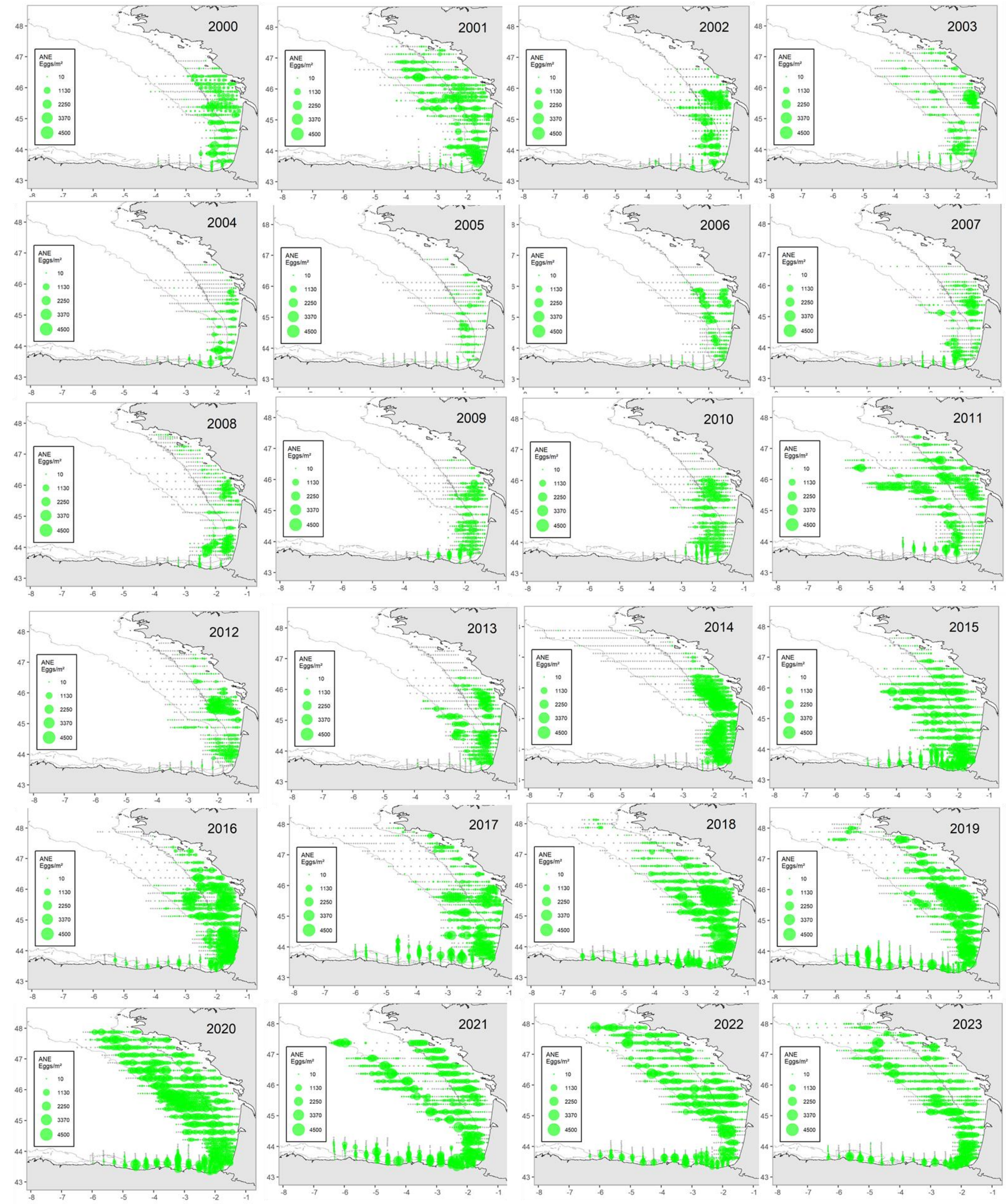


Figure 3.4.2.1 - Anchovy egg distribution and abundance from 1989 to 2023.

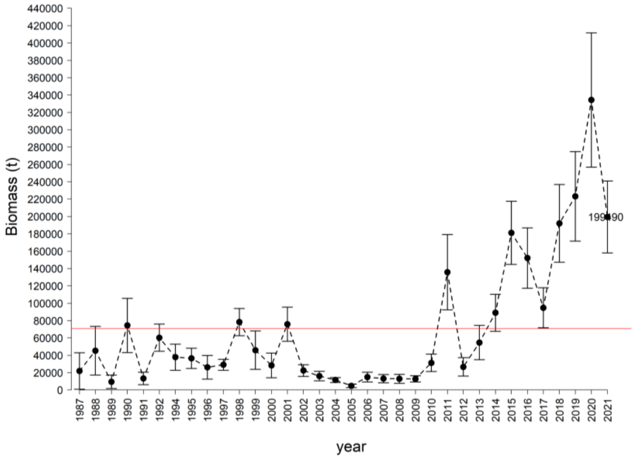


Figure 3.4.2.2 - Historical series of total biomass estimates for anchovy in the Bay of Biscay applying the DEPM. The red line represents the mean of the historical series (70 743 tons).

3.4.3 – JUVENA

JUVENA survey series aims at estimating the abundance of the pelagic community, with emphasis on anchovy juvenile population as an early estimator of recruitment, with trawl-acoustic methodology in the Bay of Biscay at the end of the summer every year. The survey is coordinated between AZTI and IEO. The sampling area covered the waters of the Bay of Biscay (being 7º22’ W and 47º65’ N the limits, Figure 3.4.3.1). Surveys methods and strategies are described in the manual for acoustic surveys coordinated under the ICES WGACEGG (Doray et al., 2021).

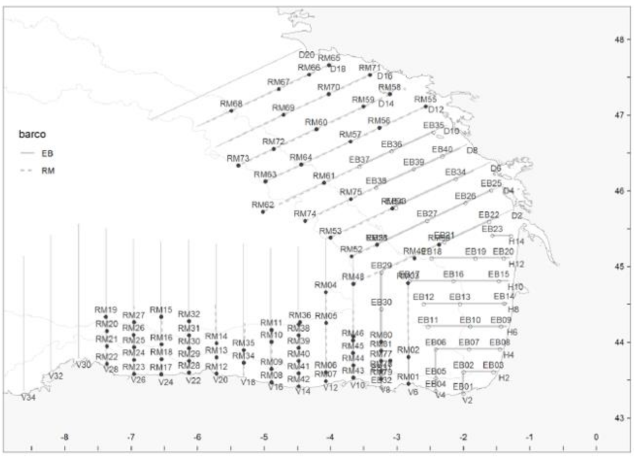


Figure 3.4.3.1 - Transects and stations of hydrography/plankton of the JUVENA 2022 survey.

Similarly to BIOMAN, the JUVENA survey series does not cover the western Cantabrian Sea, as it is focused on the core distribution area of the Bay of Biscay stock. However, it can be seen from the distribution and abundance of anchovy since 2003 (Fig. 3.4.3.2) that abundance started to increase in 2009 but was especially high during 2014, preceding the peak of abundance observed in the western Iberia (see section 4, Figure 4.1). Moreover, from 2014, the distribution of juveniles expanded further to the west Cantabrian Sea, reaching the western limits of the area covered by the survey. Regarding adults, these are mostly concentrated in northern Bay of Biscay, although in some years, large abundances can also be found in the Cantabrian Sea, such as 2011, 2017, 2020 and 2022. These last years precede those when anchovy abundance peaked in western Iberian waters (see section 4, Figure 4.1).

a)

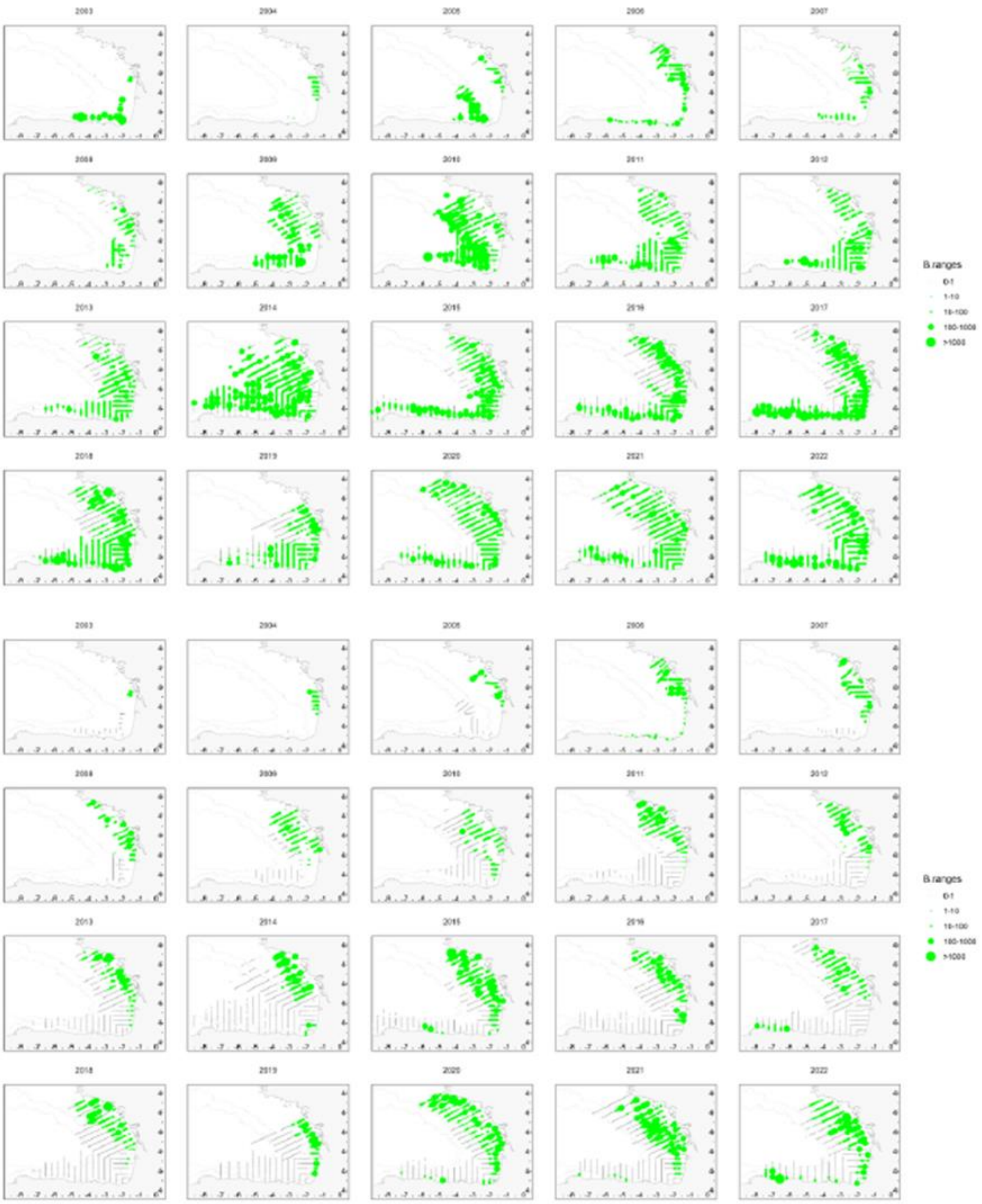


Figure 3.4.3.2 -Spatial distribution and acoustic NASC energy of anchovy juveniles (top) and adults (bottom) from 2003 to 2022.

3.5 - TRAWL SURVEY SERIES – PORTUGUESE CONTINENTAL COAST

Data on the occurrence of anchovy in the time series of demersal trawl surveys since 1990 until 2017 was analysed to investigate the distribution of the species in seasons different from that analysed in the spring acoustic survey series. The surveys follow a fixed grid of 97 sampling stations, spread throughout the shelf between 36 and 710 m. The time series of data (1990–2017) collected by 43 surveys conducted in the fall (26 surveys), summer (10 surveys), spring and winter (5 and 1 survey, respectively). The fishing gear used is a bottom trawl (type Norwegian Campell Trawl 1800/96 NCT) with a 20 mm codend mesh size. The target duration of each tow was 60 min and further details on the methodology of the surveys can be found in Cardador et al. (1997).

Most fish caught in the Portuguese demersal trawl surveys are distributed in the subdivision 9aCN, particularly near Aveiro - Figueira da Foz and in the southern coast (Algarve) (Fig. 3.5.1 and 3.5.2). The occurrence of anchovy in subdivision 9aCS is almost limited to the area around Lisbon, which has a similar trend to that found in the spring acoustic survey series. A persistent gap in distribution in southwestern Iberian waters is evident during all years, including the recent ones when anchovy abundance reached peak values (Fig. 3.5.2).

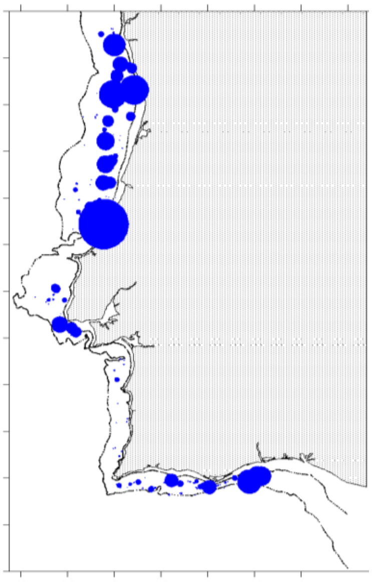


Figure 3.5.1. Distribution of the anchovy in demersal research trawl surveys conducted in the Portuguese continental margin from 1990 until 2017 during summer and autumn months. Symbol is proportional to the square root of the catch rate (number of fish caught per hour). Source: IPMA data.

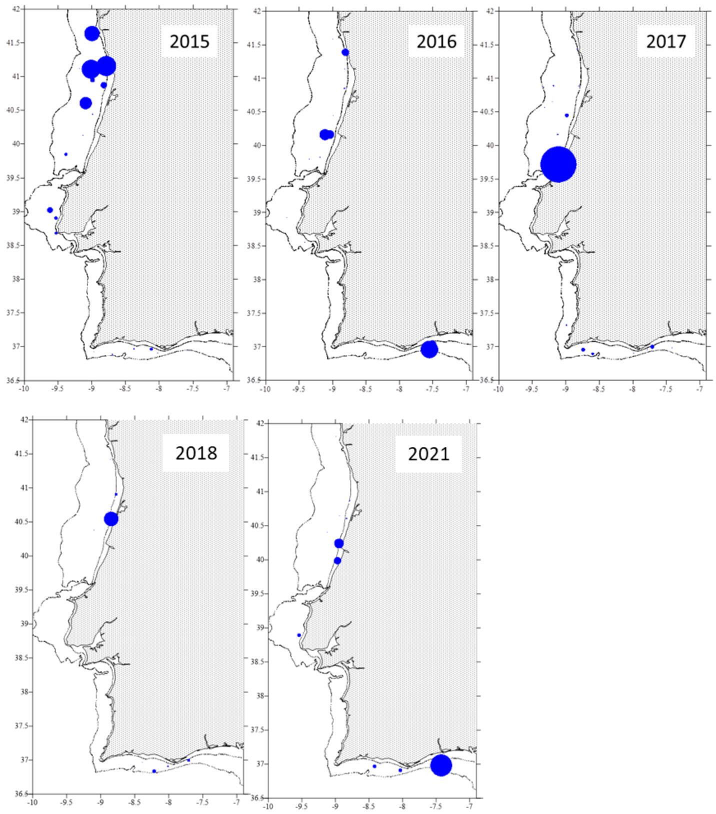


Figure 3.5.2. Distribution of the anchovy in demersal research trawl surveys conducted in the Portuguese west and south coasts from 2015 to 2021 autumn surveys. No survey was carried out in 2019 and 2020. Symbol is proportional to the square root of the catch rate (number of fish caught per hour).

3.6 – ANCHOVY DISTRIBUTION IN PORTUGUESE ESTUARIES

According to different works with seasonal sampling in the Portuguese estuaries were conducted during different years: small anchovy (<10 cm) is frequently detected in estuaries, namely in estuaries of rivers Lima, Douro, Mondego, Tejo, Sado, Mira, Arade and Guadiana (Figure 3.6.1, Table 3.6.1) (França et al. 2011, Ramos et al. 2006, Pombo et al. 2002, Nyitrai et al. 2012, Marques et al. 2007, Ribeiro et al. 2006, Marques 2003, Cardoso et al. 2011, Chicharo et al. 2006, Chicharo et al. 2012), only 1 study did not detect the species, in River Minho estuary (Mota et al. 2014).

Figure 3.6.1 – Location of Portuguese estuaries.

Frequency of occurrence of anchovy during several years in the Aveiro estuary (several studies throughout the 1900' until 2000) showed a persistence of the species in the estuary (Nyitrai et al. 2012) as reproduced in Table 1.

Table 3.6.1 – Occurrence of several species including anchovy in the Portuguese estuary of Ria de Aveiro, summarised in Nyitrai et al. (2012).

TABLE II. Fish species, grouped by families, that have occurred in the Ria de Aveiro.

Family	Species	1912	1915	1981	1988	1997	1999	2000
Ammodytidae	*Ammodytes tobianus*	×	×	×	×		×	
Ammodytidae	*Gymnammodytes cicerelus*							
Ammodytidae	*Hyperophus lanceolatus*	×		×	×		×	
Anguillidae	*Anguilla anguilla*	×	×	×	×	×	×	×
Atherinidae	*Atherina boyeri*				×	×	×	×
Atherinidae	*Atherina presbyter*	×	×	×	×	×	×	×
Balistidae	*Balistes carolinensis*						×	
Belonidae	*Belone belone*	×	×	×	×	×		
Blennidae	*Lipophrys pholis*	×	×					
Blennidae	*Parablennius gattorugine*	×	×	×	×		×	×
Blennidae	*Parablennius sanguinolentus*	×			×		×	
Callionymidae	*Callionymus lyra*		×	×	×	×	×	×
Carangidae	*Trachurus trachurus*	×		×		×	×	×
Centrarchidae	*Micropterus salmoides*			×				
Clupeidae	*Alosa alosa*	×	×			×	×	×
Clupeidae	*Alosa fallax*	×	×	×	×	×	×	×
Clupeidae	*Sardina pilchardus*	×	×	×	×	×	×	×
Clupeidae	*Sprattus sprattus*	×	×	×				
Cobitidae	*Cobitis taenia*			×	×			
Congridae	*Conger conger*	×	×	×			×	
Cottidae	*Taurulus bubalis*	×			×			
Cyprinidae	*Barbus bocagei*		×	×				
Cyprinidae	*Carassius auratus*	×						
Cyprinidae	*Carassius carassius*	×	×	×	×	×		×
Cyprinidae	*Rutilus macrolepidotus*	×	×	×				
Engraulidae	*Engraulis encrasicholus*		×	×	×	×	×	×
Gadidae	*Ciliata mustela*	×	×	×	×		×	×
Gadidae	*Gaidropsarus mediterraneus*	×	×		×			

A comparative study of many of these estuaries revealed very high abundance in the Sado estuary from May to July 2006 (França et al. 2011).

4. HISTORIC DYNAMICS OF STOCK BIOMASS SIZE INDICATORS

The distribution of anchovy biomass between the western and southern components of the 9a stock, as shown from the PELACUS and PELAGO spring acoustic survey series (Fig. 4.1) shows that, in the beginning of the time series (2007 to 2015), most anchovy biomass was recorded in the southern Iberia (>70%), with the exception of 2011 when anchovy increased in the west and comprised 34% of anchovy biomass in the 9a Division. Since 2016, the biomass in the western component has increased sharply and a similar biomass estimate was registered for the two components during 2016, 2017 and 2020 but significantly higher in the west in 2018 and 2021, the peak biomass years for the western component, representing > 70% of anchovy biomass in the 9a Division.

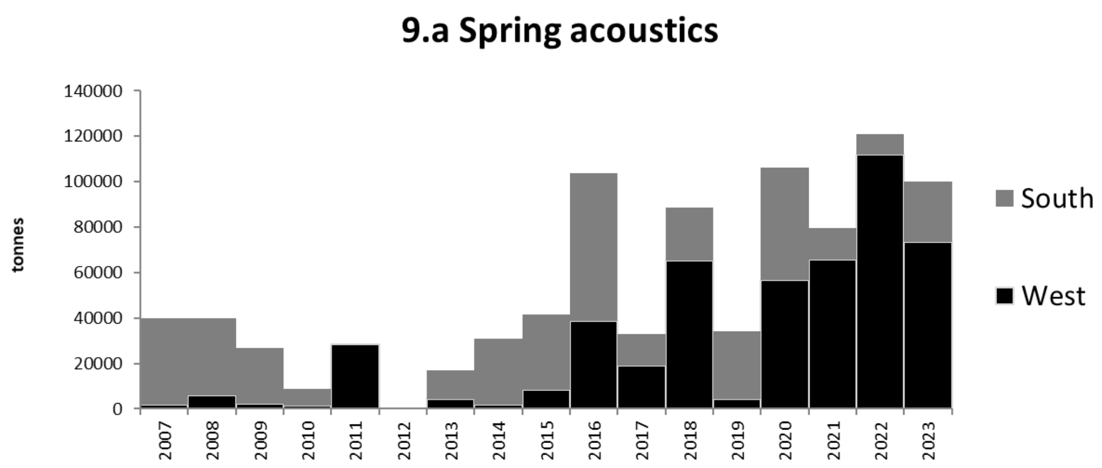
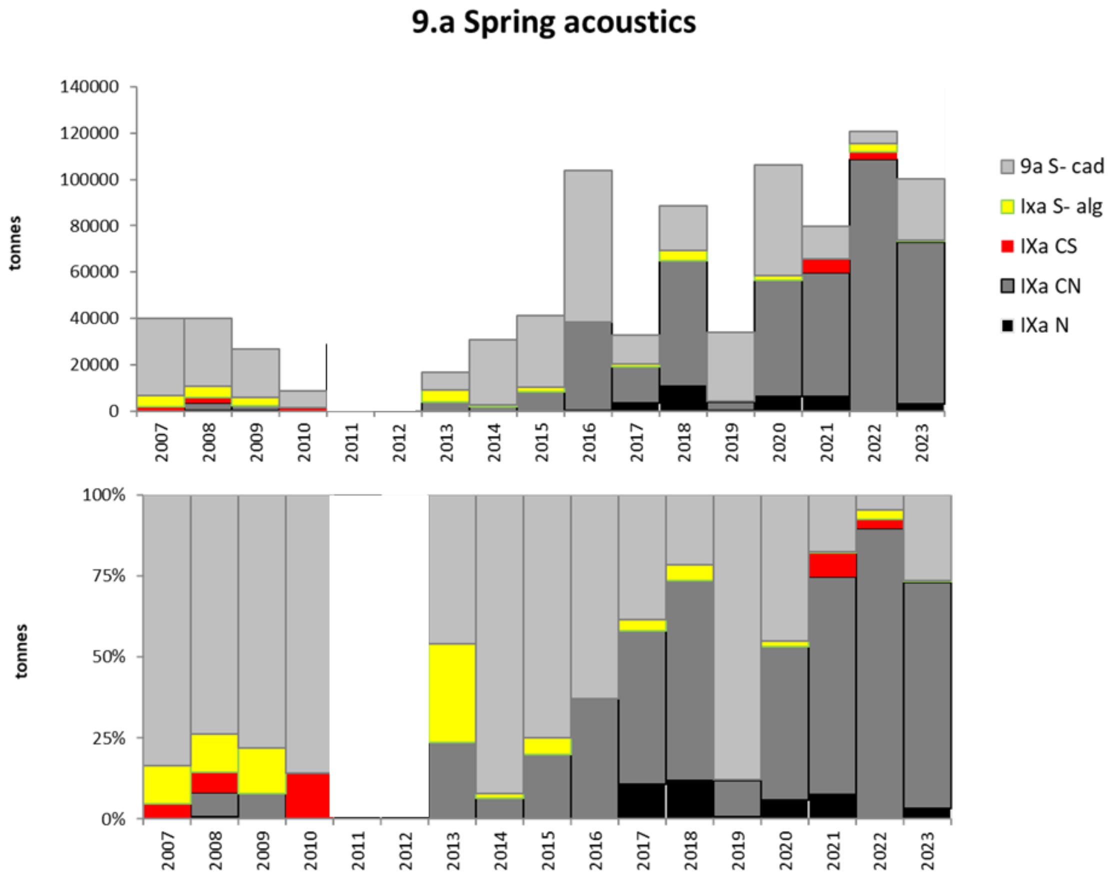


Figure 4.1. Distribution of anchovy biomass between the western and southern components of the 9a stock.

Within the western Iberia (comprising sub-divisions 9aN, 9aCN and 9aCS), most anchovy is concentrated in the 9a-Central North, followed by the 9a North while anchovy is absent or has residual abundance in the 9a Central South during most years. In Southern Iberia, most anchovy is located in the 9a South Cadiz area, and anchovy in the 9a South Algarve has a residual abundance (Fig. 4.2).

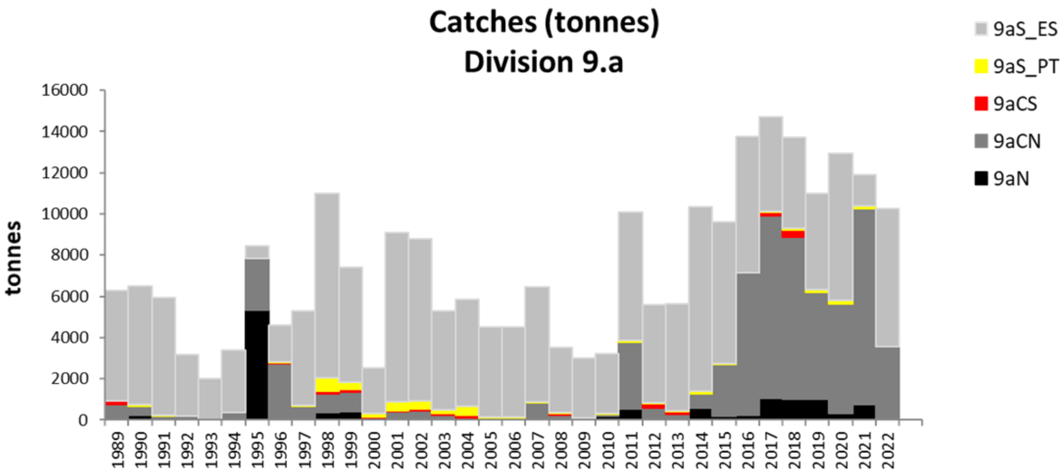


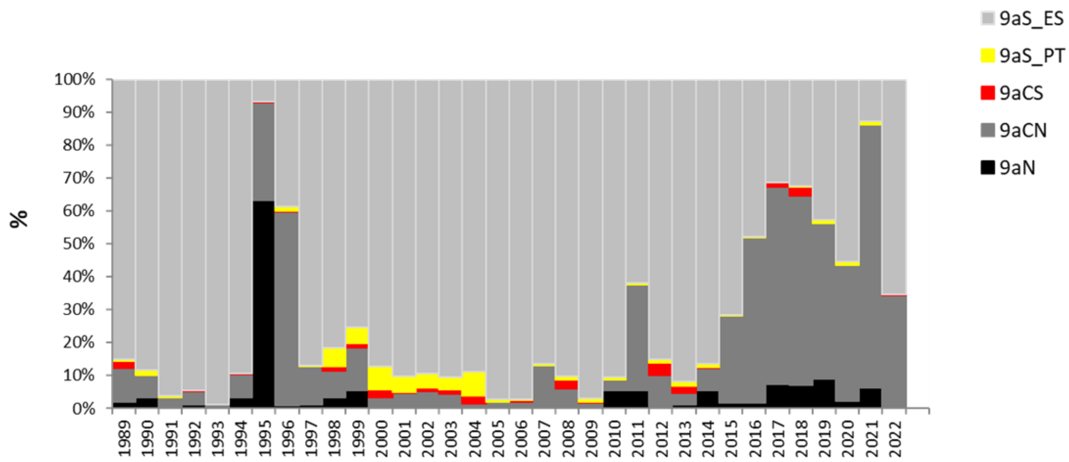
	9a N	9a CN	9a CS	9aS_alg	9aS_cad
mean 2007-2023 (%)	4	19	1	2	74
Mean 2017-2023 (%)	4	38	1	1	57

Figure 4.2. Biomass estimates for all the 9a sub-divisions estimated in the spring acoustic surveys PELACUS (Subdivision 9a N) and PELAGO (Subdivisions 9a CN, 9a CS, 9a S alg, 9a S cad).

5 - HISTORIC DYNAMICS OF LANDINGS

Anchovy in Division 9a is mostly harvested by purse-seine fleets (generally 99% of total catches). For the period with complete data for the whole Division (from 1989 to present), landings have ranged from 1,984 t (1993) to 13,775 t (2018) (Fig. 5.1). Landings have been dominated by those done in the Gulf of Cadiz (Subdivision 9a South – Cadiz) for most time series, representing >80% of catches during most years. In contrast, in the western Iberia, anchovy was only harvested during years of high abundance. As of 2016, the majority of catches were taken in the western Iberia, of which >90% concentrated in the 9a Central North Subdivision (Fig. 5.2, 5.3).





	9a N	9a CN	9a CS	9aS_alg	9aS_cad
mean 1989-2022 (%)	9	35	2	5	49
Mean 2012-2022 (%)	6	56	2	2	34

Figure 5.1. Time series of anchovy catches in Division 9a (1989-2020) in ICES Subdivisions 9a North, Central-North and Central-South (western component) and Subdivisions 9a South-Alg and 9a South-Cad (Southern Component).

The annual contribution observed in each fishing zone in the Portuguese landing of anchovy from 2003 to 2023 shows an increasing trend in northwestern and southwestern Iberia, contrary to southern Portugal. In the first three years of the time series most catches occurred in the south while in recent years, the large majority of catches occurs in northwestern Portugal (Fig. 5.2 and 5.3).

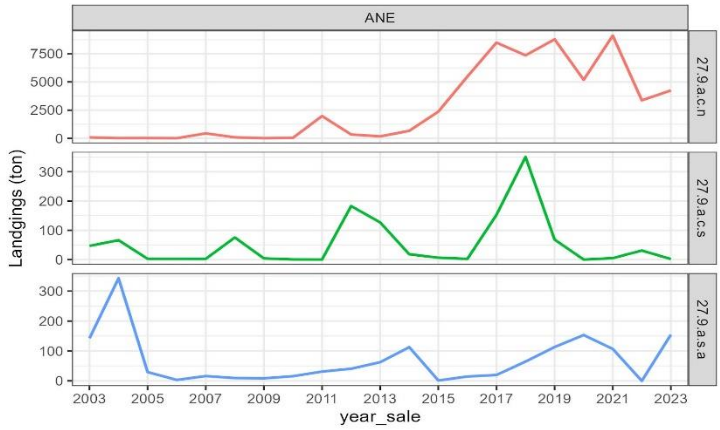


Figura 5.2 - Time series of anchovy landings carried out by the purse seine fleet in Portugal by area (Northwest - 27.9.a.c.n, Southwest - 27.9.a.c.s and South - 27.9.a.s.a) from 2003 to 2023.

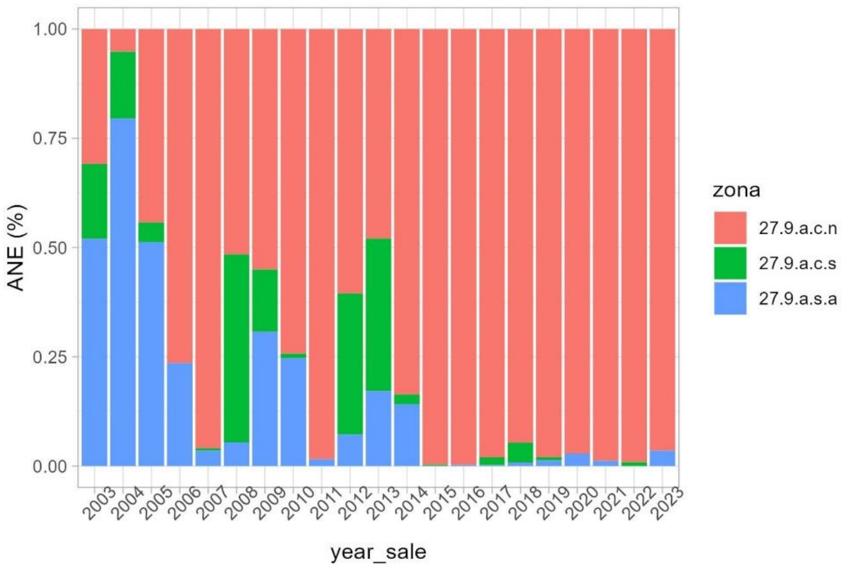


Figure 5.3 - Annual proportion of anchovy landings in Portuguese ports carried out by the purse seine fleet in each zone (Northwest - 27.9.a.c.n, Southwest - 27.9.a.c.s and South - 27.9.a.s.a), in the period from 2003 to 2023.

The distribution of catches by main fishing ports in Portugal reveals that the great majority of catches concentrate in the northern part of the northwestern Iberia (north of 9aCN area), followed by the area around Lisbon (port of Sesimbra) with catches 1 order of magnitude lower, catches while those in southwestern south Iberia and significantly lower (Fig. 5.4).

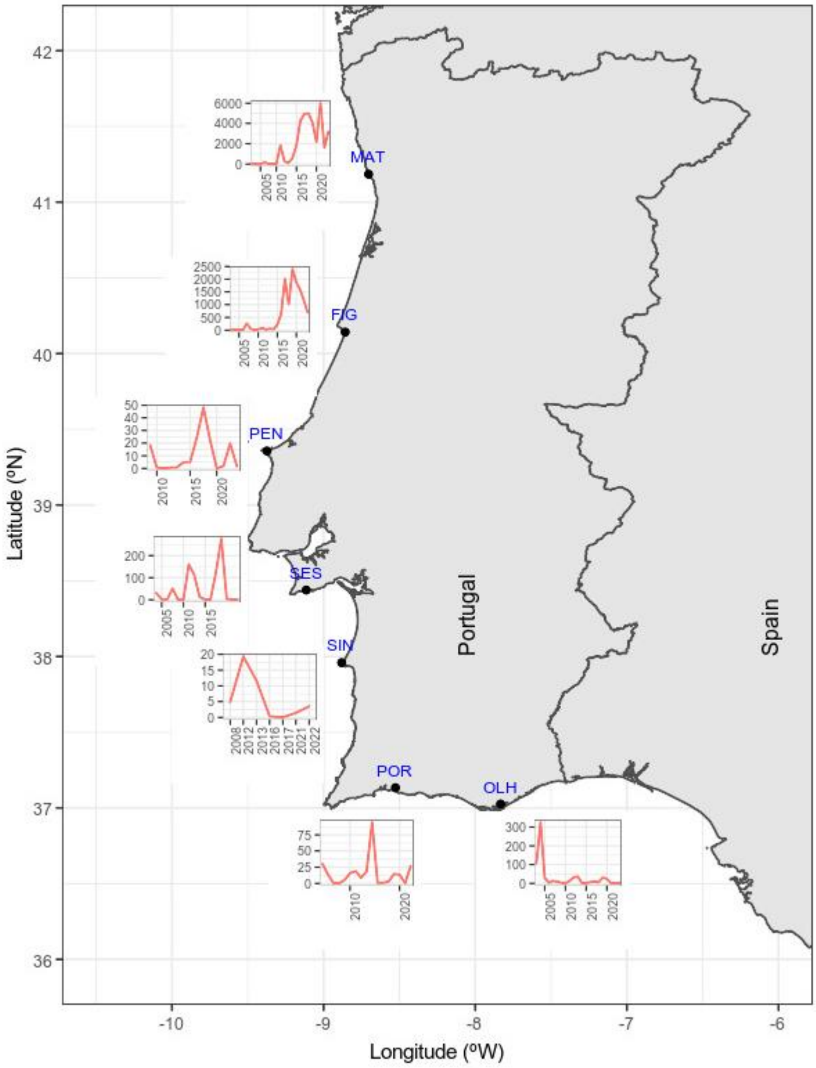


Figure 5.4 – Distribution of catches (tons) in the main fishing ports (Matosinhos - MAT, Figueira da Foz – FIG, Peniche – PEN, Sesimbra – SES, Sines – SIN, Portimão – POR, Olhão – OLH) of Portugal from 2003 to 2023.

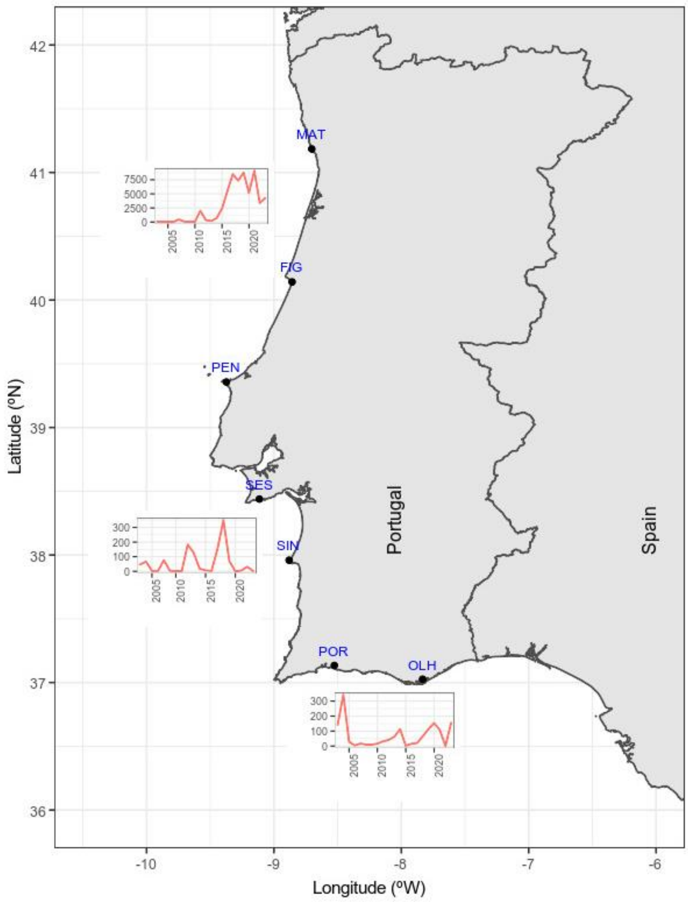


Figure 5.5 – Distribution of catches (tons) by area (27.9.a.c.n, 27.9.a.c.s, 27.9.a.s.a) of Portugal from 2003 to 2023.

Correlation analysis of the historical series of catches per Subdivision, previously analysed by Ramos et al. (2001) and Garrido et al. (2018), comparing the western and southern components of the stock were updated until present days. Annual landings per Subdivision (period 1989-2021) were analysed with the Spearman correlation test showing no significant correlation between the landings for the two components (Spearman correlation=0.33, p=0.06). An alternative correlation analysis was done to test whether the fluctuations of catches along the Division were the result of a potential northward migration (theoretically from Gulf of Cadiz to northern areas). In this second approach, correlations were estimated by comparing catches in the year y from the southern area (Algarve and Gulf of Cadiz) with the ones landed in the year y+1 in the western area (9a-N+9-CN+9-CS). No significant correlation (Spearman correlation=0.7, p=0.07) was found accounting for this one-year lag, which would be consistent with a northward migration between areas.

6 - POPULATION DIFFERENCES IN ANCHOVY LIFE HISTORY TRAITS IN DIVISION 9A.

6.1 BIOLOGICAL DATA

6.1.1 - MEAN LENGTH AND WEIGHT

Mean length and weight of anchovy in spring acoustic surveys shows a latitudinal gradient, being generally lower in the Gulf of Cadiz, followed by the portuguese western coast (9aCN+9aCS, areas presenting similar length-at-age), the 9aN and finally the Cantabrian Sea (subdivision 8c) (Fig. 6.1.1.1). Similarly, anchovy weight at age presented a latitudinal gradient increasing to the north (Fig. 6.1.1.2).

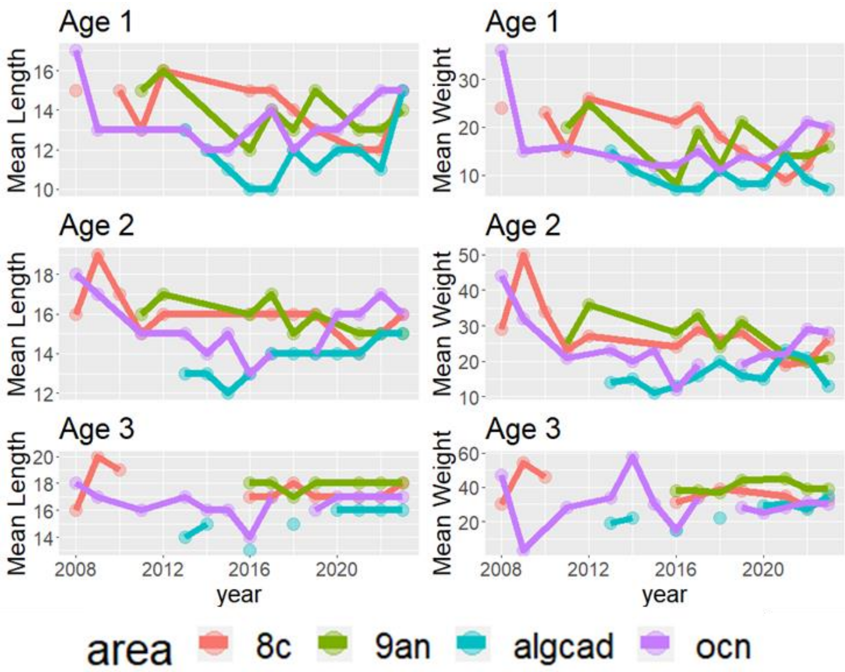


Figure 6.1.1.1. Anchovy mean length (left panels) and mean weight (right panels) estimated for fish captured during the spring acoustic surveys (PELACUS and PELAGO) for each area of ICES Division 9a and for the Division 8c occupied by the Bay of Biscay anchovy.

Continuous information on mean length and mean weight at age in catches from the Portuguese fishery (9a.C.N) started to be available in 2017 whereas time series for areas 9a.N and 9a.S-Cadiz are longer. Comparing the period when there is information for Portuguese and Spanish fisheries, it can be seen that, similarly to spring acoustic surveys, mean length and weight at age in the catches are smaller in the 9a South Cadiz area while data from 9a North and Central North are similar (Fig. 6.1.1.2). Due to the residual catches occurring each year, there is no length and age data available for the 9a Central South and 9a South Algarve areas.

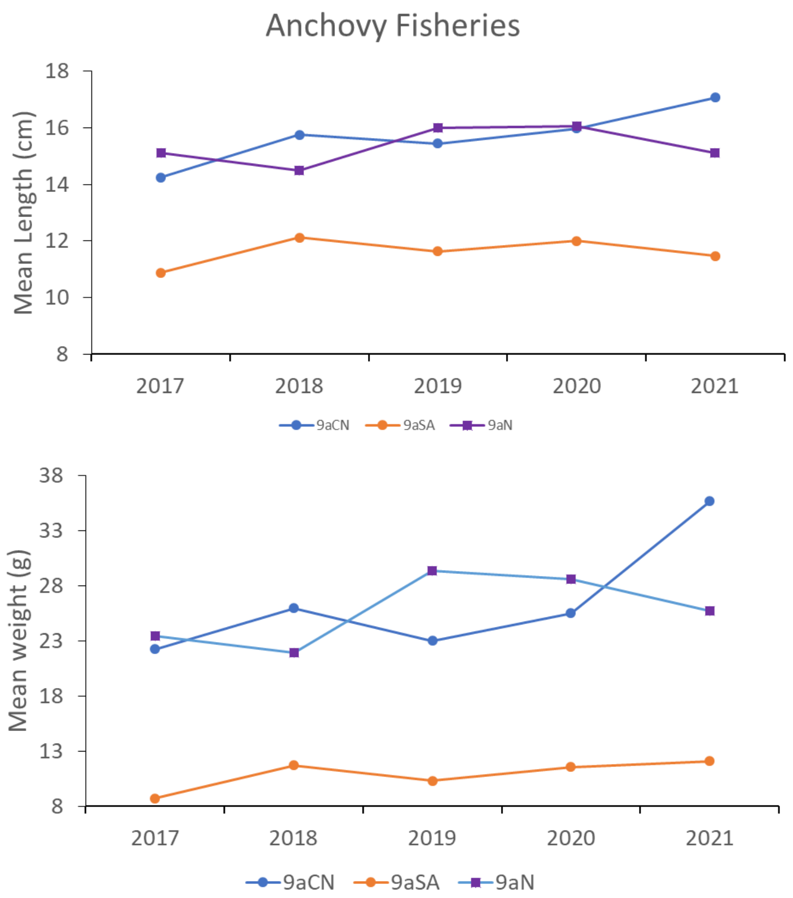


Figure 6.1.1.2. Anchovy mean length (upper panel) and weight (lower panel) in catches from the Spanish fishery in subdivisions 9a-N and 9a-S.

6.1.1 - Cohort tracking

Potential connectivity of anchovy populations from the Western and South Iberia was investigated by cohort tracking, comparing the abundance at age of fish from the different components or subdivisions estimated during spring acoustic surveys.

When comparing the abundance at age of fish from the western and southern components of the 9a anchovy stock, no significant correlation was found for fish of the same age. Moreover, no correlation was found between age 1 individuals from the South component with age 2 individuals of the western component in the following year (Fig. 6.1.3).

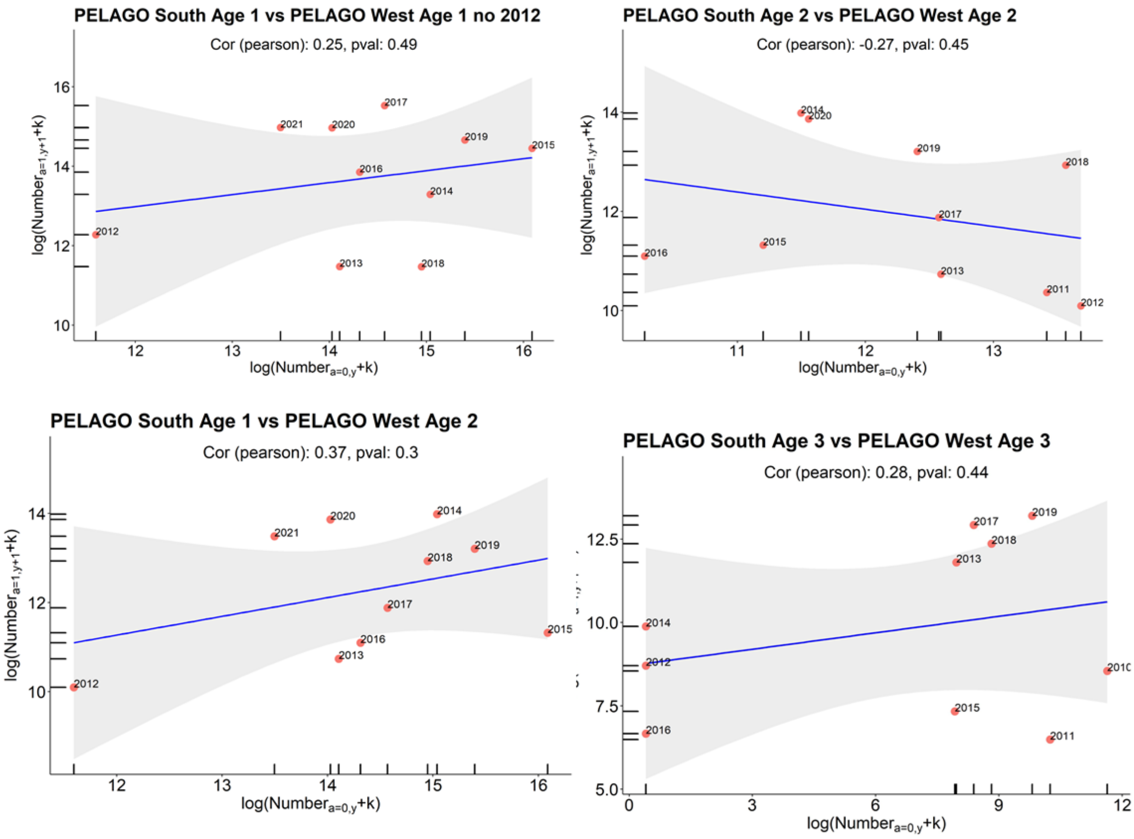


Figure 6.1.3. Relationship between the abundance of Age 1, 2 and 3 individuals estimated in the PELAGO survey series and in the West and South Iberian coasts (top panels and right bottom panel), and with Age 1 in the south and Age 2 in the West Iberian coast (left bottom panel). Units for both axes are Log the number of individuals + K, being K half the minimum N observed, method described in ICES, 2004; Payne et al., 2009).

The same type of analysis was carried out to investigate the potential connectivity of anchovy populations from the western Iberia with those of division 8c (different stock)) estimated during spring acoustic surveys. A significant correlation was found in the abundance of fish of the same age between the areas, for the three ages tested. Moreover, a significant correlation was found between age 1 individuals in the division 8c with age 2 individuals of the western Iberia in the following year, suggesting a potential southern migration during the juvenile stage (Fig. 6.1.4).

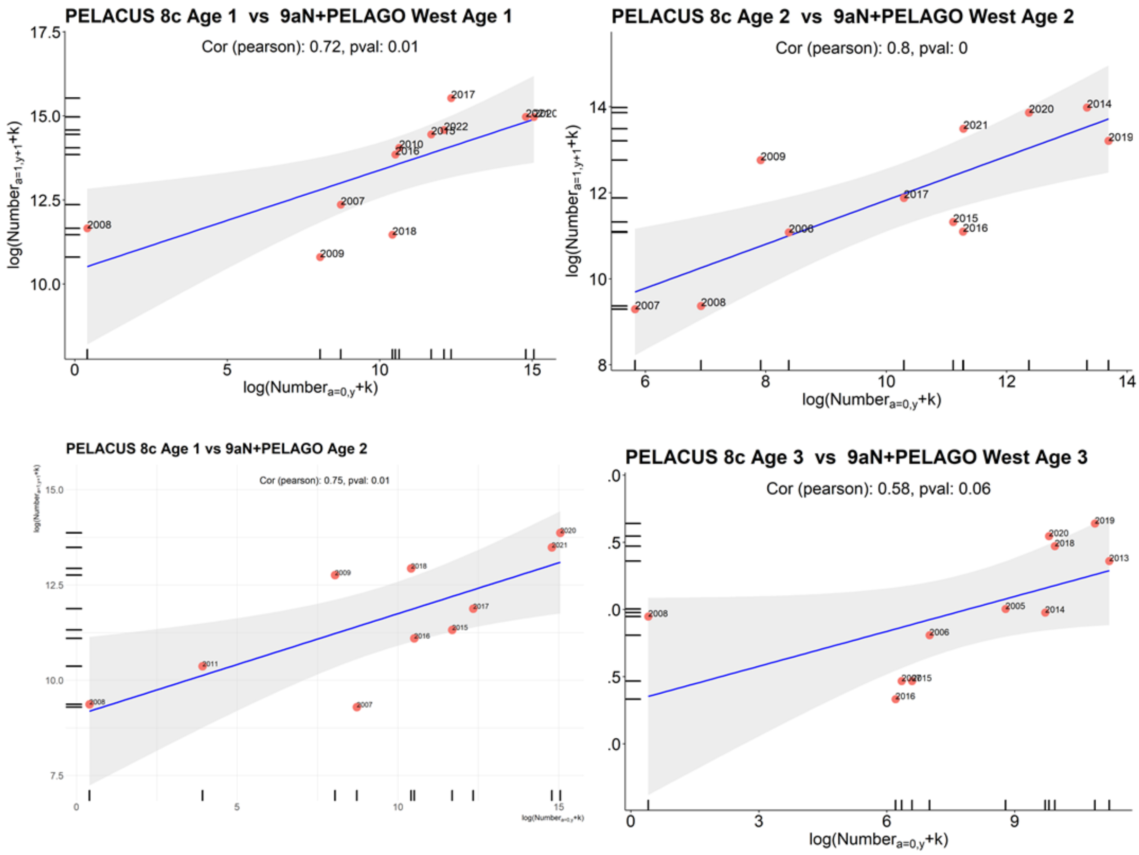


Figure 6.1.4. Relationship between the abundance of Age 1, 2 and 3 individuals estimated in the PELAGO+PELACUS survey series and in the Cantabrian Sea (division 8c) (top panels and right bottom panel), and with Age 1 in the Cantabric and Age 2 in the West Iberian coast (left bottom panel). Units for both axes are Log the number of individuals + K, being K half the minimum N observed, method described in ICES, 2004; Payne et al., 2009).

6.2 SYNOPSIS OF PUBLISHED WORKS ON POPULATION STRUCTURE

Several studies have been conducted on the population structure of the anchovy in Atlantic waters, namely using morphometrics, otolith shape analysis and genetic analysis.

6.2.1 - MORPHOMETRICS

Morphometric differentiation between anchovy populations from north of Division 9a (Sub-division 9a North) and populations from the Bay of Biscay were obtained by Junquera and Pérez-Gándaras (1993), also suggesting the existence of an intermediate population in the Cantabrian area (west of the 8c). Subsequent studies of morphometrics and genetics have failed to sample fish in the western Cantabrian, which is probably related to the low abundance of the species in this area. Morphometric analysis conducted in fish collected during 2000 and 2001 from the Bay of Biscay to the Southern Iberia in the Algarve (Caneco et al. 2004) point to a clear separation between anchovies from the Bay of Biscay (ICES Subarea 8) and those from Division 9a, as well as a north-south cline along the Portuguese and Gulf of Cadiz area, with fish from the Gulf of Cadiz being mostly different from those in northern 9a area. The group of fish from the Algarve (E) was the one whose separation was less robust, given that the classification by crossvalidation attributed most of its fish on western Portuguese coast groups rather than on itself. Results from this study indicate that fish from the Iberian area (i.e. Division 9a) have larger heads and smaller medium-posterior body dimensions than the ones from Bay of Biscay (Subarea 8). These differences were more pronounced in the Spanish waters of the Gulf of Cadiz (Subdivision 9a-South, Cadiz). Anchovies from the Spanish waters of the Gulf of Cadiz had the greater head-to-body ratios, having shown the greater divergence from the Biscay populations. The Iberian samples also had greater dorsal fin base lengths.

6.2.2 - OTOLITH SHAPE ANALYSIS

Bacha (2014) showed that the Alborán Sea anchovy population is distinct from the Northeast Atlantic populations, including neighbouring populations (e.g. Gulf of Cadiz) using otolith shape analyses. Anchovies were analysed from seven locations in the SW Mediterranean Sea and Atlantic Ocean along the northwestern African (Morocco) and Portuguese (Bay of Cadiz) coasts (Bacha et al. 2014). According to this study, three distinct anchovy stocks were identified: the Algero-Provençal Basin, the southern Alborán Sea, and the Atlantic Ocean (Morocco and Gulf of Cadiz). Shape variability of anchovy otoliths was associated with the presence of the Almeria-Oran front (AOF), and the strait of Gibraltar. The Southern Alborán stock was distinct from the Algero-Provençal Basin and from the closest Atlantic stocks (Gulf of Cadiz or Atlantic coast of Morocco).

6.2.3 - GENETIC ANALYSIS

The European anchovy exhibits a complex evolutionary history that has produced conflicting results regarding its population structure within the Atlantic Ocean (Table 6.3.2.1). The presence of two ecotypes (hereinafter, oceanic, and coastal) that differ both genetically and morphologically was first documented in the Mediterranean Sea (Borsa, 2004). Additional analyses based on comprehensive datasets in terms of genetic markers and number of samples have confirmed the presence of these two ecotypes also in the Atlantic Ocean (LeMoan et al. 2016, Montes et al. 2016). Interestingly, there is more differentiation between ecotypes (oceanic/coastal) than between Atlantic Ocean and Mediterranean Sea locations within the same ecotype (LeMoan et al. 2016; Catanese et al. 2017). Besides, both ecotypes hybridize, although it is not known in which proportions (LeMoan et al. 2016; Montes et al 2016). Additionally, analyses based on mitochondrial DNA have found presence of two lineages with different proportions in each area and which are not related to the oceanic and coastal ecotypes (Magoulas et al. 2006; Borrell et al. 2012, Viñas et al. 2014, Silva et al. 2014a, Silva et al. 2014b). Adding a further layer of complexity, Zarraonaindia et al. (2012) suggested the presence of other two ecotypes (unrelated to the coastal/oceanic ones) associated with narrow or wide oceanic platforms respectively. This complex evolutionary history makes inferences of population connectivity among locations difficult without further studies considering presence of ecotypes and mitochondrial lineages. From the studies available thus far, there seems to be population differentiation between the North Sea+English Channel populations and the Bay of Biscay (Petitgas et al. 2012; Montes et al. 2016, Huret et al. 2020), although some studies suggest otherwise (Zarraonaindia et al. 2012, Silva et al 2014a). Concerning the connection between West Galicia and North of Portugal with the Gulf of Cadiz anchovies, two studies suggest differentiation (Silva et al. 2014a, Zarraonaindia et al. 2012), but results might be biased by the small number of markers used and/or by the different proportions of each ecotype in the samples used.

Table 6.2.3.1: Summary of the genetic studies trying to decipher the population structure of European anchovy who include the area of interest for this WD.

Reference	Number of individuals	Locations	Number and type of markers	Results	Sampling
Magulas et al. (2006). MPE 39: 734–746	24	Bay of Biscay, Portuguese coast; Gulf of Cádiz; Canary Islands; Senegal; Alboran Sea; other regions in Med	mitochondrial RFLP	Two co-occurring mitochondrial genetic lineages; BoB about 40-60%; rest of the Atlantic locations, one more dominant	Fishing vessels and fish markets
Zarraonaindia *et al.* (2012). PLOS ONE 7(7): e42201	626	North Sea, English Channel, Bay of Biscay, Coast of Portugal, Gulf of Cádiz, Canary Islands, South Africa, Alboran Sea, other regions in the Med	47 nuclear and mitochondrial SNPs (not clear how they were selected)	Patterns compatible with two ecotypes: one group included samples from the North Sea and English Channel, the Bay of Biscay and the Mediterranean (excluding Alboran Sea); the other group included samples from eastern Atlantic locations from Galicia to south Africa (and Alboran Sea)	Acoustic surveys (BIOMAN, PELGAS, ECOCADIZ, ECOMED, PELACUS)
Petitgas et al (2012). MEPS 444: 1–13	797	Bay of Biscay, English Channel, North Sea	49 nuclear SNPs (extracted from Zarraonaindia et al. 2012)	Differentiation between North Sea/English Channel and Bay of Biscay; conflicting interpretations with respect to Zarraonandia et al. 2012, despite using common samples and same SNPs.	not specified
Borrell et al (2012). IJMS 69: 1357–1371	141	Bay of Biscay, Med	mitochondrial cytb & 16S/14 microsats	Two co-occurring genetic groups; BoB about 50-50% in the French coast and one coastal location in the Cantabrian sea; 75-25% in offshore Cantabrian sea and and 25-75% in Getarian coast	not specified
Viñas et al. (2014). 71: 391–397	563	Bay of Biscay, Cadiz, Med, Canarias	mitochondrial Control Region	Two genetic groups; Bay of Biscay about 50-50%, Cadiz, one more dominant	Mediterranean, fishing vessels; BoB (THALES, AZTI)
Silva et al. (2014). J. Biogeogr. 41: 1171-1182.	312/462	Eastern Atlantic: Norway to Ghana	mitochondrial cytb/9 microsats	2 co-occurring mitochondrial lineages whose frequency vary along the distribution area; 4 nuclear genetic clusters (ecotypes not considered): Norway+English Channel+Bay of	fish markets and scientific surveys (IMR, IFREMER,

				Biscay/Portugal north+Malaga/Gulf Cadiz +Canaries+GuineaBissau+Ghana/Tangier+Senegal .	AZTI, CCMAR, IEO, WRI)
Silva et al. (2014). Proc. R. Soc. B. 281201410932014109 3	2776 (455 new)	North Sea, Baltic sea, English Channel, Bay of Biscay, Coast of Portugal, Gulf of Cadiz, Canary Islands, eastern Atlantic African coast to South Africa, Mediterranean Sea	mitochondrial cytb	Two co-occurring genetic groups, one is present all over the distribution area, whereas the other one is absent from the tropics; Temperature and dissolved oxygen are significantly correlated with the latest (particularly from the BoB to the North Sea).	fish markets and scientific surveys (IMR, IFREMER, AZTI, CCMAR, IEO, WRI)
Le Moan *et al.* (2016). Mol. Ecol. 25: 3187–3202	128	Coastal and marine locations from Atlantic and Mediterranean French coast (Bay of Biscay for the Atlantic, Bay of Leon for the Med)	5,638 SNPs (RADseq)	2 ecotype which hybridize. Higher differentiation between ecotypes than between Mediterranean and Atlantic. Lower differentiation between offshore ecotypes than between coastal ecotypes. Gene flow between ecotypes; limited enough to maintain high differentiation between the ecotypes.	ad-hoc for study
Montes *et al.* (2016). Mar. Biol. 163:205	851	Whole distribution: North Sea, Bay of Biscay, NW and S Iberian Peninsula, Mediterranean Sea and Canary Islands	456 SNPs (exons, might not have power to detect fine population structure)	Presence of two ecotypes in the Bay of Biscay. The Bay of Biscay offshore population is closely related to Mediterranean populations and secondarily to northern populations in the Irish, Norwegian and Baltic seas	Scientific Surveys (PELGAS, EVHOE, CAMANOC, CGFS, French IBTS, NOURDEM)
Catanese et al (2017). Sci. Rep. 7: 4180	1008	Bay of Biscay, Cadiz, Med, Canarias	96 SNPs (Catanese et al. 2016; most differentiating pops within Med and btw Atlantic and Med. Sea)	Confirm the presence of two ecotypes. Partial overlap in habitat use for ecotypes in the Med. Most outlier SNPs identified for the Med are shared with the Atlantic. Confirm higher difference between ecotypes than between Med vs Atlantic.	ad-hoc for study
Huret *et al*. (2020). Fish Res. 229: 105619	602	Atlantic French coast, English Channel North Sea and Irish Sea (In total 25 sampling locations, 4 in estuaries)	308 SNPs from Montes et al 2016 select as a trade-off between	Two ecotypes. Within the oceanic ecotype, genetic differentiation between the subareas 8abd stock and further north locations, with populations boundary located west of Brittany. Anchovy from the English Channel cluster	Scientific Surveys Professional vessels for Irish Sea. Samples from Montes et al. 2016.

			number of samples and number of SNPs	together with samples form the North Sea, both showing high differentiation from the Bay of Biscay for both ecotypes.	

6.3 – NEW DATA ON POPULATION STRUCTURE

6.3.1 GENETIC ANALYSIS

To unravel the genetic connectivity of anchovy, a team from AZTI (Del Rio et al. in preparation) has assembled a dataset of 7000 Single Nucleotide Polymorphisms from 382 individuals covering the distribution range of the species from the English Channel (north) to the Canary Islands (south) plus Mediterranean waters and including coastal and oceanic locations (Figure 6.3.1.1).

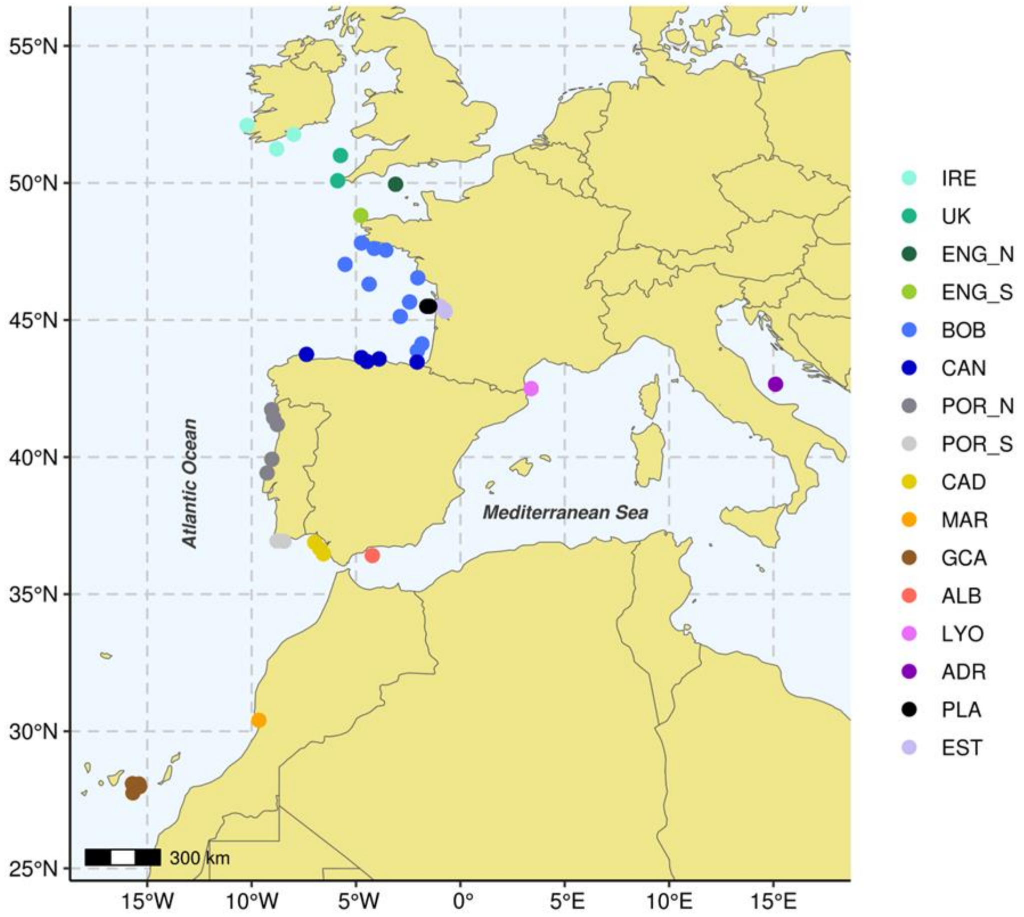


Figure 6.3.1.1 - Map showcasing the locations where the anchovy samples included in this study were collected

Our results (Figure 6.3.1.2, 6.3.1.3) revealed that: i) the Atlantic Iberian waters stock is composed of two genetically distinct lineages with the southern one being connected to the African coast and, to a lesser extent, the Mediterranean Sea; ii) the Bay of Biscay stock is genetically connected to northward locations not considered in the assessment; iii) the coastal and oceanic ecotypes coexist at different space-time proportions and hybridise.

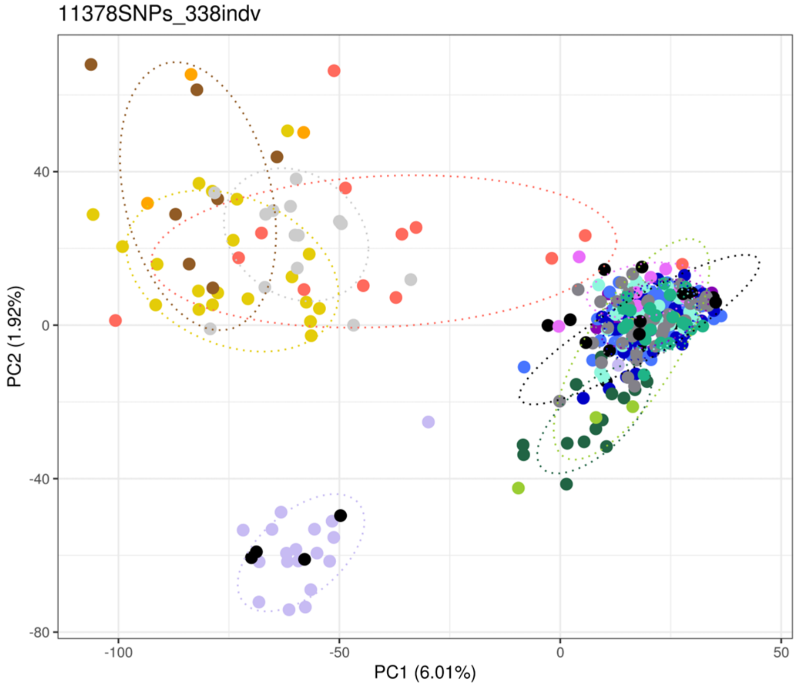


Figure 6.3.1.2 - Principal Component analysis based on 7000 SNP markers. Colours are the same as in the map in Figure 6.3.1.1

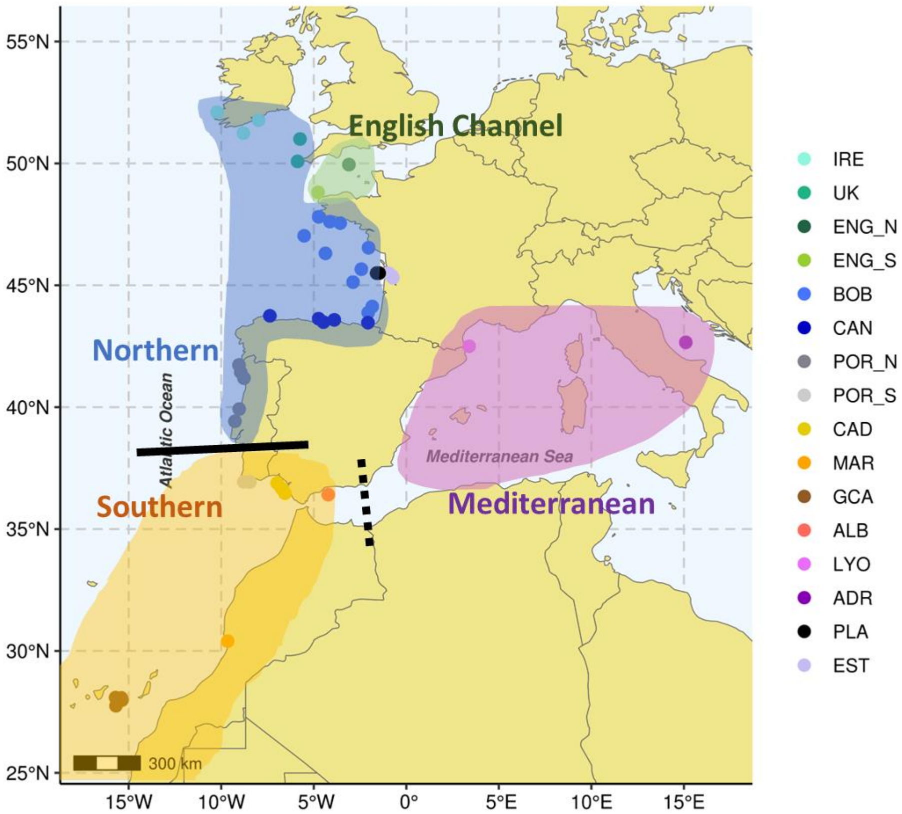


Figure 6.3.1.3 - Summary of the conclusions based on the genetic analyses concerning the marine ecotype showing the main identified groups

This discovery challenges the current stock delimitation in European anchovy. In particular, in what concerns the Atlantic Iberian stock, where the southern part is clearly differentiated from the northern part and connected to a southern lineage.

These findings call for future monitoring of the influence of the southern locations in the southern Portugal and Gulf of Cádiz anchovy, and that of the coastal ecotype in the oceanic one, which is the one managed and targeted by fisheries. Moreover, our study sheds light on prior conflicting results about the population structure and connectivity of European anchovy and carries significant implications for the conservation of this important species.

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6.3.2 STABLE ISOTOPE COMPOSITION

To study the connectivity of anchovy populations in the Iberian and surrounding waters, an analysis of the stable isotope composition was conducted by IPMA (Sakamoto et al., in preparation). Eye lenses are incrementally growing protein tissue whose layers, i.e. laminae, hardly turn over after formation. Since the stable isotope ratios of laminae reflect the ratios of prey consumed prior to formation, eye lenses serve as recorders of isotope chronologies (Wallace et al., 2014). It is known that the carbon and nitrogen isotopes ($\delta^{13}C$ and $\delta^{15}N$) of phyto- and zooplankton exhibit considerable geographical variation depending on various factors such as SST, nutrient source and availability. The isotopes of the eye lens centres can therefore have different values depending on the nursery area and thus serve as markers for the geographical origin of the fish (Sakamoto et al., 2023). Although chemical analysis of otoliths is widely used for the purpose, sample processing and isotope analysis of eye lenses is far less time-consuming and costly. This advantage enables the generation of larger data sets at limited cost, which is particularly important for stock identification.

To test this concept, the $\delta^{13}C$ and $\delta^{15}N$ values of the central part of the eye lens with a diameter of 0.7 to 1 mm, which probably corresponds to the laminae formed from hatch to 3 to 5 cm SL, were analysed for 344 anchovies caught with a midwater or bottom trawl during cruises (PELAGO, IBERAS and SARLINK, etc.) between 2016 and 2022 (Fig. 6.3.2.1). Taking into account the age-length relationships reported for each region (see Uriarte et al, 2016), fish less than 11 cm TL in the Gulf of Cadiz (CAD), the Portuguese south coast (ALG) and the Alboran Sea (ALB) and less than 13 cm TL in the Bay of Biscay (BIS), the northern and southern west coasts of Portugal (OCN, OCS) and the west coast of Morocco (MOR) were assumed to be age-0 and the others age-1 or older.

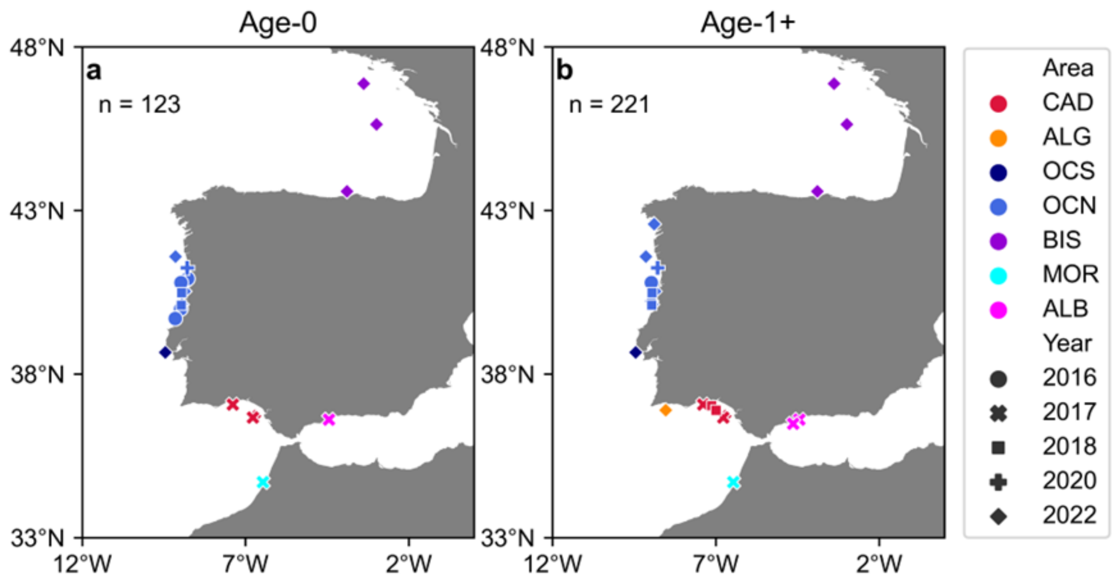


Figure. 6.3.2.1. Locations of sample collection of age-0 (a) and age-1 or older (b) anchovies for eye len isotope analysis.

The isotopes of the eye lens centres of age-0 anchovies showed considerable geographical differences (Fig. 6.3.2.2a-c). The δ^{13}C was lower in the northern areas (BIS, OCN) than in the southern areas (CAD, ALB, MOR), reflecting the general positive relationship between the SST and the δ^{13}C of marine phytoplankton (Goericke and Fry, 1994). The δ^{15}N was higher in CAD than in the other regions (mostly > +9‰), presumably reflecting the lower nutrient availability compared to the Bay of Biscay and coastal upwelling regions. The remarkably low δ^{15}N in ALB (< +7‰) despite the limited nutrient availability there is likely due to nitrogen fixation in the Mediterranean Sea. Interannual variation was analysed in OCN samples from four different years (Fig. 6.3.2.2d, e), and a significant difference was found in δ^{13}C (Kruskal-Wallis test, Chi-square = 15.03, $p = 1.8*10^{-3}$) but not in δ^{15}N (Chi-square = 3.7, p = 0.29), indicating the greater robustness of δ^{15}N as a geographical marker. These results suggest that eye lens isotopes vary depending on local processes of primary production in each nursery area and thus provide insight into individual origin of anchovy. It is noteworthy that the values of BIS and OCN overlap considerably (Fig. 6.3.2.2a-c), possibly due to limited variation in plankton isotope values or mixing during the early life stages, making it difficult to detect fish migration between these areas.

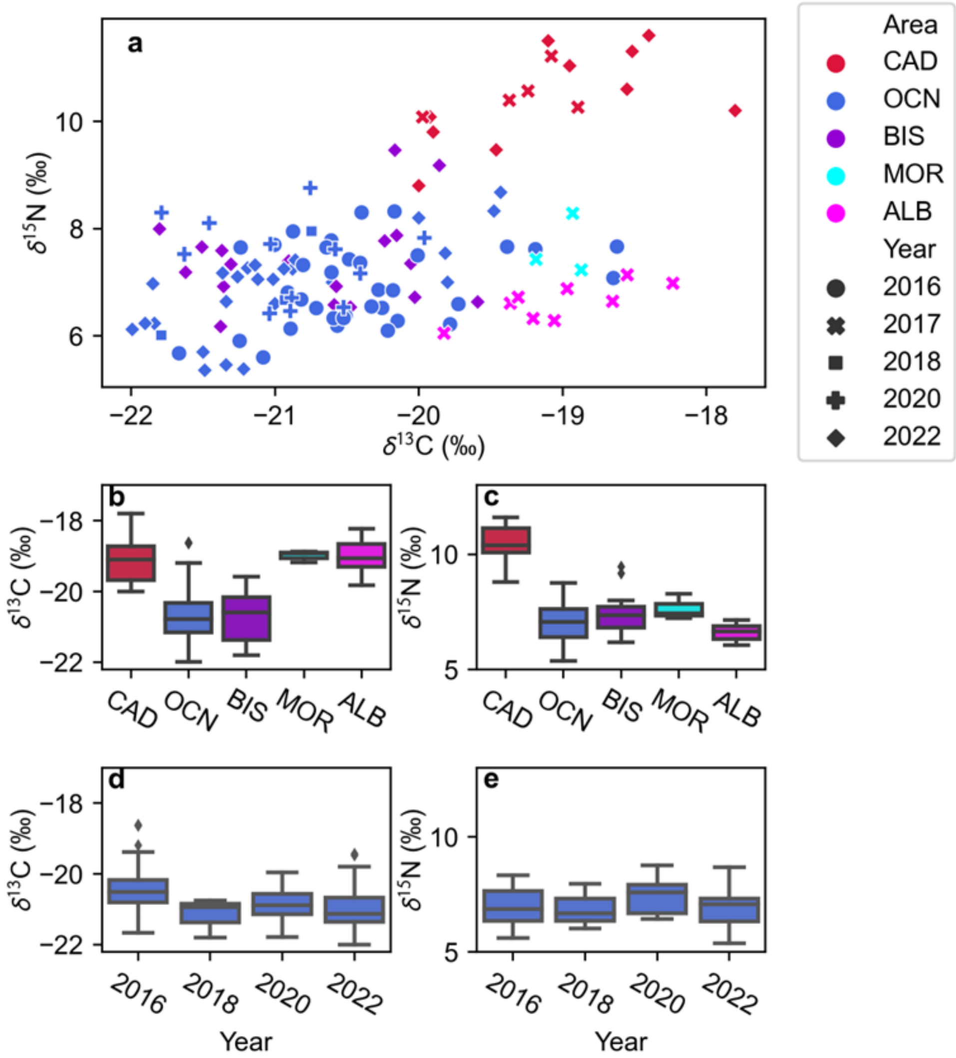


Fig. 6.3.2.2. The carbon and nitrogen isotope values in eye lens centres of age-0 anchovies (a). Data distribution of $\delta^{13}C$ (b) and $\delta^{15}N$ (c) for each area. Distribution of isotope values in age-0 in OCN from different years (d, e).

The isotopes of the eye lens centres of age-1 or older anchovies showed largely consistent geographical variations with those of age-0 (Fig. 6.3.2.3 a-c), suggesting that migration of anchovies between regions is generally limited. Fish from the west coast of Portugal (OCN, OCS) and the south coast (CAD, ALG) mostly showed $\delta^{15}N$ values lower and higher than +9‰, demonstrating that it is the local recruits that dominate in the adult assemblages. Some adults off the west coast showed exceptionally high $\delta^{15}N$ values, even higher than values in CAD. Since such individuals were found exclusively near estuaries (at the mouth of the Tagus River and in the Ría de Arousa) and phytoplankton $\delta^{15}N$ is generally higher in estuarine waters than in marine waters (Vinagre et al., 2011), it is likely that they originated from local estuaries. Some ALG fish showed lower $\delta^{15}N$ (+8 to +9‰) and higher $\delta^{13}C$ (-20 to -17.5‰), which overlap with values of age-0 and age-1+ in MOR, suggesting a possible northward migration from the African coast. The ALB fish consistently showed lower $\delta^{15}N$ than CAD fish at both age-0 and age 1+, suggesting that migration across the Strait of Gibraltar may be rare.

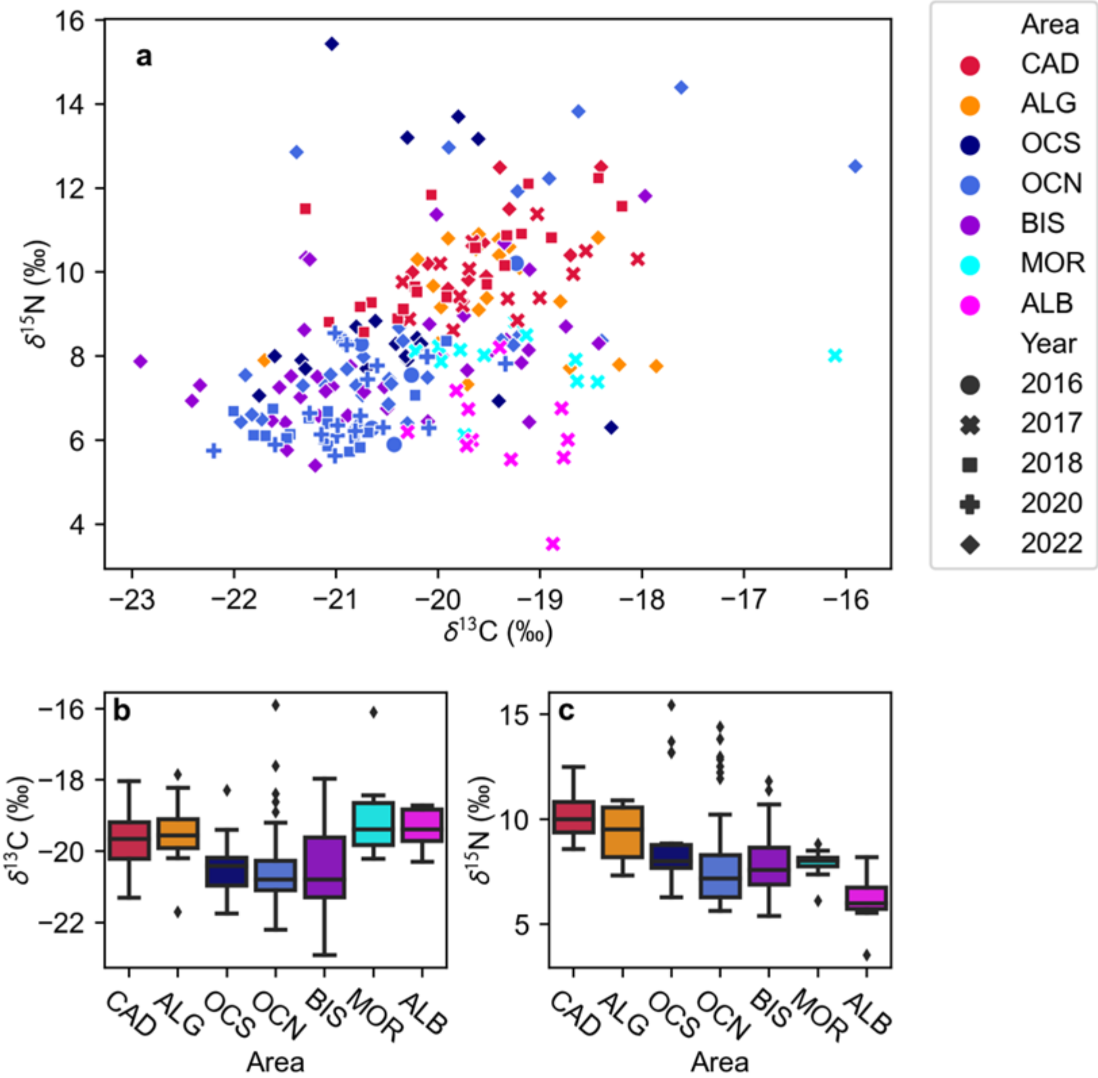


Fig. 6.3.2.3. The carbon and nitrogen isotope values in eye lens centres of age-1 or older anchovies (a). Data distribution of $\delta^{13}C$ (b) and $\delta^{15}N$ (c) for each area.

These results support the hypothesis that connectivity between the western and southern Iberian coasts is limited. We can also conclude that eye lens isotopes are robust and cost-effective markers of nursery area, and the extension of sample coverage will significantly deepen the understanding of population connectivity across the European anchovy habitat. In the meantime, analysing the isotope ratios of larvae in the Bay of Biscay and the Portuguese west coast is important to clarify whether fish movements between these areas can be verified based on eye lens isotopes. The agreement with the genetic analysis, especially regarding the association between estuarine ecotype and individuals with high $\delta^{15}N$ in the eye lens, also needs to be tested in the future for further validation.

6.3.3 LARVAL DISPERSAL

In this section we used a set of different models to simulate the dispersion and survival of anchovy early life stages in the Iberian region. At first we focused on the years preceding the increase in anchovy abundance in the Western Iberian margins since 2015 to try to explain if this increase is a result of dispersal from nearby recruitment areas, higher survival rates of early life stages due to favourable environmental conditions, or both. The results of the simulations for the period 2013-2015 are already published (Teles-Machado et al 2024). Later we extended the simulations to 2020, and plan to extend them to the present date the results (Teles-Machado et al., in preparation). An ocean model simulation with the model CROCO provided the fields used as background for Lagrangian simulations coupled to an individual-based model of anchovy eggs and larvae (Fig 6.3.3.1). We deployed eggs from the Bay of Biscay and from the Gulf of Cadiz (areas represented in Fig 6.3.3.2).

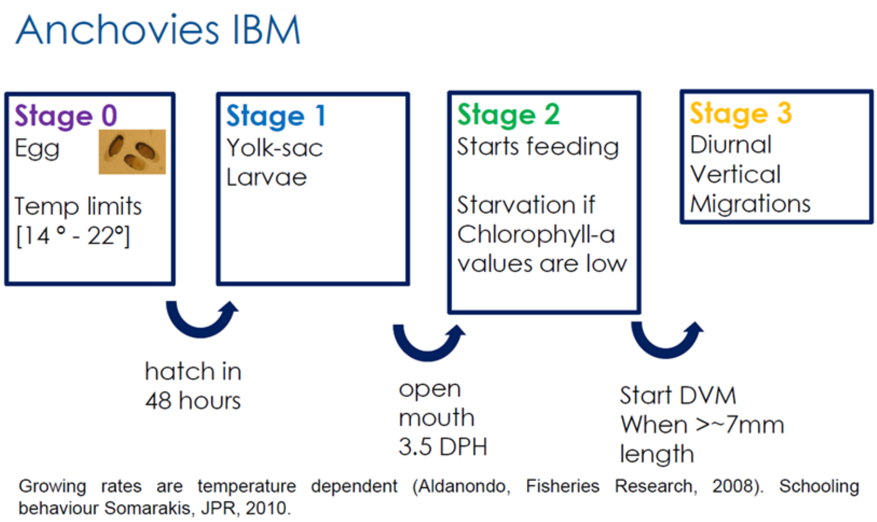


Figure 6.3.3.1. Schematics of the anchovy individual-based model (IBM) representing the different early life stages considered. DPH: days post hatch; DVM: diurnal vertical migration.

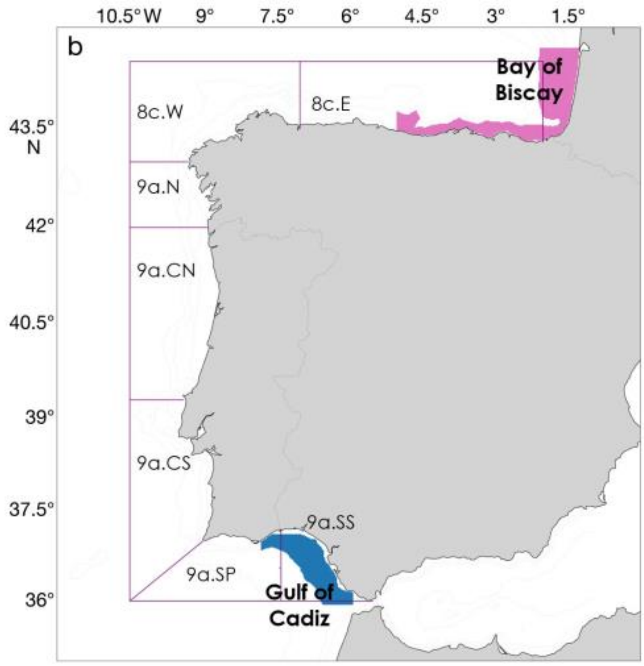
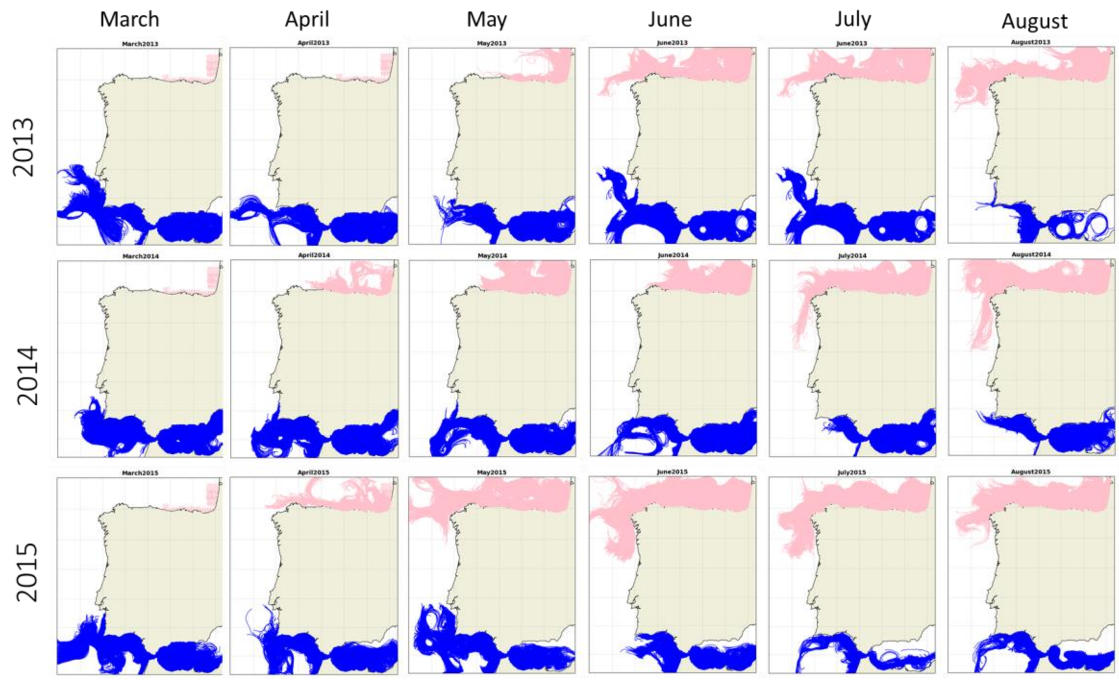


Figure 6.3.3.2. Shaded areas represent the anchovy spawning locations in the Bay of Biscay (BoB) (pink) and Gulf of Cadiz (GoC) (blue). The lines delineate geographical sub-divisions and areas within ICES Divisions 8c and 9a.

The results show that in 2014 and 2015, anomalous upper-ocean circulation patterns with strong and persistent eastward currents transported a large number of eggs and larvae from the Bay of Biscay (BoB) eastward along the Northern Iberian margin (Figs 6.3.3.3 and 6.3.3.4)



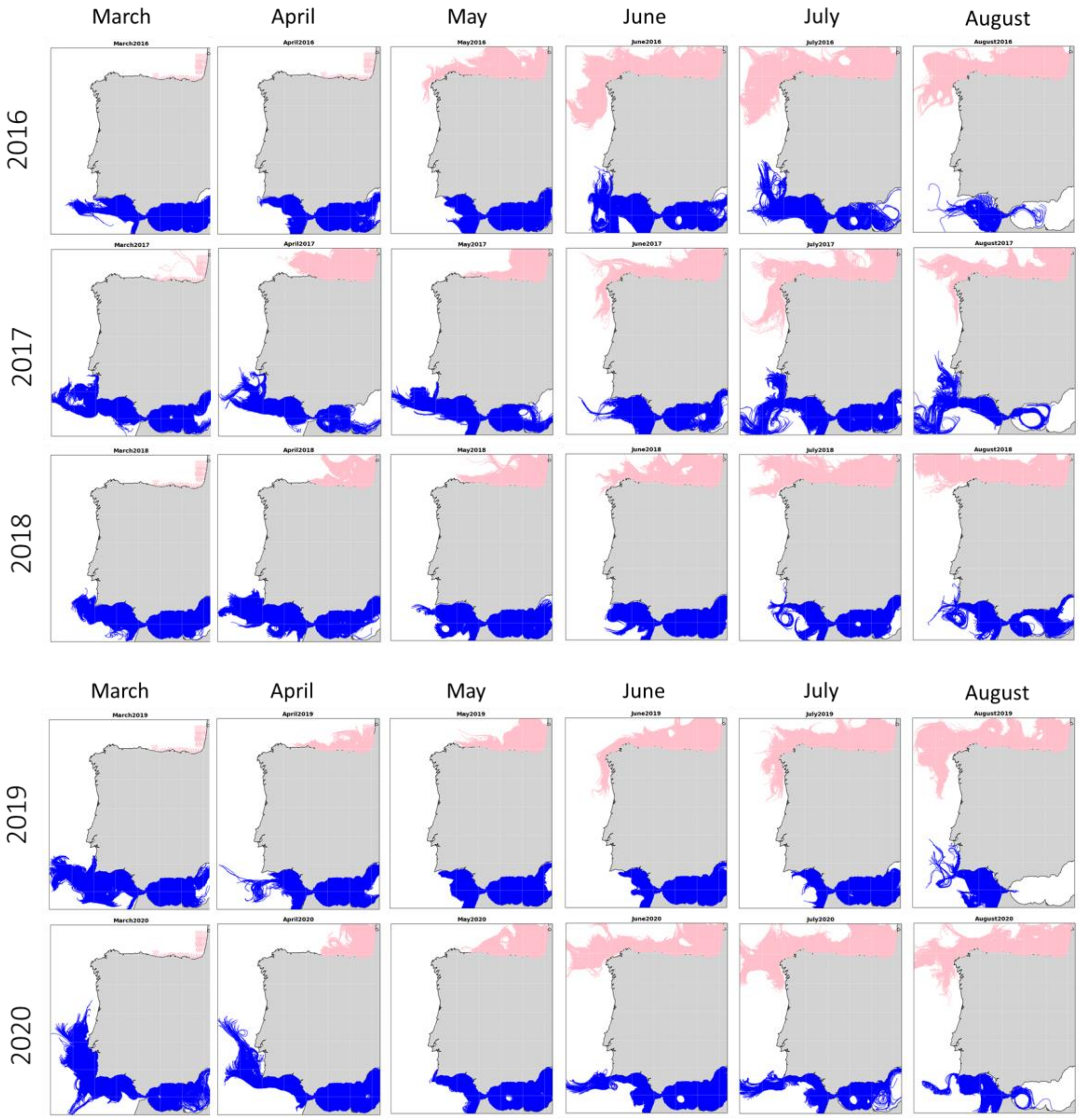


Figure 6.3.3.3. Trajectories of anchovy larvae deployed from the spawning grounds in the Bay of Biscay (BoB, pink) and Gulf of Cadiz (GoC, blue) in the main months of the spawning season (March to August) from 2013 to 2020

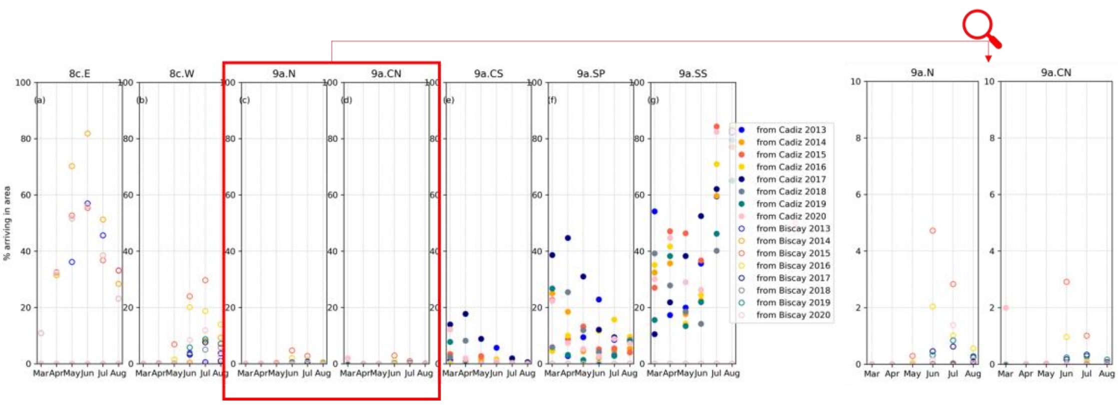
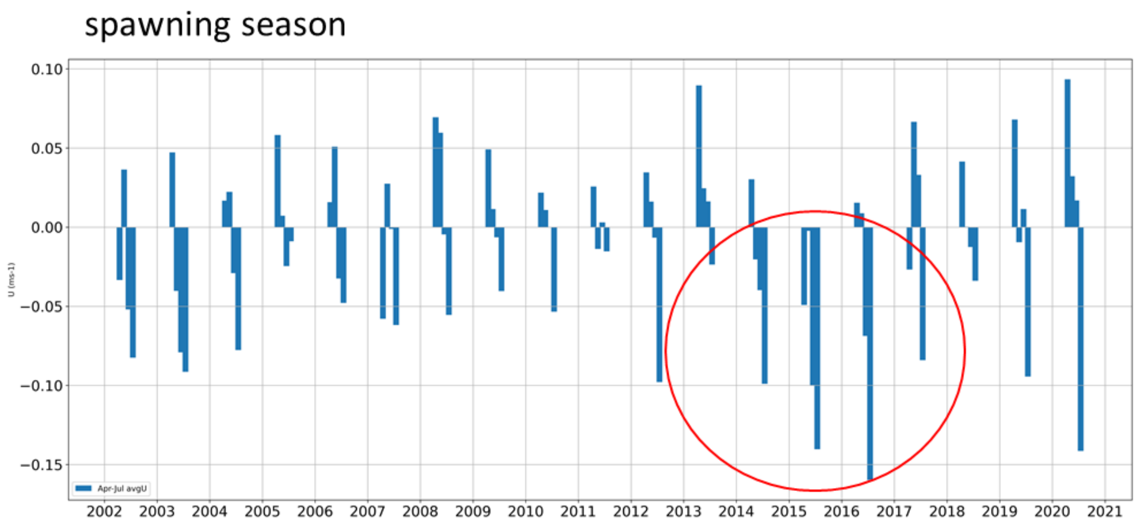


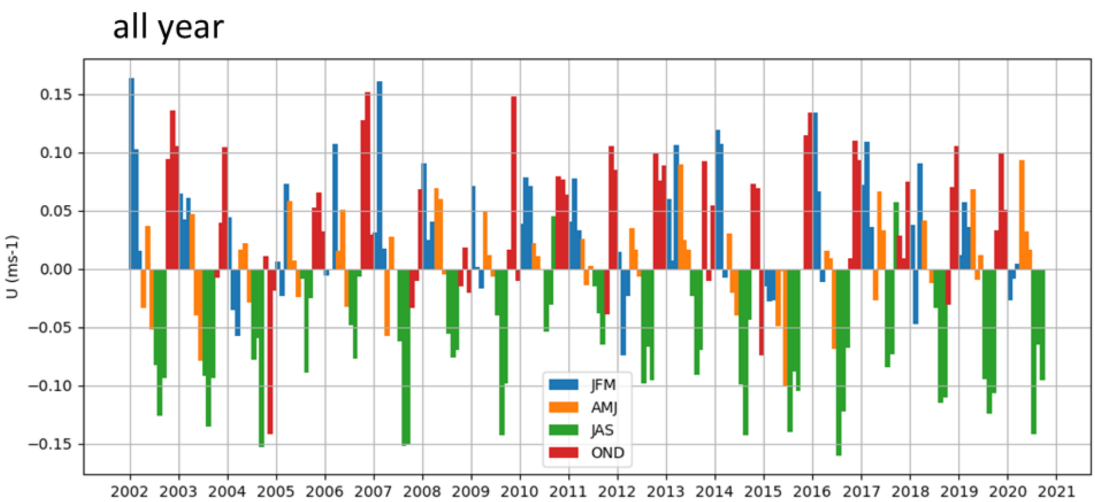
Figure 6.3.3.4. a) Percentages of particles deployed from the Gulf of Cadiz (GoC, closed circles) and Bay of Biscay (BoB, open circles), in each month of the spawning seasons (x-axis) of 2013

to 2020 (colours in the legend of the figure), that arrived in the different ICES areas shown in Fig. 6.3.3.2. Each plot represents a different destination area. b) zoom of the areas 9a.N and 9a.CN

The maximum transport to the northwestern coast (areas 9a.N and 9a.CN) occurred in June and July 2015, when 8 and 4%, respectively, of the eggs spawned in the Bay of Biscay potentially reached the Iberian west coast as larvae. This process might explain the increase in anchovy abundance in the Western Iberian ecosystem.

In order to verify if this was an anomalous or recurrent event in terms of ocean circulation, we computed the average surface zonal (east–west) velocity along the northern Iberian Coast (Fig. 6.3.3.6). Each bar represents the monthly average, and we represent the months of April to July, the main months of the anchovy spawning season. The years 2014, 2015, and 2016 stand out as 3 consecutive years of strong westward velocities, especially in July 2014, June and July 2015, and July 2016. The year 2015 was particularly anomalous due to the consecutive months of westward intense surface velocities.





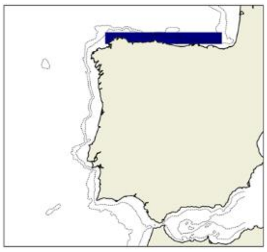


Figure 6.3.3.5. Time series of monthly averages of zonal (E–W) velocity, spatially averaged (avgU) in an area that covers the Iberian northern coast. The area is represented as a blue box in the subplot c). a) Only the months corresponding to anchovy peak spawning season are represented (April to July); b) all year; c) area where spatial averages were computed.

The results also show that the connectivity between areas varies dramatically with time. The extension of the simulations to 2020 showed that according to the model results, after 2015, every year eggs/larvae were advected from Biscay to 9a.N, except in 2018 (Fig.6.3.3.3, Fig. 6.3.3.4 b)), although the maximum values of connectivity occurred in 2015.

Only during March 2020 oceanographic conditions dispersed eggs from 9aS to 9aCN (Fig 6.3.3.4 b). In the rest of the years there are eggs/larvae reaching the west coast, but only the area 9a.CS (Fig 6.3.3.4 b). Modelling results indicate a consistent oceanographic connectivity between the south (9a.S) and the southwestern coast (9a.CS), yet survey data reveals significant egg presence only in two years. Further investigation is needed to determine whether the eggs dispersed offshore during these surveys or if the surveys aligned with months where no (or weak) transport events occurred. The number and distribution of eggs in these simulations is the same for every spawning season because the objective was to test the impact of the oceanographic conditions on the survival and dispersion patterns; to make it possible to compare the results with the biomass time series it is essential to consider a more realistic egg distribution.

7 - IMPLICATIONS FOR MANAGEMENT

Currently, advice for the west and south components of the 9a stock is given separately, but a single TAC is set for the 9a Division, resulting from the sum of the advices for each component. Given the independent dynamics of the two components, in the short time series when the stock is being assessed (2018-2023), it is frequently observed opposite trends of biomass for the two components in several years, resulting in very different advice (Table 7.1). The fact that fishing opportunities are set for the whole 9a Division can result in overfishing the component with limited fishing opportunities. For example, in the period July 2022-June 2023 the agreed TAC of 15 777 tonnes was based on the sum of the separated TACs according to which 89% corresponded to the western component and 11% to the southern component. However, the TAC was set at 15 777 tonnes for the whole stock in division 9a. This resulted in provisional catches of 10 231 tonnes, from which 35% corresponded to the western component and 65% to the southern component. Consequently, catches in the Southern component were almost 3 times larger than the advised ones.

Table 7.1 - Anchovy in Division 9.a. ICES advice, the agreed TAC, and ICES catches. All weights are in tonnes. Catches from 1 July to 30 June in the following year to match the advised period.

Management year	Catches corresponding to advice		Agreed TAC	ICES catches	
	West component	South component		West component	South component
Jul 2018 – Jun 2019	13308	3760	17068	10093	3815
Jul 2019 – Jun2020	2662	6290	10240	2624	6472
Jul 2020 – Jun 2021	4347	11322	15669	5461	7904
Jul 2021 – Jun 2022	7824	7181	15005	11217	5839
Jul 2022 – Jun 2023	14083	1694	15777	3548*	6683*
Jul 2023 – Jun 2024	18354**	2201**	20555		

* Catch estimates of the first two quarters of 2023 are provisional.

** Preliminary data resulting from WGHANSA May 2024.

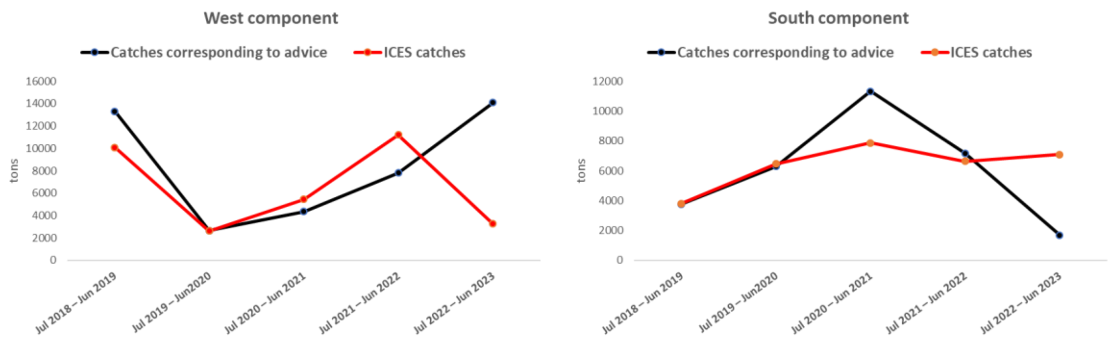


Figure 7.1. Time series of real catches and those corresponding to the advice for the western component of the anchovy 9a stock.

8 – CONCLUSIONS

From the results presented above the following conclusions can be drawn when assessing the potential connectivity of the western and southern components of the anchovy 9a stock:

- Data of the spatial distribution of anchovy in division 9a (surveys and landings) shows a persistent discontinuity of the western and southern components of the stock (around 9aCS), for all the life stages (eggs, juveniles and adults) and seasons of the year.

- No significant correlation was found of anchovy abundance at age between the western and southern stock components, suggesting independent cohort dynamics and low or absent connectivity.

- Morphometric studies point to a separation of the Gulf of Cadiz anchovy population from that in the western Iberia, although results from the Algarve were absent.

- Genetic studies conducted in the past were not conclusive as they might be confounded by the presence of a coastal and a marine ecotype. However, new genomic results taking these ecotypes into consideration show that the southern anchovy component is clearly differentiated from the western component and that the populations belong to two different genetic lineages.

- New larval dispersal results suggest it is unlikely that the eggs being spawned in the Gulf of Cadiz can disperse and survive to the northwestern coast in any relevant numbers for all years tested (2013-2020), suggesting low to absent connectivity during the early life stages.

- New analyses on isotopic composition of the eye lenses of juvenile and adult anchovy collected during different years show a clear isolation of the western and southern populations.

- The current management, combining the advised catches of the two components in a single TAC is causing overexploitation of the component with lower biomass, which can risk the sustainability of the stock.

Moreover, from the results presented above the following conclusions can be drawn when assessing the potential connectivity of the western component of the 9a anchovy stock and the neighbour stock in the Bay of Biscay (Subarea 8):

- The spatial distribution of the anchovy in the Cantabrian Sea (division 8c) varies from year to year, but during some years with high anchovy abundance, there is a continuous distribution of eggs (SAREVA, PELACUS) and adults (PELACUS) and occasionally high abundances in the westernmost tip of the Cantabrian Sea, contiguous to the 9aN sub-division. The western limit of the BIOMAN and JUVENA surveys is also extended.

- There is a significant correlation of anchovy abundance-at-age between the western Iberia and the Cantabrian Sea, either of fish of the same age and with a 1 year lag (assuming migration of recruits from the Cantabrian Sea to the western Iberian coast). It is unclear if it is revealing movement or a response of both populations to the same environmental queue.

- New results on larval dispersal modelling suggest a high connectivity between the Biscay anchovy populations and the Western Iberian populations, particularly during years with strong and persistent westward currents, which can disperse eggs to the NW Iberian coast in relevant numbers. These westward currents occurred in higher prevalence during the years matching the recent increase in abundance of anchovy in the western Iberia.

- Morphometric studies point to contrasting results, revealing either an intermediate population on western Iberia or similarity between 9a west and Bay of Biscay. These results can be confounded by the presence of a coastal and a marine ecotype.

- New isotopic analysis shows an overlap of isotopic values between the juveniles and adult anchovy of the western and northern Iberia which suggests either a strong connectivity of these populations or low baseline contrast between the two areas.

- Finally, recent genomic results show that the Bay of Biscay anchovy is genetically connected to the western populations.

As a result, WGHANSA considers there is compelling evidence to separate the two components of the anchovy 9a stock into two different stocks for which management options should be provided separately.

WGHANSA also considers that, although several results show that the western and northern Iberian populations might be strongly connected, more studies should be conducted to confirm these results. A larger and more sample-intensive work using stable isotopic composition is underway to help understanding the population structure of the anchovy in this area.

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Ane.27.9a stock (Anchovy in ICES Division 9a). Southern component (Anchovy in ICES Subdivision 9a South): Fishery, Biological and Surveys data. Data availability and trends.

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1. Landings in subdivision 9a South.

1.1. Total landings and landings by country.

Anchovy in subdivision 9a South (also termed as Gulf of Cadiz – GoC- anchovy) is harvested by an international fishery operated by Portuguese and Spanish fleets (at present – 2022 - composed by 22 Portuguese vessels and 54 Spanish ones targeting the species). The Portuguese annual landings statistics date back to 1943 (Pestana, 1996; ICES, 1997). Spanish annual landings started to be available since 1989 because of the mixing of catches coming from the Spanish and Moroccan fishing grounds in the official fishery statistics until that year. Therefore, a complete coverage of catch statistics for the entire subdivision is only available for the post-1989 fishery. This period will be the one which will be assessed with the Gadget model.

For this recent fishery, the official landings statistics are the result of the cross-checking of first sale notes and log-books (which are mandatory for vessels larger than 10 m in the Spanish fishery since 2004). In both countries landings are not considered to be significantly under reported. Some irrelevant landings misallocations to some unlikely artisanal gears may be detected in the Spanish official statistics. National statistics are provided to the ICES WGHANSA by subdivision/quarter/*métier*. Since 1998, both Spanish IEO and Portuguese IPMA (former IPIMAR) have used a common Excel Workbook (the Data Submission Work Book) to provide all necessary annual landings and sampling data (on a quarterly basis), which was originally developed for the former ICES Working Group on the Assessment of Mackerel, Horse-mackerel, Sardine and Anchovy (WGMHSA). In more recent years, commercial catch and sampling data are uploaded in the InterCatch software and formats by the respective national submitters and then processed by the stock coordinators.

Since 1943 on, Portuguese annual landings of GoC anchovy have oscillated between 12 501 t (1957) and less than 1 t (1972, 1992-1995, 2022), (historical average 1943-2022: 1537 t). This historical series reveals alternating periods of high and very low catches (Pestana, 1996; ICES, 1997; ICES, 2023; **Figure 1.1.1**). The greatest contribution to the Portuguese annual landings came from 9a South during the period 1943-1967 (mean value 4526 t). After this period, the landings from this subdivision decreased to 386 t (mean value) from 1968 to 1983 and abruptly to 32 t (mean value) from 1984 to 1997. Landings increased again to 366 t (mean value) from 1999 to 2004, but they decreased up to 55 t (mean value) from 2005 to 2022.

Spanish annual landings from the subdivision 9a South for the period with available and contrasted data (since 1988) have ranged between 571 t (1995) and 8977 t (1998), (historical average 1988-2022: 5021 t), (ICES, 2023; **Figure 1.1**). Although the environmental forcing has been suggested as the main cause (Ruiz *et al*., 2006), the historical minimum record in 1995 was mainly the result from a severe reduction in the fishing effort caused by the interruption of fishing (from May to December) by the most powerful fleet segment in the Gulf, the Barbate's single-purpose purse-seine fleet, to pressure to the National Fisheries Administration because of problems with the renewal of the EU-Morocco fisheries agreement in that year (Moroccan North-Atlantic fishing grounds are also traditionally exploited by these vessels targeting anchovy under these fisheries agreements) (see de Carvalho-Souza *et al*., 2021). The Spanish fishery also experienced periods of high and low catches. Historical peaks were recorded in 1998 (8977 t) and 2014 (8933 t). Decreased catches were recorded in the periods 1992-1996 (2068 t on average, including the abovementioned historical minimum in 1995), 2000 (2182 t), 2008-2010 (2997 t on average) and 2017-2019 (4573 t on average), (**Figure 1.1.1**).

Since 1988 on, total landings from the international fishery in the subdivision 9a South have oscillated between 571 t (1995) and 9543 t (1998), (historical average: 5127 t), (ICES, 2023; **Figure 1.1.2**).

The Spanish fishery in the Gulf of Cadiz is the main responsible for the anchovy fishery in the subdivision (98% of total landings on average) and, with the exception of some years (1995, 1996, 2011 and 2016-2022), in the entire Division 9a as well (66% of total landings on average if all the years in the 1988-2022 are considered).

1.2. Landings by *métier*.

Portugal and Spain routinely provide landings statistics by *métier* to ICES on an annual and quarterly basis. The *métiers* harvesting anchovy in subdivision 9a South are the following:

- Portuguese fishery:
    - Purse-seine (PS_SPF_0_0_0):
    - Otter bottom trawl directed to demersal fish (OTB_DEF_>=55_0_0).
    - Artisanal (mixed gears) using artisanal PS (also called in their national statistics as "polyvalent" vessels) (MIS_MIS_0_0_0_HC).
- Spanish fishery:
    - Purse-seine (PS_SPF_0_0_0).
    - Otter bottom trawl directed to mixed crustacean and demersal fish species (OTB_MCD_>=55_0_0). Until 2000 anchovy was captured as by-catch. Since then anchovy is discarded.
    - Artisanal (mixed gears) (MIS_MIS_0_0_0_HC) (incidental catches).

Figure 1.2.1 shows the contribution of each of these *métiers* in the GoC anchovy fishery for the period 1989-2022. The Spanish purse-seine fleet is the main responsible for the anchovy fishery in the subdivision, accounting for 95% of the total anchovy landings on average for the considered time series. The Spanish bottom trawl fleet is the following fleet in importance (c.a 3% on average), but such contribution is mainly restricted to the period 1993-2000, when this fleet fished anchovy as by-catch. The Portuguese purse-seine fleet contributed with 2% on average.

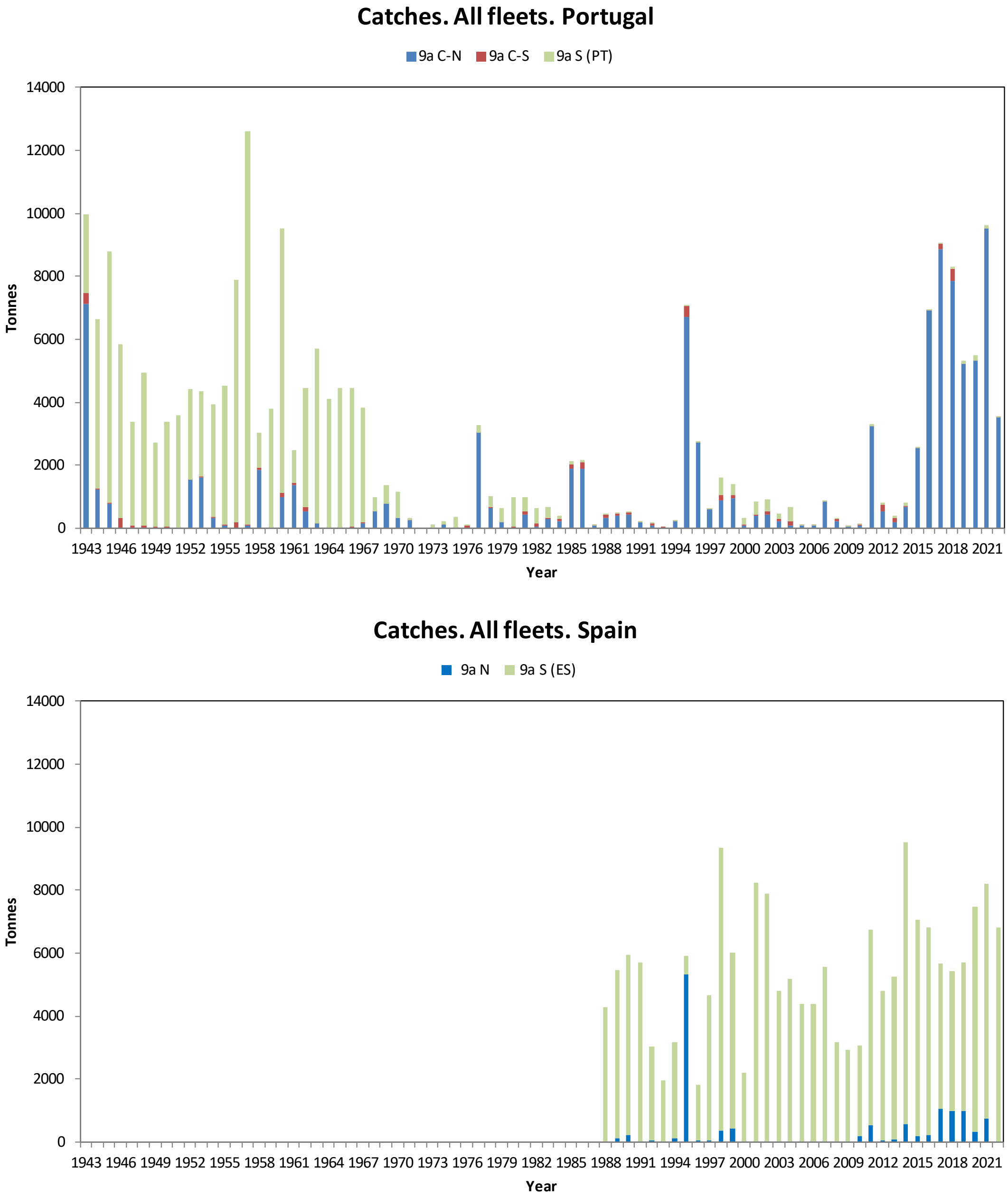


Figure 1.1.1. Ane.27.9a stock. Anchovy fishery in Division 9a. Anchovy catches (all fleets, in tonnes) in the Portuguese (top) and Spanish (bottom) fisheries by subdivision. Source: ICES (2023).

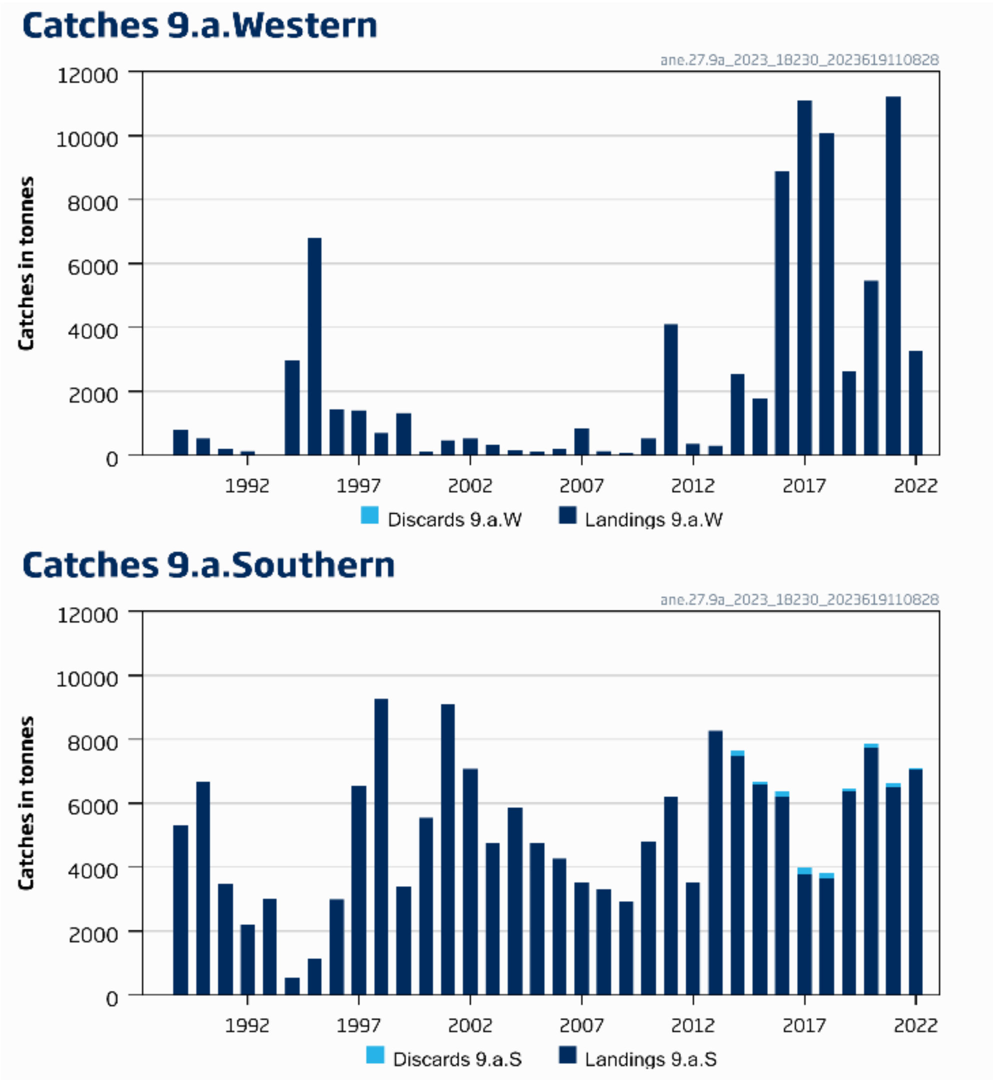
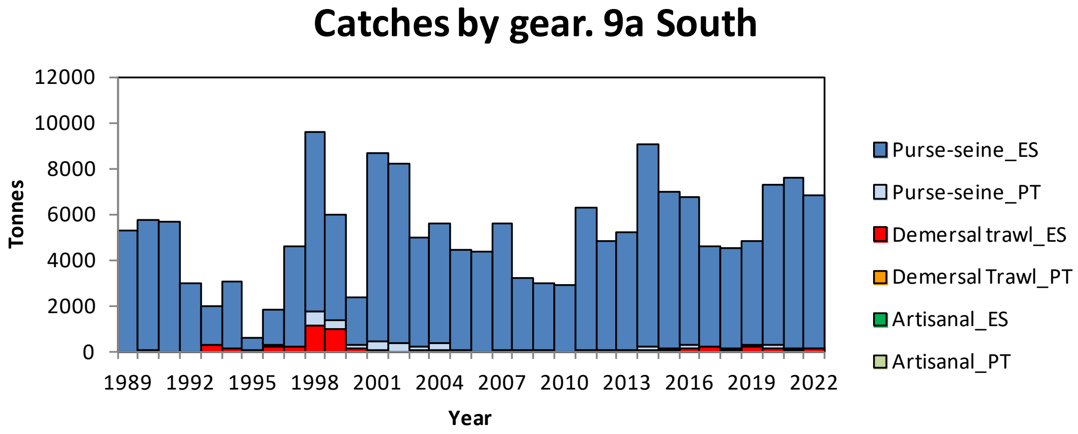


Figure 1.1.2. Ane.27.9a stock. Anchovy fishery in Division 9a. Anchovy catches (all fleets, in thousand tonnes) by stock component (9a W: western component, includes the subdivisions 9a North, 9a Central-North and 9a Central-South); 9a S: southern component (includes the subdivision 9a South). For both components, the years correspond to the 12-month management period, e.g. 1989 corresponds to the period 1 July 1989 to 30 June 1990. Source: ICES (2023).



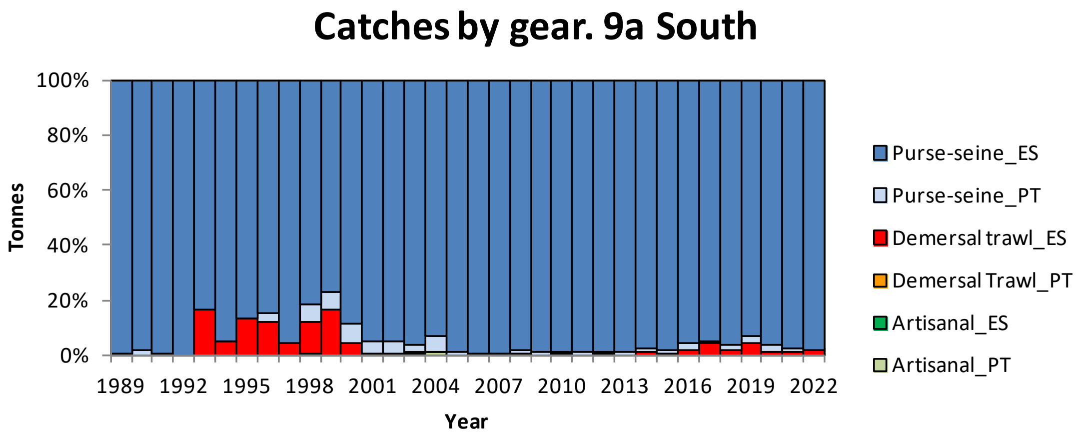


Figure 1.2.1. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. Annual catches by fishing gear in absolute (in tonnes, top) and relative (bottom) terms. Fleets-fishing gears-*métiers* are differentiated by country. Source: ICES WGHANSA.

2. Discards.

Discards are sampled by Portugal and Spain within their respective EC-DCR-based National Sampling Schemes. Discard sampling strategies and methods follow those adopted by the ICES Workshop on Discard Sampling Methodology and Raising Procedures (ICES, 2004a).

Discards are very difficult of measure. As with other pelagic fisheries that exploit schooling fish, discarding occurs in a sporadic way and with often extreme fluctuation in discard rates (100% or null discards). Extreme discards occur especially when the entire catch is released ("slippage"), which tend to be related to quota limitations, illegal size and mixture with unmarketable by-catch. Quantifying such discards at a population level is extremely difficult because they vary considerably between years, seasons, species targeted and geographical region (Stratoudakis & Marçalo, 2002; see also pil.27.8c9a Stock Annex).

Since 2004 official information provided to ICES states that there are no anchovy discards or they are negligible in the Portuguese fishery in the Gulf of Cadiz. Therefore, landings can be equalled to catches.

Data on anchovy discarding in the Spanish fisheries operating in 9.a South started to be gathered on a quarterly basis since the fourth quarter in 2005 on, within the Spanish National

Sampling Scheme framed into the EC Data Collection Regulation (DCR). However, the sampling intensity applied until 2013 to assess the anchovy discarding was very low because it was limited to the agreed minimum sampling scheme (2 trips per quarter, 8 trips per year). Such a sampling scheme resulted in unreliable and not representative quarterly discard estimates which were also affected by high CVs. This low sample size made their results not conclusive and hence they were not considered. Since 2014 on a more intense sampling scheme was developed which also extends to the Spanish fishery in Sub-division 9.a North. Overall annual discard ratios estimated since 2014 oscillate between 0.01 (1%)–0.026 (2.6%), hence anchovy discards can also be considered as negligible in the Spanish fishery in the 9a South. Notwithstanding the above, since 2014, discards are estimated by quarter/*métier*/size/age and aggregated to landings to provide catches.

3. Size composition of landings (and catches).

The sampling coverage and intensity of the length frequency distribution (LFD) of landings are very different for the GoC Portuguese and Spanish fisheries in the southern component and depends on the resource availability and commercial interest (**Table 3.1**). Thus, anchovy is not a priority fishing species for the Portuguese fishery, unless it is abundant, and this fact is reflected in the almost null LFD availability throughout the period under analysis. In fact, raw LFDs sufficiently representative to be raised to the total landings are only recorded in some quarters in 2013, 2014 and 2016, but they were not enough to derive annual LFDs in those years.

Conversely, anchovy is the target species for the Spanish fishery in this subdivision. LFDs are available since 1989 (**Figure 3.1**). During the period 1989-2008 LFDs were sampled in fishing harbours, between 2009 and 2013 from a concurrent sampling both in land and at sea, between 2014 and 2021, from a concurrent sampling directly at sea, and since 2023 on again from a concurrent sampling in harbours. For the whole period under analysis the sampled raw LFDs of landings correspond to the purse-seine fishery, the main responsible for the Spanish anchovy fishery in the subdivision. These raw LFDs are sampled on a monthly basis, raised to monthly total landings and then pooled and provided by quarter and year to ICES. LFDs from bottom trawl landings (which occurred between 1993 and 2012, especially between 1993 and 2000) were not sampled because their relatively low representativeness in the whole fishery (not higher than 18% in those years with the highest landings). **Figure 3.1** shows annual LFDs for the whole Spanish fishery. Those LFDs for the period 1989-2013 were estimated raising the purse-seine LFD to the total catches (catches from all fleets pooled) by assuming the abovementioned scarce representativeness of the other *métiers* than purse-seine. Since 2014, quarterly LFDs from discarded catch are sampled by *métier* and raised to total estimated discards, as previously described in **Section 2**, and then pooled to the quarterly LFDs of landings to derive the LFD of annual catches.

The anchovy size range in Spanish catches for the whole 1989-2022 period oscillated between 3.5 and 20.5 cm size classes. The lowest and highest annual mean lengths and weights were recorded in 1996 (6.6 cm, 2.6 g) and 2008 (12.3 cm, 13.1 g), respectively (**Figure 3.2**). The LFDs during the period between 1989 and 2002 were characterised by the occurrence of 2-3 modal classes, with the smallest one, at around 5.0 - 7.0 cm size classes, even being the dominant mode in some years. This smallest mode disappeared from 2003, when the LFDs became basically unimodal, with the annual modes located at about 10.0 - 11.5 cm size classes, suggesting a probable shift in the fishing pattern. Mean lengths started to show some increasing trend since 2001 on (**Figure 3.2**). One of the causes which could explain this shift in the fishing pattern may be the establishment in June 2004 of a Marine Protected Area (Fishing Reserve) in the Guadalquivir River mouth, where neither purse-seine nor bottom trawl fishing is allowed (see **Section 7** and **Figure 7.1**). This protected area is the main anchovy recruitment area in the GoC (Baldó *et al*., 2006; Catalán *et al*., 2006) and, until then, the main fishing ground for the smallest, lighters and less autonomous purse-seine vessels of the Spanish fleet (Millán, 1992; **Figure 3.3**). Additionally, a progressive strengthening of the fulfilment of the minimum landing size (10 cm) since 1995 (established by the Royal Decree 560/1995) by the Spanish Fishing Authorities may also have contributed to the abovementioned shift, although it seems that started to be more effective since 2001 on.

The sampling programs coordinated by the IEO (on-shore, at-sea and biological sampling) were suspended in most of 2020 (first and second quarters in 2020) due to administrative problems and to the covid-19 disruption. In the Spanish fishery in 9a South LFDs in the first (Q1) and second (Q2) quarters in 2018 and 2019 showed statistically significant similar between them and different from the homologous quarters in previous years. LFDs from the same quarter were then pooled for 2018 and 2019 and the resulting LFDs were raised to the corresponding quarterly catches in 2020. The *PELAGO 20* ALK for GoC waters was applied to both quarterly LFDs for the age structuring of catches.

4. Age structure of landings (and catches).

4.1. Age reading.

The 2014 ICES Planning Group on Commercial Catch, Discards and Biological Sampling (PGCCDBS; ICES, 2014a) identified the need of a full-scale European Anchovy (*Engraulis encrasicolus*) otolith exchange to take place in 2014 under the coordination of IEO and AZTI (Spain). It was the second exchange after that's of 2009 (ICES WKARA; ICES, 2010) that anchovy otoliths of Atlantic and Mediterranean were included together. In view of the results of that exchange (Villamor & Uriarte, 2015), the ICES Working Group on Biological Parameters in 2015 (WGBBIOP; ICES, 2015), recommended the realization of a Workshop on Age Reading of European Anchovy to discuss the results of the previous exchange and the development of validation studies in this species.

The aim of this last workshop (ICES WKARA 2; ICES, 2017b) was to review the information on age determination, discuss the results of the previous exchange (2014), review the validation methods existing on these species, clarify the interpretation of annual rings and update the age reading protocol and a reference collection of well-defined otoliths.

ICES WKARA 2 suggested threshold values of agreements around 80% and of CVs around 20% in the training process as a minimum for age readers to be operative to deliver inputs for assessment. And targets should be for agreements above 90% and CV of 10% or less. Nevertheless, ageing anchovy otoliths from Division 9a is quite difficult, and much more from 9a S (ES). IEO and IPMA age readers of anchovy in Division 9a showed a 75.7% agreement (CV=33.0%), which showed as a not very bad result. The IEO expert reader for the GoC anchovy (9a S (ES)), the most important fishing area in the Division, reached a 94% agreement and ICES WKARA 2 considered that quality for age reading is good for the GoC anchovy assessment reader. ICES WKARA 2 recommended, as far as possible, that only the age readings of the most expert readers by areas are used for the assessment inputs. Such recommendations are being applied to the GoC anchovy ageing.

A new ICES WKARA 3 was held in 2021 (ICES, 2023b). The results of an IEO-IPMA age inter-calibration analysis of age readings from anchovy in Division 9a, held in 2018, were presented in that WK. The readers appeared in agreement among them and with the previously proposed WKARA 2 suggestions, but some discrepancy among readers was detectable in the assignment of age 2, due to the misinterpretation of the spawning check. Preliminary results on a validation study conducted on GoC anchovy were also presented in that WK, showing the use the marginal increment analysis (MIA) and the nature of the edge analysis (EA) as age corroboration studies.

Some inconsistencies of anchovy age attribution by Spanish and Portuguese readers were still detected during the WGHANSA 2023 meeting (Portuguese expert age reader retired in 2020). For this reason, a recent IPMA-IEO inter-calibration exercise between Spanish and Portuguese anchovy age readers was performed, which resulted in a revision of the ages attributed to anchovy in surveys *PELAGO* 2020, 2021 and 2022.

4.2. Age structure of landings (and catches).

So far, no catch-at-age data are available from the Portuguese fishery in the subdivision. For the Spanish fishery, catch-at-age data (catch numbers-at-age, mean weight-at-age, mean length-at-age) are derived since 1989 from the raised national figures routinely provided by Spain. Both age length keys and length/weight relationships are compiled on a quarterly basis from monthly market samples.

Information gaps on Spanish catch-at-age data for the whole 1994 and second half in 1995 (only the size composition in catches is available) were solved by Millán (2002) from an iterated age-at-length key (IALK) by applying the Kimura & Chikuni's (1987) algorithm.

The sampling programs coordinated by the IEO (on-shore, at-sea and biological sampling) were suspended in most of 2020 (first and second quarters in 2020) due to administrative problems and, to a lesser extent, to the covid-19 disruption. Raising procedures to estimate LFDs and age structure of catches in Q1 and Q4 2020 in 9a South has previously been described in **section 3**.

Table 3.1. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. LFD sampling coverage and availability on an annual and quarterly basis for the Portuguese (PT) and Spanish (ES) fisheries. White background means no data, dark blue available and representative LFDs to estimate the size composition of landings. See text in section 3 for description of raising procedures used to solve problems in 2020. Source: ICES WGHANSA.

SUB-DIV	QUARTER	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
9a S (PT)	Q1																																		
	Q2																																		
	Q3																																		
	Q4																																		

SUB-DIV	QUARTER	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
9a S (ES)	Q1																																		
	Q2																																		
	Q3																																		
	Q4																																		

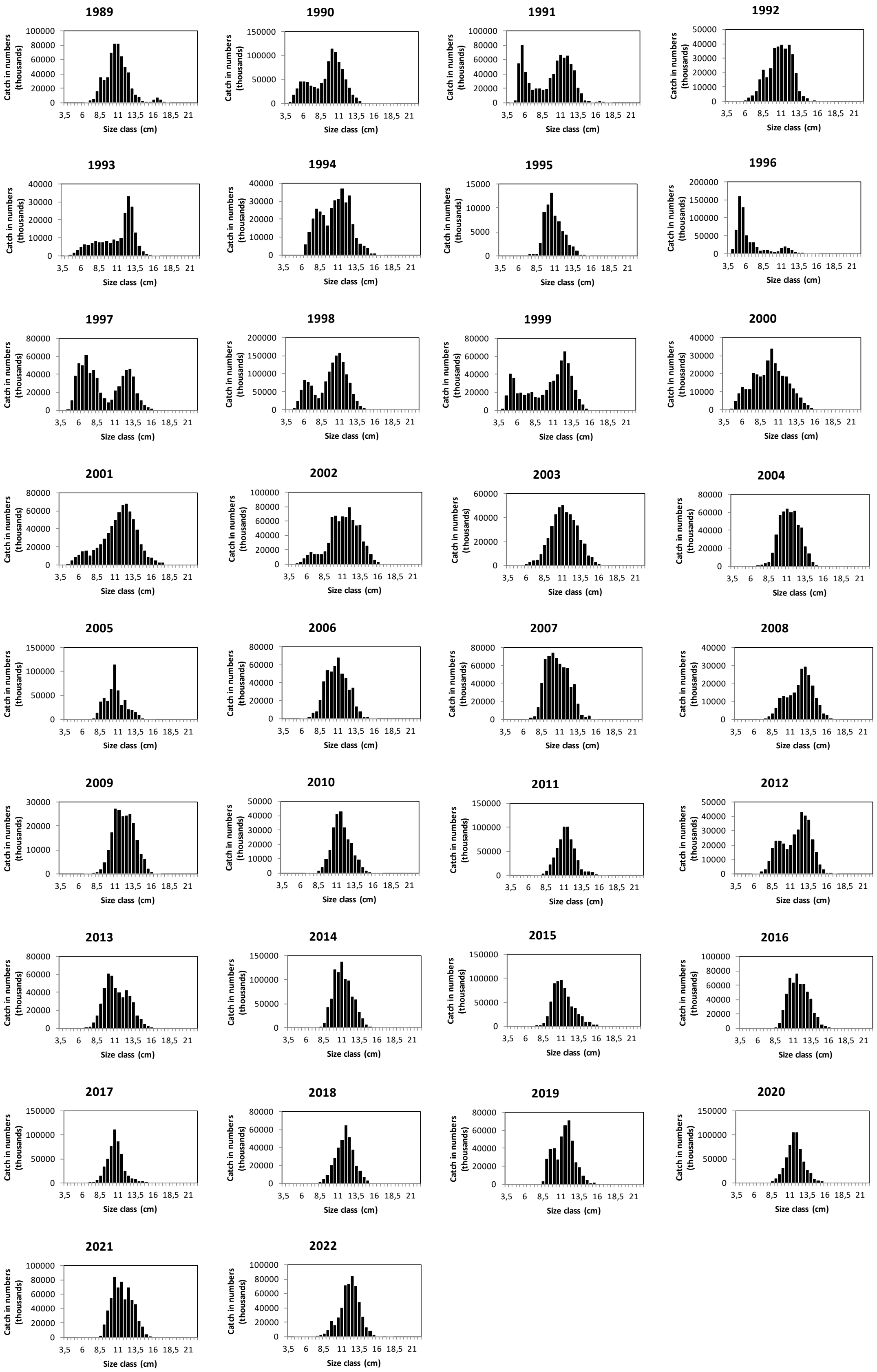


Figure 3.1. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. Annual length frequency distributions (LFDs, by 0.5 cm size class) of anchovy catches in the Spanish fishery (all fleets). Source: ICES WGHANSA.

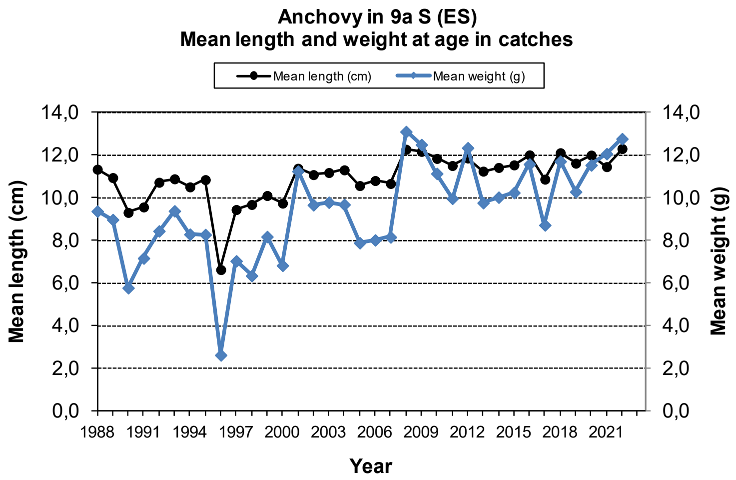


Figure 3.2. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. Mean length (cm) and mean weight (g) in anchovy catches in the Spanish fishery (all fleets). Source: ICES WGHANSA.

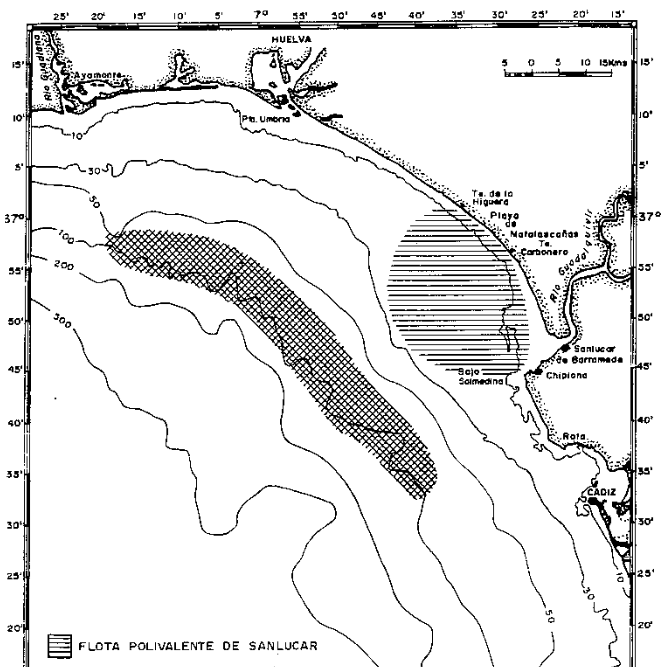


Figure 3.3. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. Traditional fishing grounds for the Spanish purse-seine fleets in the Gulf of Cadiz before the establishment of the Marine Protected Area (Fishing Reserve) of the Guadalquivir River mouth in 2004. The shallower ground was mainly frequented by the lighter, smaller and less autonomous vessels. Source: Millán (1992).

Table 4.2.1. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. Age sampling coverage and availability on an annual and quarterly basis for the Portuguese (PT) and Spanish (ES) fisheries. White background means no age data. Information gaps on catch-at-age data in the Spanish fishery for the whole 1994 and second half in 1995 (only LFDs are available) were solved from an iterated age-at-length key (IALK) by applying the Kimura and Chikuni's (1987) algorithm (Millán, 2002). See text in section 3 for description of raising procedures used to solve problems in 2020. Source: ICES WGHANSA.

SUB-DIV	QUARTER	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
9a S (PT)	Q1																																		
	Q2																																		
	Q3																																		
	Q4																																		

SUB-DIV	QUARTER	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
9a S (ES)	Q1																																		
	Q2																																		
	Q3																																		
	Q4																																		

Anchovy catches from the Spanish fishery in Subdivision 9a S (ES) are composed by fishes belonging to the Age 0 to Age 3 groups, although the bulk of the fishery is sustained by Age 0 and Age 1 groups, with the Age 2+ anchovies being incidental (**Figure 4.2.1**). The 1997, 1998, 2000, 2001, 2006 and 2013 cohorts seem to have been the strongest ones in the recent fishery.

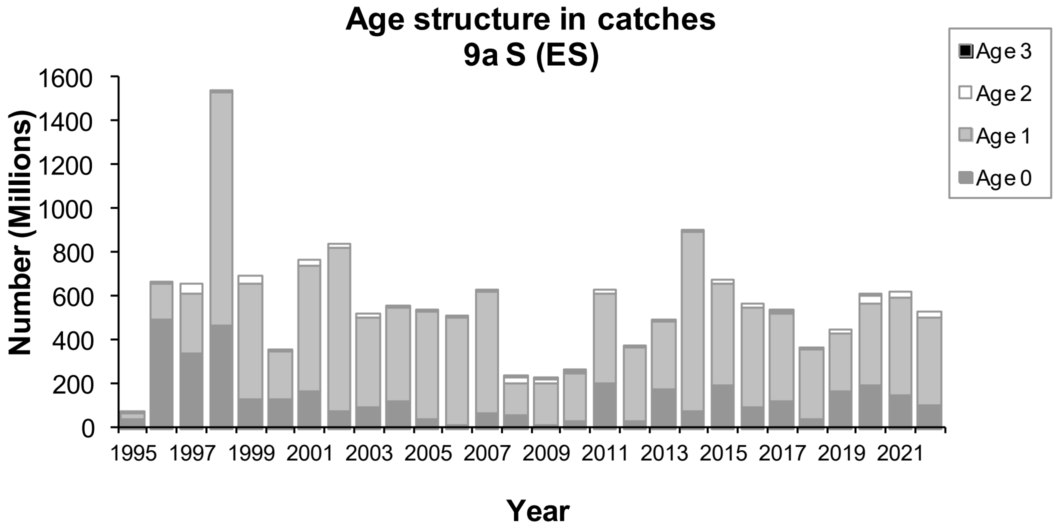


Figure 4.2.1. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. Spanish annual catch in numbers (in millions) at age. Data for 1994 and second half in 1995 estimated from an iterated ALK by applying the Kimura and Chikuni's (1987) algorithm. Source: ICES WGHANSA.

5. Surveys series.

5.1. General.

Table 5.1.1 shows the list of surveys series providing direct estimates for anchovy in Sub-division 9a S. The main characteristics of these surveys are the following:

PELAGO **spring acoustic-trawl survey series** (until 2006 termed as SAR surveys): Portuguese survey series conducted by IPMA with the RV *Noruega* until 2020 and onboard the RV *Miguel Oliver* afterwards. Originally it was routinely performed for the acoustic estimation of the sardine abundance in Division 9a off the Portuguese continental shelf and Gulf of Cadiz (20 – 200 m depth), during March-April (sardine late spawning season). Since 2007 on, the spring surveys are being planned as 'pelagic community' surveys. This shift in planning mainly entailed, as compared with previous years, a substantial increase in the number of fishing stations in the Sub-division 9a S, where the species diversity is higher, changing the series its former name by the one of *PELAGO* surveys. This survey series is currently financed by DCF. Gulf of Cadiz anchovy estimates from these survey series started to be available since March 1999.

ECOCADIZ **summer acoustic-trawl survey series**: the *ECOCADIZ* Spanish survey series is an integrated pelagic community survey series conducted by IEO in the Spanish and Portuguese shelf waters (20 – 200 m depth) of the Gulf of Cadiz (GoC). These acoustic-trawl surveys have been financed by UE-DCF. They were firstly conducted with the RV *Cornide de Saavedra* (2004-2013) and then with the RV *Miguel Oliver* (2014-2020) afterwards. Survey dates were initially planned to be coincident with the GoC anchovy peak spawning (late spring-early summer), but these dates were progressively delayed until late July-early August because ship-time availability and prioritisation of other surveys. Such a delay in the survey dates should be taken into consideration when interpreting the acoustic estimates in the temporal (inter-annual) and spatial contexts.

The series started in 2004, but with gaps during the first years of the series, in 2005, 2008 and 2011, because of the available ship-time had to be invested in the conduction of the anchovy DEPM triennial survey *BOCADEVA* (see below). Since 2014 both surveys are conducted almost synchronously, with the DEPM-ichthyo-plankton component being sampled by the RV *Ramón Margalef* during the *BOCADEVA* surveys and with the *ECOCADIZ* surveys providing adult anchovy samples. The 2009 and 2010 *ECOCADIZ* surveys suffered a shortage of the days at sea (10 and 7 days, respectively) in relation to the duration usually scheduled (ca. 14 days) because financial problems, which culminated with the cancellation of the 2012 survey. More recently, the 2021 survey was neither conducted because a serious RV breakdown, nor the 2022 survey because a cessation of this surveys series. However, acoustic estimates were again available in 2023 during a combined *ad hoc* DEPM/acoustic-trawl survey (*ECOBOCADEVA 0723*) conducted on board the RV *Ramón Margalef*. However, no *ECOCADIZ* survey has been scheduled in 2024 and subsequent years. The time-series' average coverage index of valid fishing hauls/EDSU (*Elementary Distance Sampling Unit*, 1 nm; Simmonds & MacLennan, 2005) is 0.07 hauls/EDSU (ca.23 hauls per survey), one of the highest indices reached in acoustic-trawl surveys of similar characteristics conducted in ICES waters (Doray *et al*., 2021). Egg samples are collected underway every 3 nm, with the CUFES system (water pumped from 3 m from the surface, system fitted with a 335 µm mesh size net; Checkley *et al*., 1997), concurrently to the acoustic surveying along the trajectory of the acoustic transects.

***BOCADEVA* summer DEPM survey series**: Spanish survey series conducted by IEO firstly with the RV *Cornide de Saavedra* (until 2011) and afterwards with the combined use of RV *Ramón Margalef* (ichthyoplankton samples) and RV *Miguel Oliver* (adult samples during the *ECOCADIZ* acoustic surveys). The surveys series is aimed at the estimation of the GoC anchovy SSB hence the surveyed area is restricted to the GoC shelf waters (20 – 200 m depth). The surveys are conducted triennially, starting in 2005. This survey series is currently financed by DCF. The continuity of this survey series by IEO in the next years is not totally guaranteed because of unavailability of ship-time for collecting adult samples, the shortage of technical staff required for the histological processing of those samples and the inability of providing adult estimates in due time (whenever the current dates of the survey – late July-early August – are still maintained).

***SARNOV* autumn acoustic-trawl survey series**: Portuguese survey series conducted by IPMA with the RV *Noruega*. The survey was also originally performed for the acoustic estimation of the sardine abundance in Division 9a off the Portuguese continental shelf and Gulf of Cadiz (20 – 200 m depth), during November (early spawning and recruitment season). The series started in 1998 and finished in 2008 but showed several gaps without surveys. GoC anchovy estimates from this survey series are only those from November 1998, 2000, 2001 and 2007.

***ECOCADIZ-RECLUTAS* autumn acoustic-trawl survey series**: the abundance of GoC anchovy and sardine recruits started to be acoustically assessed by the IEO in autumn 2009. However, that survey was considered a pilot experience due to a series of events that drastically reduced the ship-time and the area covered (Ramos *et al*., 2010). This autumn survey was conducted again in 2012 as *ECOCADIZ-RECLUTAS 1112*; it was financed by the Spanish Fisheries Secretariat and planned and conducted by the IEO to obtain an autumn estimate of GoC anchovy biomass and abundance. That survey was carried out onboard RV *Emma Bardán*, but restricted to the Spanish waters only (Ramos *et al*., 2013). *ECOCADIZ-RECLUTAS 2014-10* re-started the series two years later, with the surveys being conducted with the RV *Ramón Margalef* (the 2022 survey was conducted on board RV *Ángeles Alvariño*, twin vessel of the former) and covering both the GoC Portuguese and Spanish waters as the agreed standard sampling scheme and sampling methods (identical to the ones described for the *ECOCADIZ* summer survey series, but in these autumn surveys no ichthyo-plankton sampling by CUFES is performed; Doray *et al*., 2021). Since 2014 on, the series should therefore be considered as the standard one. The 2017 survey is not included in the series since the RV's propeller system suffered from an unexpected and serious breakdown, leading to an earlier survey's ending and an incomplete coverage of the survey area (only the seven easternmost transects were sampled). The survey series, although planned as a pelagic community survey, is aimed at the acoustic estimation of both GoC anchovy, sardine and chub mackerel juveniles and restricted to the Sub-division 9a S (20 – 200 m depth). Thus, the general objective of these surveys is the acoustic assessment by vertical echo-integration and mapping of the abundance and biomass of recruits of small pelagic species (especially anchovy, sardine and chub mackerel), as well as the mapping of both the oceanographic and biological conditions featuring the recruitment areas of these species in Division 9a. The long-term objective of the surveys is to assess the strength of the incoming recruitment to the fishery of these species the following year.

The time-series' average coverage index of valid fishing hauls/EDSU is 0.06 hauls/EDSU (ca.20 hauls per survey). The surveys are usually conducted during the 3 last weeks in October, although some deviations to this schedule occurred in 2016 and 2021 (they finished in the first week in November), and in 2020 and 2023 (they started earlier, in late September). The series is also suffering of a progressive reduction in its duration (from 21-20 days to the current 16-15 days). This survey series is currently financed by DCF.

5.2. Methods.

Since 2005 the above surveys series are coordinated and standardized (with updated surveys protocols) within the frame of the ICES *Working Group on Acoustic and Egg Surveys for small pelagic fish in NE Atlantic* (WGACEGG). Doray *et al*. (2021) thoroughly describe SISP protocols and methods for the acoustic-trawl surveys series (see also Simmonds & MacLennan, 2005 for theory underlying fisheries acoustics and Massé *et al.*, 2018 for a previous review of these surveys series). The corresponding SISP protocols of egg surveys are still in progress. Complementary information is also found in ICES WGHANSA and WGACEGG reports (ICES 2023, 2024) and ane.27.9a Stock Annex.

Figures 5.2.1, **5.2.2** and **5.2.3** show the sampling grids adopted in the surveys series analyzed in this WD.

Table 5.1.1. Ane.27.9a stock. Surveys providing direct estimates for anchovy in Sub-division 9a South. (1): *ECOCADIZ-COSTA 0709*, (pilot) Spanish survey surveying shallow waters <20 m depth and complementary to the standard survey; ((Month)): surveys that were carried out but did not provide any anchovy acoustic estimate because of its very low presence and/or for an incomplete geographical coverage (some areas were not covered: either the Spanish or the Portuguese part of the Gulf of Cadiz). Sources: ICES WGHANSA, ICES WGACEGG.

Survey	***PELAGO***		***SAR***	***ECOCADIZ***		***ECOCADIZ-RECLUTAS***	***BOCADEVA***	
Institute (Country)	**IPMA (Portugal)**		**IPMA (Portugal)**	**IEO (Spain)**		**IEO (Spain)**	**IEO (Spain)**	
Method	**Acoustic**		**Acoustic**	**Acoustic**		**Acoustic**	**DEPM**	
Year/Quarter	**Q1**	**Q2**	**Q4**	**Q2**	**Q3**	**Q4**	**Q2**	**Q3**
1993								
1994								
1995								
1996								
1997								
1998			Nov					
1999	Mar							
2000			Nov					
2001	Mar		Nov					
2002	Mar							
2003	Feb		(Nov)					
2004		(Jun)		Jun				
2005		Apr	(Nov)				Jun	
2006		Apr	(Nov)	Jun				
2007		Apr	Nov		Jul			
2008		Apr	(Nov)				Jun	
2009		Apr		Jun	(Jul)(1)	(Oct-Nov)		
2010		Apr			(Jul)			
2011		Apr						Jul
2012						(Nov)		
2013		Apr			Aug			
2014		Apr			Jul-Aug	Oct		Jul
2015		Apr			Jul-Aug	Oct		
2016		Apr			Jul-Aug	Oct-Nov		
2017		Apr			Aug	Oct		Jul
2018		May			Aug	Oct		
2019		Apr			Aug	Oct		
2020	Mar				Aug	Oct		Jul
2021	Mar					Oct		
2022	Mar					Oct		
2023	Mar				Jul-Aug	Oct		Jul

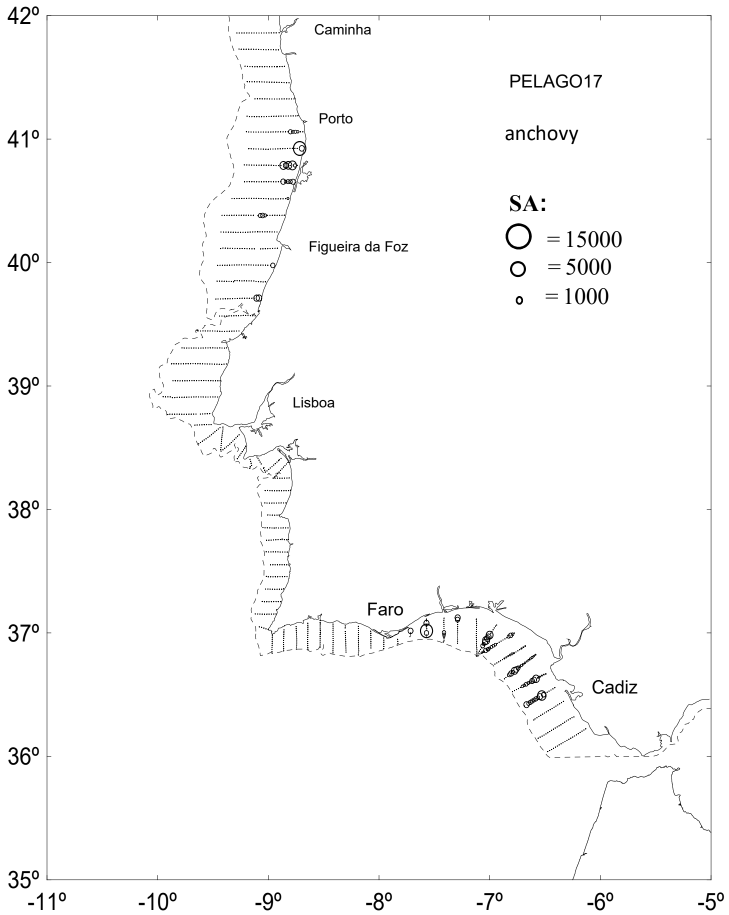


Figure 5.2.1. Ane.27.9a stock. Anchovy in 9a S. *SAR/PELAGO* (spring) and *SARNOV* (autumn) acoustic surveys. Location of the acoustic transects sampled during the survey based on the *PELAGO 2017* survey. Source: ICES WGACEGG.

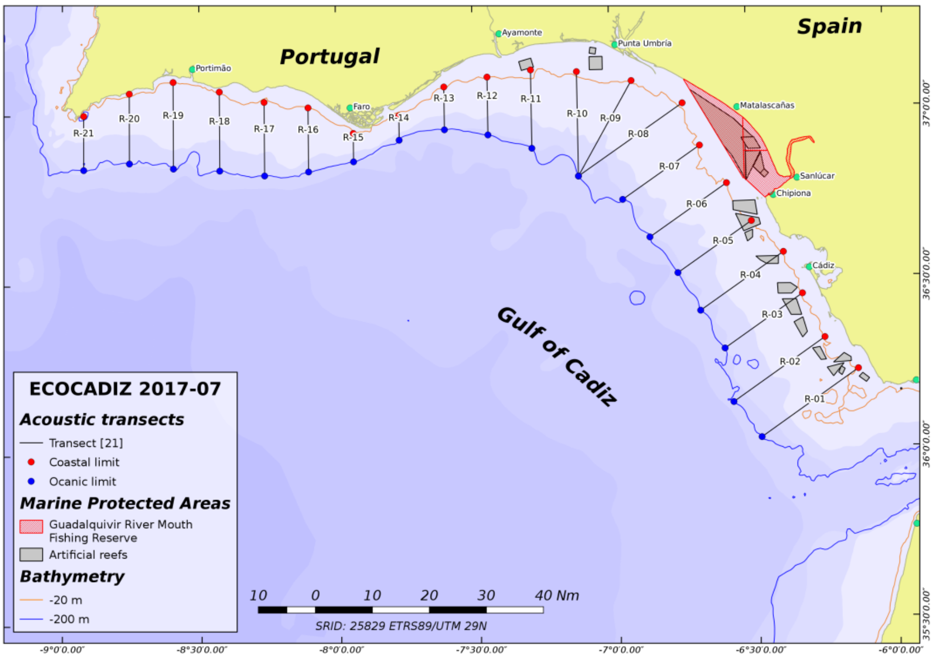


Figure 5.2.2. Ane.27.9a stock. Anchovy in 9a S. *ECOCADIZ* (summer) and *ECOCADIZ-RECLUTAS* (autumn) acoustic surveys. Location of the acoustic transects sampled during the survey based on the *ECOCADIZ 2017-07* survey. Source: ICES WGACEGG.

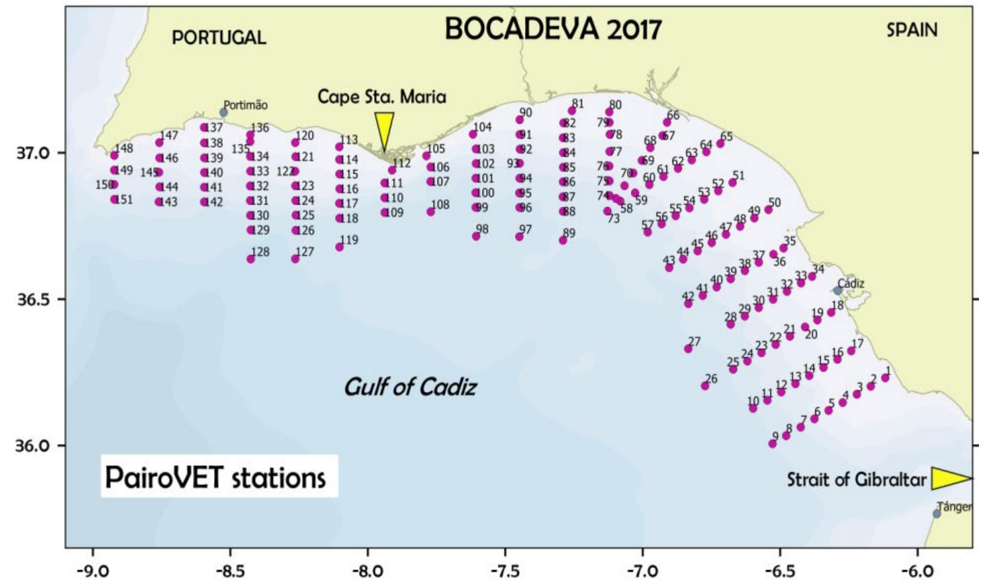


Figure 5.2.3. Ane.27.9a stock. Anchovy in 9a S. *BOCADEVA* GoC anchovy DEPM surveys series. Sampling grid adopted in the surveys based on the *BOCADEVA 2017* survey. Source: ICES WGACEGG.

5.3. Data availability.

Table 5.3.1 summarizes the data availability from Portuguese and Spanish surveys surveying the anchovy population in 9a S.

The *PELAGO* time-series with estimates for anchovy in 9a S dates back to 1999, with gaps in 2000, 2004 and 2012. Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) of the estimated population in numbers and biomass, but age-structured estimates are provided by IPMA only since 2008 on. Aiming to achieve a complete time-series of age-structured estimates, the Spanish commercial ALKs of the quarter coinciding with the survey season was applied to the acoustic estimates from 1999 to 2007. However, age-based information on the population was included in the Gadget assessment model tested in the last benchmark only for the period 2014-2017, when the age-length keys from the surveys were available in that moment. That information on age structure has been subsequently updated in the assessment model until nowadays.The *SARNOV* surveys providing GoC anchovy estimates were only those ones conducted in 1998, 2000, 2001 and 2007. These estimates neither were provided by IPMA with age-structure.

The *ECOCADIZ* surveys dates back to 2004, but also show some gaps in 2005, 2008, 2011 (because the triennial *BOCADEVA* DEPM surveys were carried out instead), 2012, 2021 and 2022 (no survey). Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) and age-structure of the estimated population in numbers and biomass.

The *ECOCADIZ-RECLUTAS* (autumn in 9a S) acoustic surveys series, composed by surveys in 2012 (only Spanish waters) and 2014-2023, with a gap in 2017 (R/V breakdown at the start of the survey). Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) and age-structure of the estimated population in numbers and biomass.

The *BOCADEVA* GoC anchovy DEPM surveys series is so far composed by the 2005, 2008, 2011, 2014, 2017, 2020 and 2023 data points. SSB estimates are provided with a CV estimate but without size composition and age structure. SSB estimate in 2014 was estimated with the spawning fraction estimate from the 2011 survey, whereas the SSB estimate in 2020 and 2023 has been preliminary computed making use of the time-series average of the spawning fraction estimates available in each moment.

Table 5.3.1. Ane.27.9a stock. Anchovy fishery in subdivision 9a South. Data availability of surveys estimates from the Portuguese (PT) and Spanish (ES) surveys. All but *BOCADEVA* survey (DEPM) are acoustic-trawl surveys. White background means no data, orange: aggregated biomass only-based estimates; blue: length-based estimates available and green: both length- and age-based estimates. Sources: ICES WGACEGG, ICES WGHANSA.

SURVEY	SUB-DIVISION	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
PELAGO	9a S (PT)								blue		blue	blue	blue		blue	blue	blue	green	green	green			green	green	green	green	blue	green	green	green	green	green	green
	9a S (ES)								blue		blue	blue	blue		blue	blue	blue	green	green	green			green	green	green	green	green	green	green	green	green	green	green
ECOCADIZ	9a S (PT)													green		green	green		green				green	green	green	green	green	green	green	green	green	green	green
	9a S (ES)													green		green	green		green	green			green	green	green	green	green	green	green	green	green	green	green

SURVEY	SUB-DIVISION	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
BOCADEVA	9a S (PT & ES)														orange			orange			orange			orange			orange			orange			orange

SURVEY	SUB-DIVISION	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
SAR (AUT)	9a S (PT)							blue		blue	blue						blue																
	9a S (ES)							blue		blue	blue						blue																
ECOCADIZ-RECLUTAS	9a S (PT)																							green	green	green		green	green	green	green	green	green
	9a S (ES)																					green		green	green	green	green	green	green	green	green	green	green

orange	Aggregated estimates
blue	Length-based estimates
green	Length- and age-structured estimates

5.4. Survey consistency.

Survey consistency is analyzed in a separate WD (Rincón *et al*., WD 2024).

5.5. Spring acoustic-trawl survey series *SAR/PELAGO*.

5.5.1. Acoustic estimates

No specific maps of GoC anchovy NASC from *PELAGO* surveys have been available to be reported in the present WD. Failing this, **Figure 5.5.1.1** shows the mapping of averaged anchovy NASC values from some of the more recent spring surveys surveying the NE Atlantic waters covered by ICES WGACEGG (*i.e. PELGAS*, *PELACUS* and *PELAGO* surveys, see ICES WGACEGG reports). In the area surveyed by *PELAGO* surveys two main centres of anchovy distribution are identified, in the GoC Spanish waters and in the north western Portuguese coast.

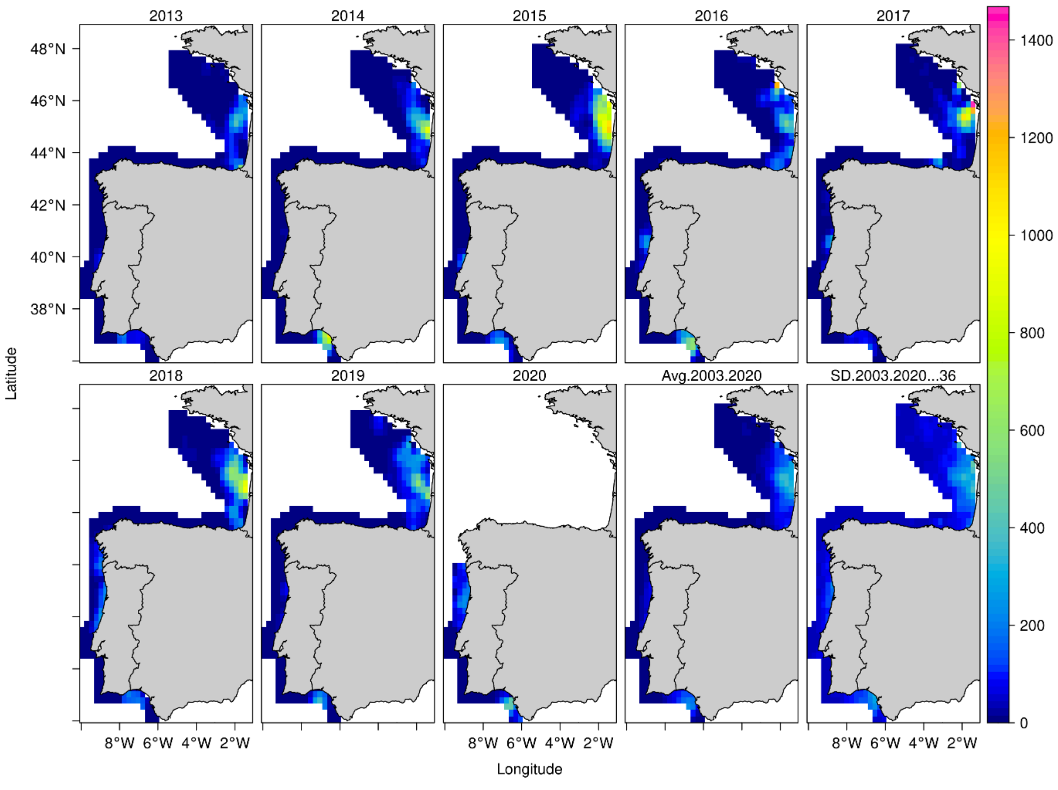


Figure 5.5.1.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *SAR/PELAGO* survey series (spring Portuguese acoustic-trawl survey in Subdivisions 9.a. Central-North, 9.a. Central-South and 9.a South). Anchovy mean acoustic density (NASC, m^2nm^{-2}) maps derived from the *PELAGO*, *PELACUS* and *PELGAS* surveys, 0.25° map cell. “Avg.2003-2020”: map of anchovy NASC values averaged over the series. “SD.2003-2020”: map of anchovy NASC standard deviation over the series. Sources: IPMA, ICES WGACEGG, ICES WGHANSA.

Figure 5.5.1.2 shows the time series of biomass estimates. The estimated abundances (not shown) oscillated between 849 (2022) and 9811 (2016) million fish (time-series average: 2744 million fish). The range of biomass estimates oscillates between 7395 (2010) and 65 345 (2016) t (time-series average: 25 945 t). The most recent estimates show strong drops in the population levels (in 2017 and 2022) after reaching the historical maxima recorded in 2016 and 2020. Spanish waters, excepting in 2013 and 2022, when the population was more evenly distributed, usually concentrate more than 80% of the total estimated population biomass (**Figure 5.5.1.3**).

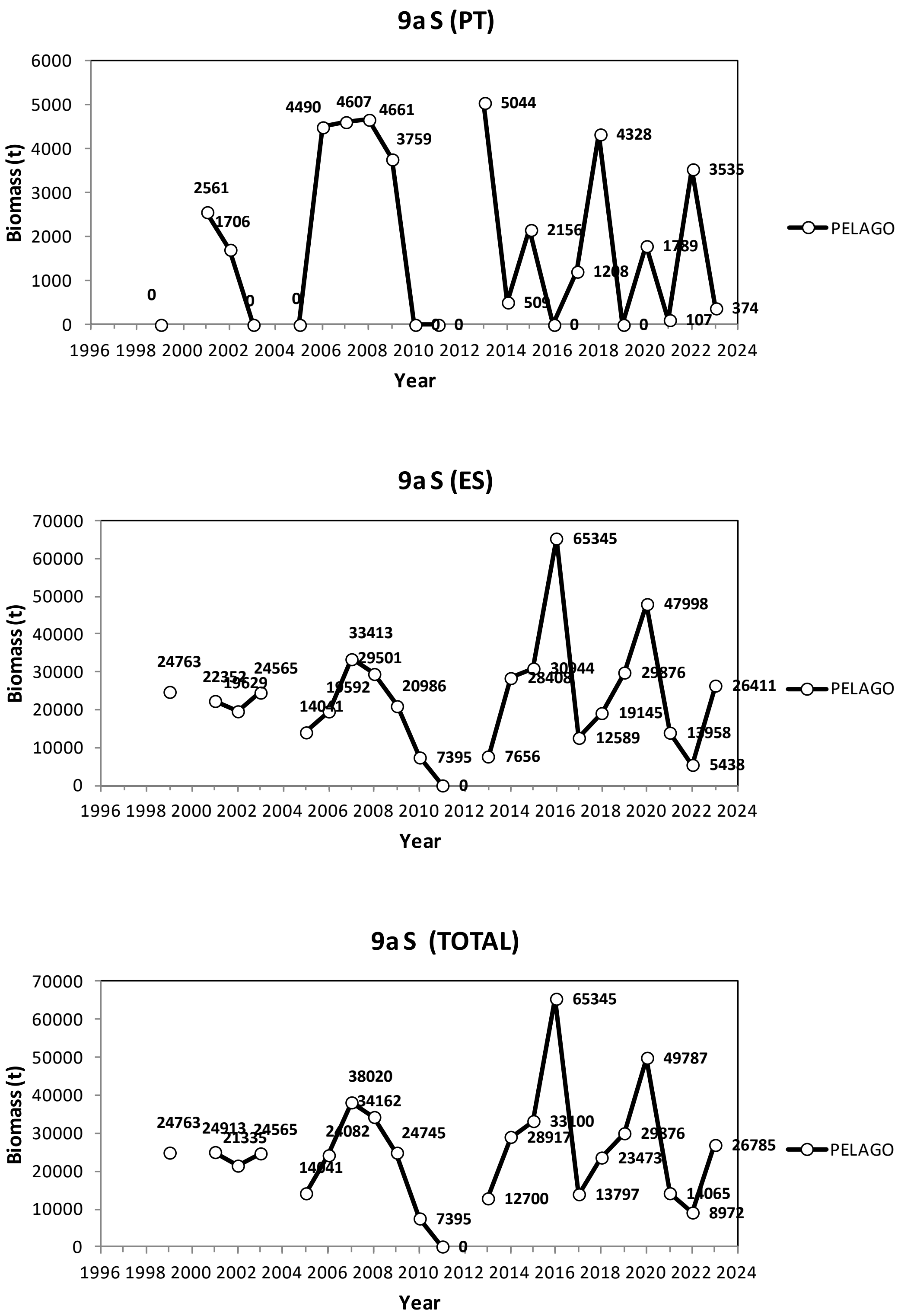
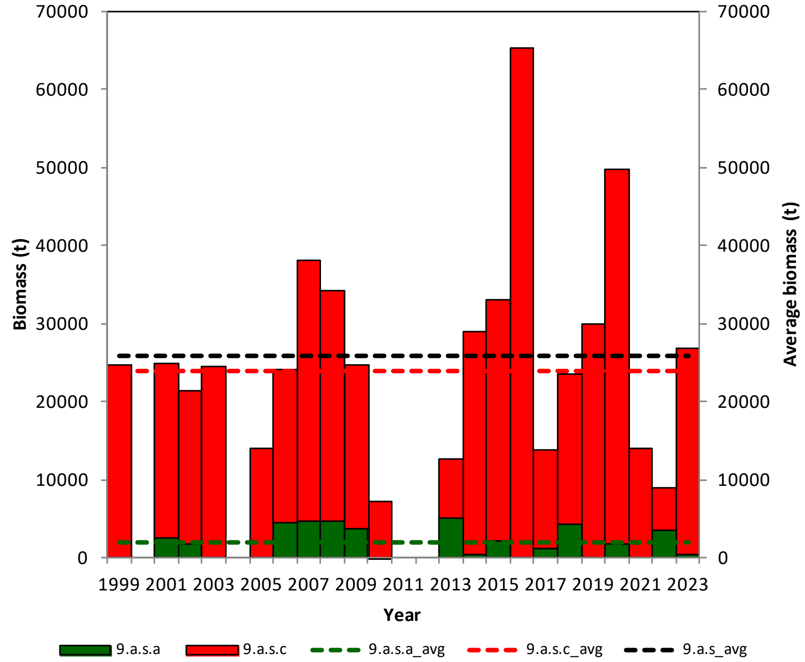


Figure 5.5.1.2. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *SAR*/*PELAGO* survey series (spring Portuguese acoustic-trawl survey in Subdivisions 9.a. Central-North, 9.a. Central-South and 9.a South). Historical series of regional acoustic estimates of anchovy biomass (t) in Subdivision 9.a.South. Note the different scale of the y axis and the occurrence of gaps through the series. The 2011 null estimate should be considered with caution. Sources: IPMA, ICES WGACEGG, ICES WGHANSA.



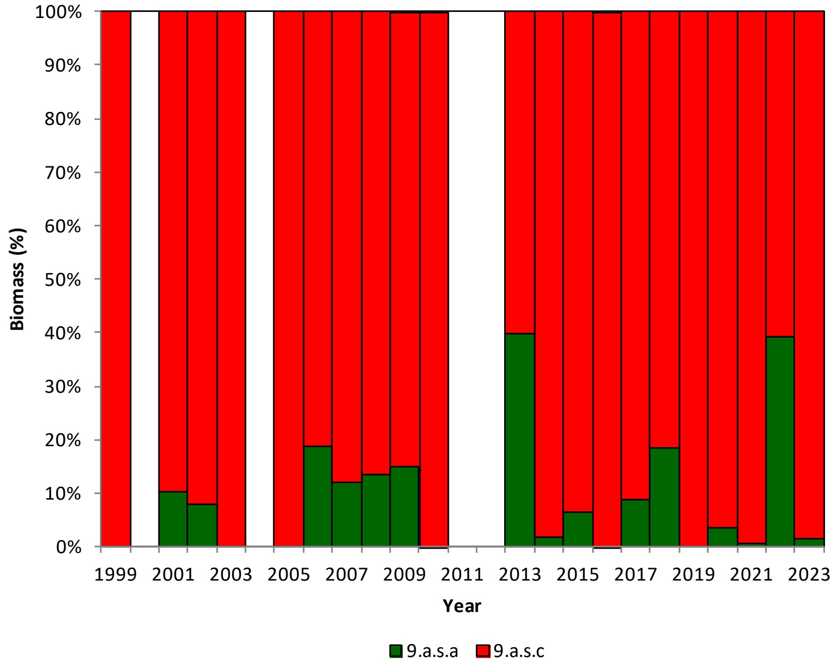


Figure 5.5.1.3. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *SAR*/*PELAGO* survey series (spring Portuguese acoustic-trawl survey in Subdivisions 9.a. Central-North, 9.a. Central-South and 9.a South). Top: historical series of regional acoustic estimates of anchovy biomass (t) with indication of the respective time-series averages (9.a.s.a: Portuguese waters; 9.a.s.c: Spanish waters; dotted lines indicate the respective historical regional average estimates). Bottom: relative importance of the regional biomass estimates. The 2011 null estimate should be considered with caution. Sources: IPMA, ICES WGACEGG, ICES WGHANSA.

The *PELAGO 2011* survey estimated a null occurrence of anchovy in 9a S as a result of a null acoustic detection of anchovy and its absence in the ground-truthing fishing hauls. However, the survey was conducted under very bad weather conditions, which could have affected both the echosounding and fishing. In fact, anchovy egg density sampled with CUFES during this survey showed relatively high, confirming the occurrence of the species in the area. On the other hand, the *BOCADEVA* DEPM survey conducted in summer that year estimated 32 757 t (see **Section 5.7**). These reasons led to the ICES WGACEGG to reject the *PELAGO 2011* null estimate.

The discrimination of anchovy echo-traces is very difficult in the GoC Spanish waters since anchovy schools are usually found embedded in a very dense (demersal) plankton layer. This layer may continuously extend over the inner-middle shelf of the central part of this area (**Figure 5.5.1.4**). In these situations are evident the advantages of using multi-frequency echo-sounding because of its greater discriminatory power and the improvement in the echogram species' scrutiny. *PELAGO* surveys used only the 38 kHz working frequency until 2016. The combined use of 38 and 120 kHz frequencies was incorporated in those surveys conducted during the 2017-2019 period. Since 2020 on, the surveys are being conducted using multi-frequency echo-sounding (18, 38, 70, 120, 200 kHz), coinciding with the use of the RV *Miguel Oliver*.

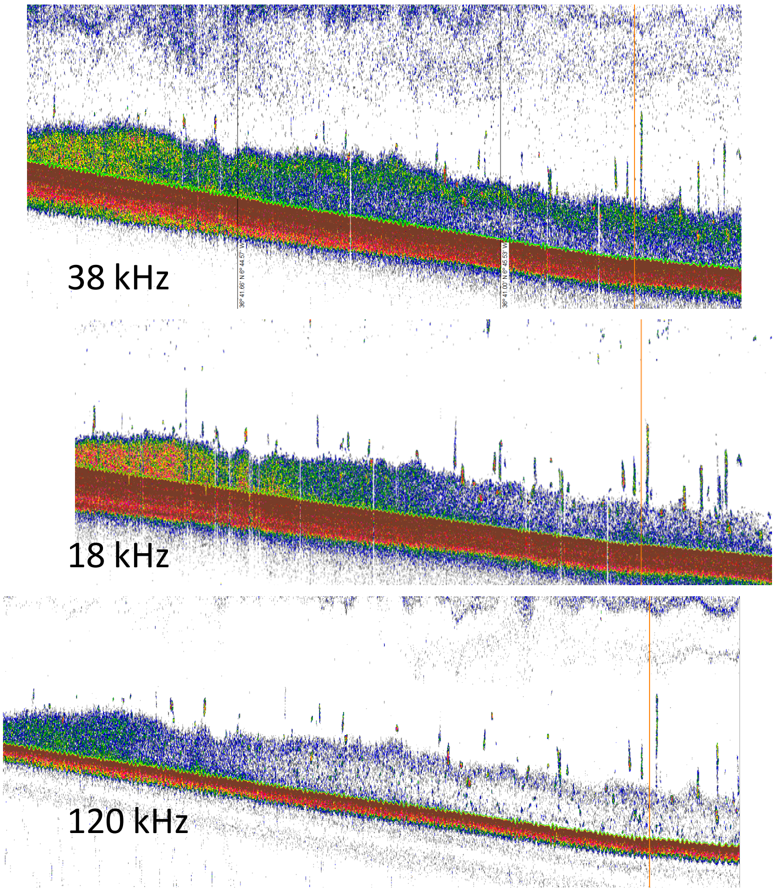


Figure 5.5.1.4. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Echograms of a typical situation of Gulf of Cadiz anchovy schools embedded inside a dense plankton layer recorded at different frequencies. Source: IEO and ICES WGACEGG.

Size composition of the estimated population ranged between 5.5 and 19.0 cm size classes (**Figure 5.5.1.5**). The time series of LFDs of the estimated population usually shows uni-modal LFDs, with the mode at around 10.0 – 13.0 cm size classes. In some years (2002, 2003, 2009, 2010, 2016. 2017, 2019 and 2023) 2 modes, at around 6.0-9.0 cm and 11.0-13.0 cm, are found in the LFDs.

Age-structure of the estimated population is shown in **Figure 5.5.1.6**. In the surveyed population in spring are present from 1 to 4 years old anchovies, with the bulk of the population being composed by 1 and 2 olds. The 2001, 2006, 2014, 2018 and 2019 year classes outstand as stronger cohorts.

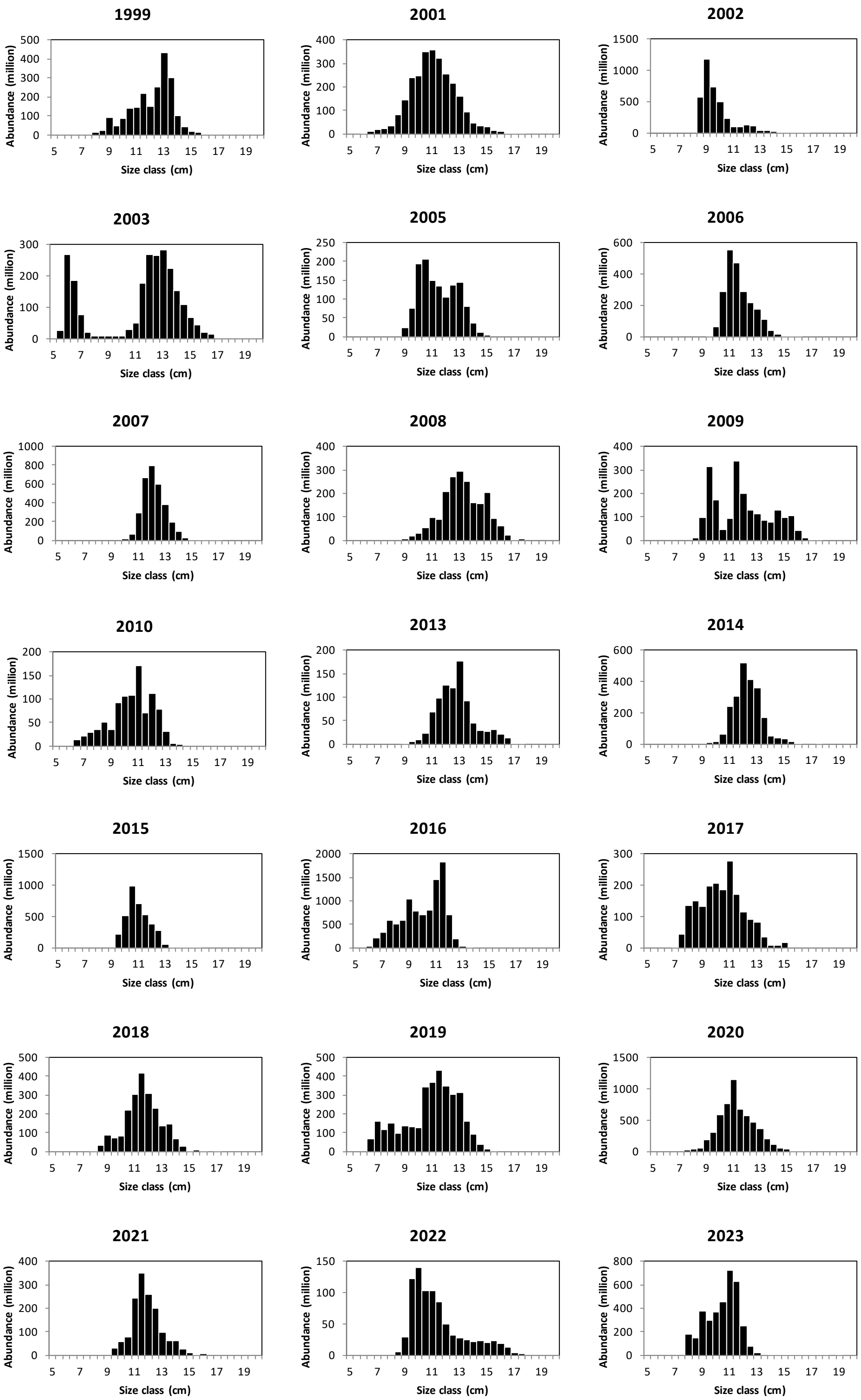


Figure 5.5.1.5. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. SAR/*PELAGO* survey series (spring Portuguese acoustic-trawl survey in Subdivisions 9.a. Central-North, 9.a. Central-South and 9.a South). Size composition (0.5 cm size classes) of the estimated population (millions). Note the different scale of the y axis and the occurrence of gaps through the series. Sources: IPMA, ICES WGACEGG, ICES WGHANSA.

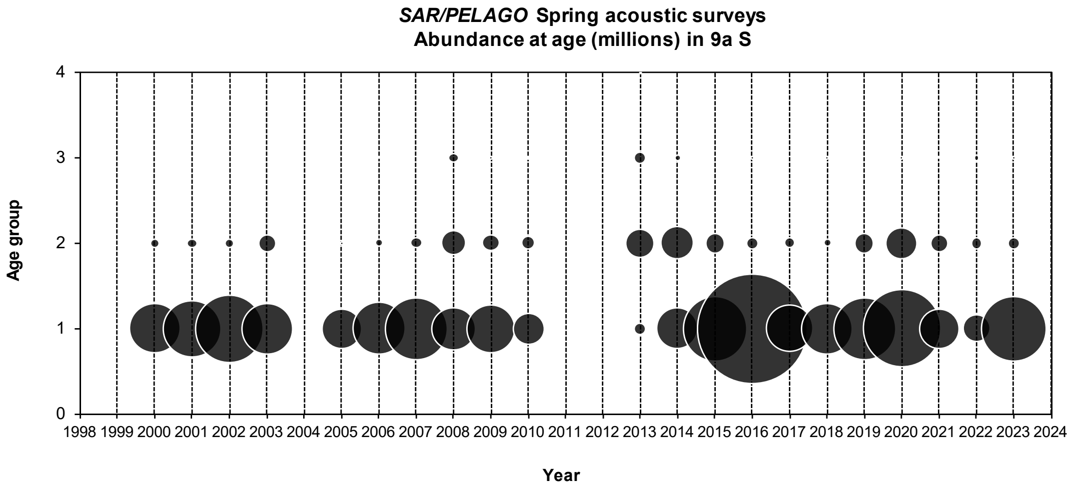


Figure 5.5.1.6. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *SAR/PELAGO* survey series (spring Portuguese acoustic-trawl survey in Subdivisions 9.a. Central-North, 9.a. Central-South and 9.a South). Age structure of the estimated population (millions). The age structure for the 2000-2007 estimates was derived by applying IEO ALKs from commercial samples from the Spanish fishery in the corresponding quarter. Since 2008 on age structured estimates were computed with their corresponding IPMA surveys' ALKs. Sources: IPMA, ICES WGACEGG, ICES WGHANSA.

5.6. Summer acoustic-trawl survey series *ECOCADIZ*.

5.6.1. Acoustic estimates.

Anchovy, together with sardine and chub mackerel (*Scomber colias*), is one of the species with the highest acoustic energy contributions (*i.e. Nautical Area Scattering Coefficient*, NASC, values) to the total acoustic energy recorded in summer for the GoC small pelagic fish assemblage. The species is also one of the most frequent one and with higher yields in the fishing hauls. The lowest anchovy NASC values were recorded in 2013-2014, 2017 and 2023, and the highest ones in 2016 and 2018-2020 (**Figure 5.6.1.1**). As mentioned above, no information on the NASC values in summer 2021 and 2022 are available since no survey was conducted in those years, hence is not possible to identify if the most recent low value recorded in summer 2023 is the result of either a progressive decreasing trend during those previous years or a sudden drop. Nevertheless, as it will be described in **section 5.8**, autumn surveys in the last 4 years confirm that the GoC anchovy population levels have been progressively decreasing down to the historical minimum recorded in 2023.

The mapping of the estimated acoustic densities allocated to GoC anchovy indicates a wide geographic distribution of the species over the GoC, with higher densities being located in the mid-outer shelf waters (75-125 m depth) between Cape Santa Maria and Bay of Cadiz, and density hotspots over the shelf waters between the Guadiana and Guadalquivir river mouths (**Figure 5.6.1.1**). Anchovy exhibits a persistent spatial pattern in the GoC in summer, with the smallest and youngest fish concentrated in the shallow waters in front of the Guadalquivir mouth and surrounding waters (coinciding with the main recruitment area in the GoC) and the largest ones in the Algarve waters.

Figures 5.6.1.2 and **5.6.1.3** show the time series of regional and total biomass estimates. The estimated abundances (not shown) oscillated between 609 (2013) and 5485 (2019) million fish (time-series average: 2538 million fish). The range of biomass estimates oscillates between 8487 t (2013) and 57 700 t (2019), (time-series average: 27 447 t). Spanish waters, excepting in 2007 when the population was more evenly distributed, usually concentrate more than 80% of the total estimated population biomass. Trends in abundance and biomass are quite similar to the ones described for the PELAGO spring surveys series. Summer acoustic biomass estimates were also at the same magnitude that those estimated by the DEMP survey *BOCADEVA* when both surveys were conducted at the same year (as it is the case since 2014), with the exception of the huge estimate from the 2020 DEPM survey (81 466 t *vs* 44 887 t estimated by *ECOCADIZ* and 49 787 t estimated in spring by *PELAGO*). The most recent summer estimates also show a strong drop in the population levels after the historical maximum recorded in 2019.

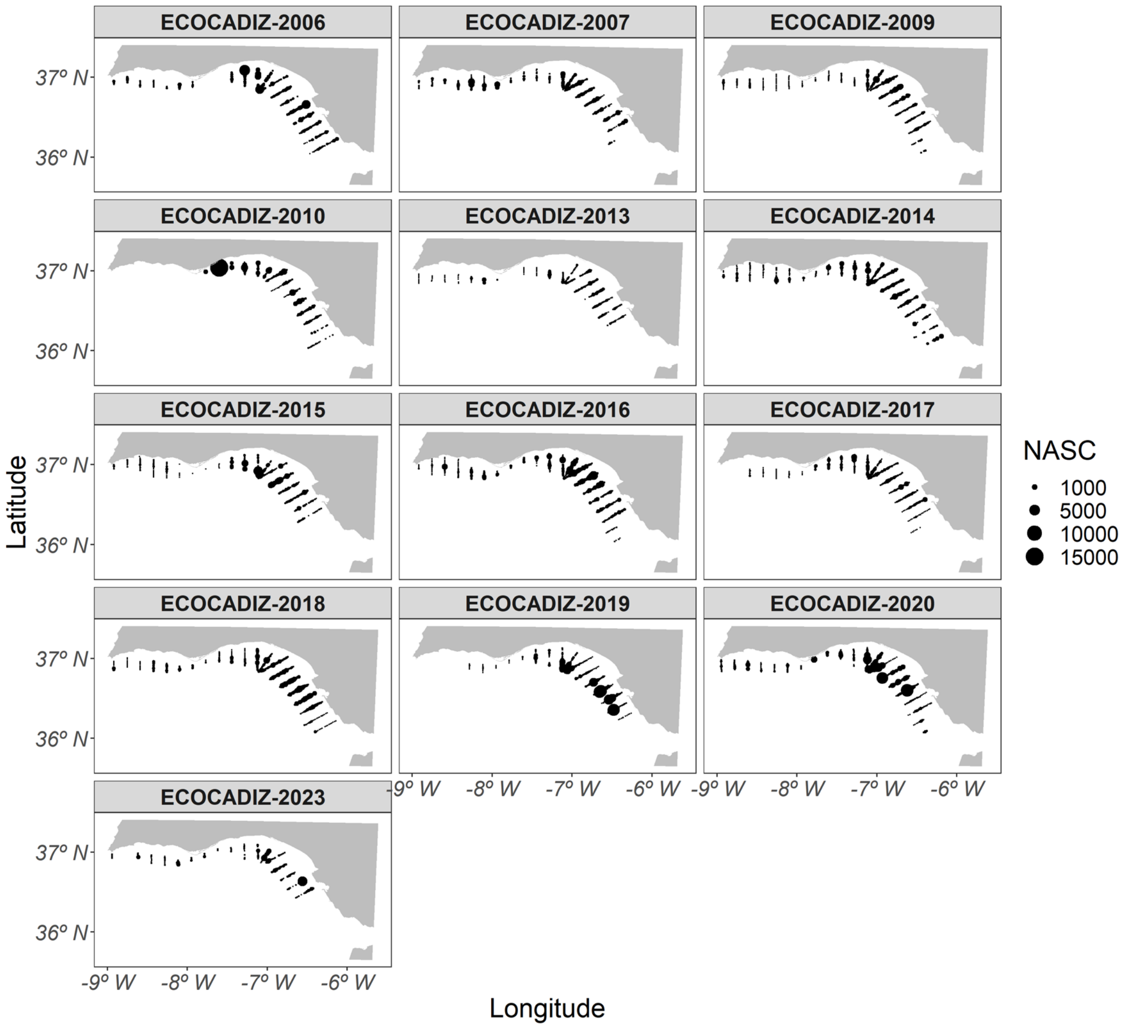


Figure 5.6.1.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Mapping of the distribution of NASC allocated to anchovy. Note the occurrence of gaps through the series. The 2010 survey only surveyed the waters comprised between Cape Santa Maria and Cape Trafalgar. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

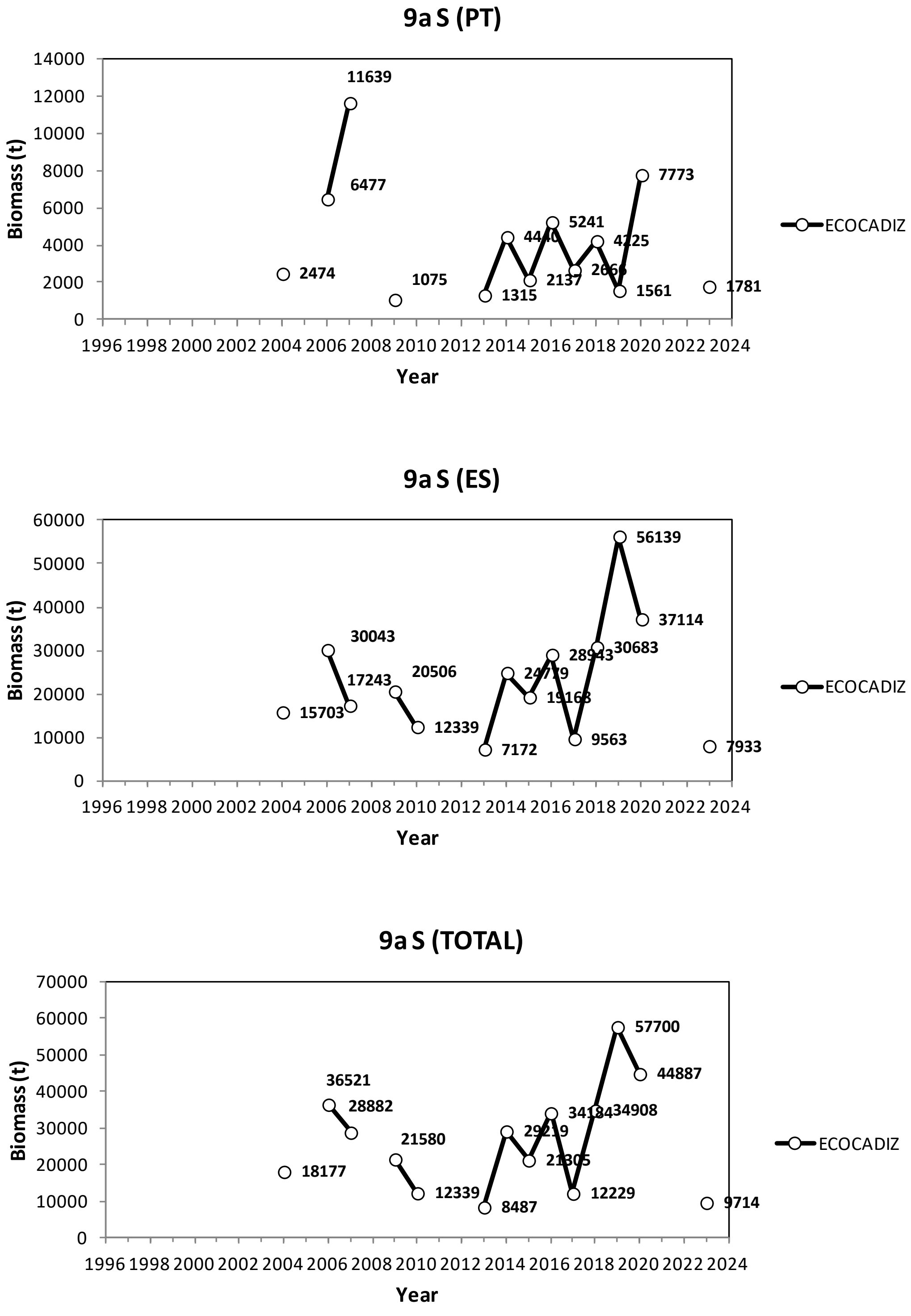


Figure 5.6.1.2. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Historical series of regional acoustic estimates of anchovy biomass (t). Note the different scale of the y axis and the occurrence of gaps through the series. The 2010 survey only surveyed the waters comprised between Cape Santa Maria and Cape Trafalgar. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

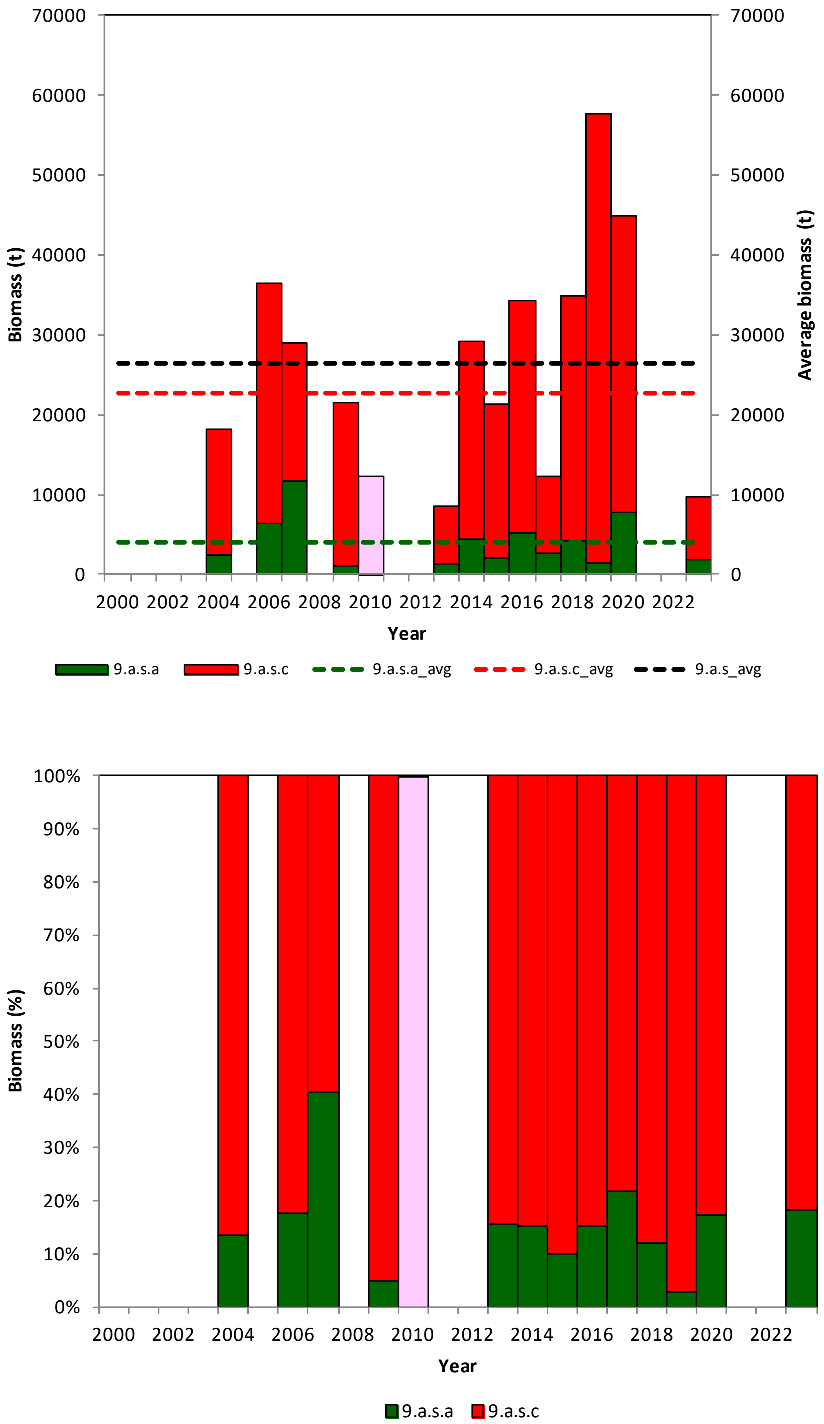


Figure 5.6.1.3. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Top: historical series of regional acoustic estimates of anchovy biomass (t) with indication of the respective time-series averages (9.a.s.a: Portuguese waters; 9.a.s.c: Spanish waters; dotted lines indicate the respective historical regional average estimates). Bottom: relative importance of the regional biomass estimates. Pink colour denotes the incomplete coverage in the 2010 survey, when only the waters comprised between Cape Santa Maria and Cape Trafalgar were surveyed. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

Size composition of the estimated population ranged between 2.0 and 19.0 cm size classes (**Figure 5.6.1.4**). The time series of LFDs of the estimated population usually shows uni-modal LFDs, with the mode at around 12.0 – 14.0 cm size classes. In some years (2010, 2013, 2015 and 2020) 2 modes, at around 8.0-11.0 cm and 10.5-14.5 cm, are found in the LFDs. In 2023 a more mixed composition was recorded, as a consequence of the occurrence of a secondary mode at 2.5 cm size class.

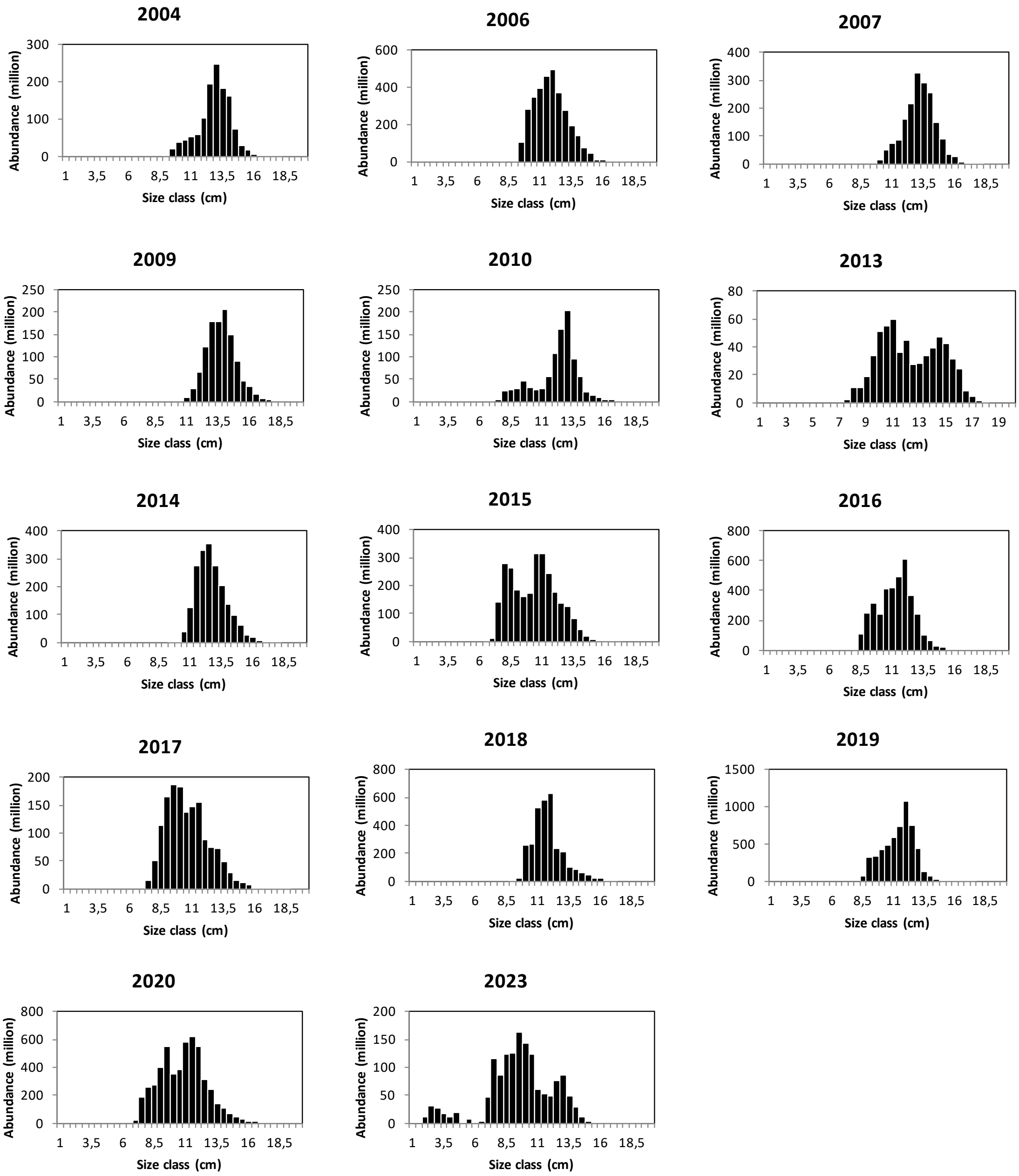


Figure 5.6.1.4. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Size composition (0.5 cm size classes) of the estimated population (millions). Note the different scale of the y axis and the occurrence of gaps through the series. The 2010 survey only surveyed the waters comprised between Cape Santa Maria and Cape Trafalgar. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

Age-structure of the estimated population is shown in **Figure 5.6.1.5**. In the surveyed population in summer are present from 0 to 4 years old anchovies, with the bulk of the population being composed by 1 and 2 olds in those surveys conducted between 2004 and 2009, and by 0 and 1 olds in later surveys. The relative importance of age 0 anchovies in those surveys conducted since 2010 is due to a delay in the survey dates (late July-early August). The 2005 and 2018 year classes outstand as the strongest cohorts followed by those ones of 2006, 2013, 2015 and 2017.

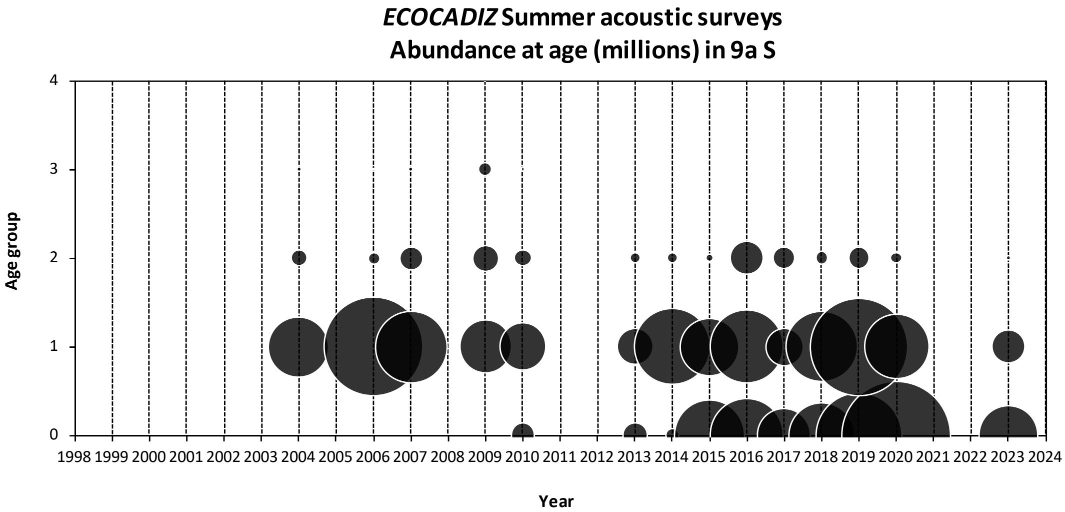
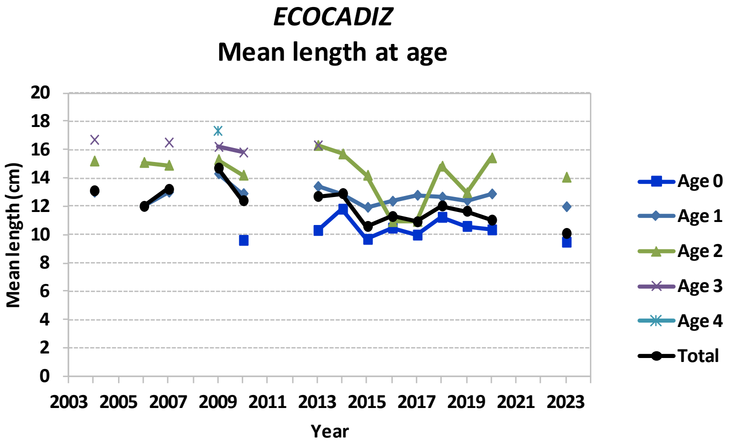


Figure 5.6.1.5. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Age structure of the estimated population (millions). The 2010 survey only surveyed the waters comprised between Cape Santa Maria and Cape Trafalgar. Note the occurrence of gaps in the series. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

Mean lengths and weights at age in these surveys are shown in **Figure 5.6.1.6**. Those estimates corresponding to the whole population oscillated between 10.1 (2023) and 14.7 (2009) cm, and 6.9 (2023) and 21.7 (2009) g, showing a decreasing trend in the last years, probably caused by the occurrence of small age 0 recruits because of the delayed survey dates.



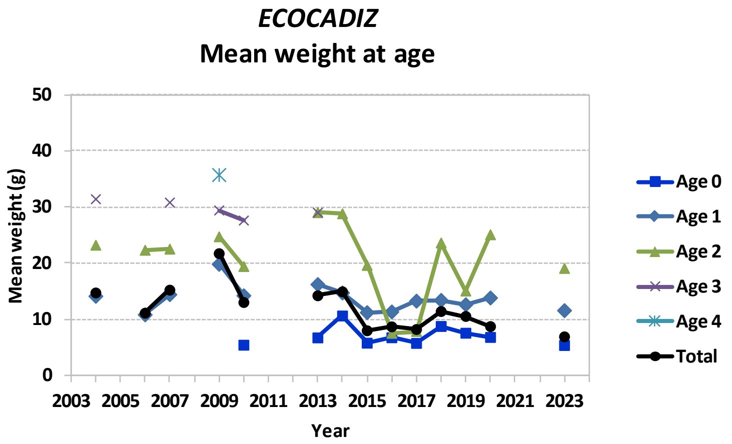


Figure 5.6.1.6. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ* survey series (summer Spanish acoustic-trawl survey in Subdivision 9.a South). Mean length (TL, in cm) and weight (g) at age in the GoC anchovy estimated population. Note the occurrence of gaps through the series. The 2010 survey only surveyed the waters comprised between Cape Santa Maria and Cape Trafalgar. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

5.7. DEPM survey series, *BOCADEVA*.

5.7.1. Egg and adult estimates.

Table 5.7.1.1 summarizes the DEPM-based eggs and adults' parameter estimates recorded during the triennial series of *BOCADEVA* surveys. SSB estimates have oscillated between 12 392 t (2017) and 81 466 t (2020), with the most recent estimate in 2023 being among the lowest one within the series. All of these estimates, however, are affected by relatively high CVs, oscillating between 0.30 and 0.62 (**Figure 5.7.1.1**). The time-series average SSB is 31 355 t.

Table 5.7.1.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *BOCADEVA* DEPM surveys series. Summary of eggs and adults' parameters estimates and SSB estimates. (1): SSB computed with the 2011 Spawning fraction estimate; (2): SSB computed with the time-series average Spawning fraction estimate. Sources: ICES WGHANSA and WGACEGG.

Year	2005	2008	2011	2014	2017	2020	2023
Eggs							
P_0 (eggs/m^2/day) (CV)	50.8(0.80) / 224.5(0.69)	184(0.44) / 348(0.35)	276 (0.32)	313.5 (0.34)	145.8 (0.55)	523.4 (0.38)	181.9 (0.54)
Z (day^{-1}) (CV)	-0.039(0.75)	-1.43(0.29)	-0.29 (1.14)	-0.33 (1.19)	-0.16	-1.11 (0.44)	-0.1228 (0.45)
P_{total} (eggs/day) (x10^{12}) (CV)	0.07(0.76) / 1.06(0.65)	0.31(0.44) / 1.80(0.35)	1.87 (0.36)	1.95 (0.34)	0.74 (0.55)	5.26 (0.38)	1.03 (0.54)
Surveyed area (km2)	11982	13029	13107	14595	15556	16223	13261
Positive area (Km^2)	6139	6863	6770	6214	5080	10058	5662
Adults							
Female Weight (g) (CV)	25.2(0.03) / 16.7(0.04)	23.67 (0.06)	15.2 (0.11)	18.22 (0.08)	16.14 (0.17)	16.63 (0.13)	17.64 (0.25)
Batch Fecundity(CV)	13820(0.05) / 11160(0.05)	13.778 (0.07)	7486 (0.12)	7502 (0.08)	7507 (0.17)	8212 (0.14)	9515 (0.144)
Sex Ratio (CV)	0.53(0.01) / 0.54(0.01)	0.528 (0.005)	0.531 (0.007)	0.54 (0.008)	0.53 (0.009)	0.54 (0.009)	0.519 (0.02)
Spawning Fraction (CV)	0.26(0.07) / 0.21(0.07)	0.218 (0.065)	0.276 (0.036)	0.276(1)	0.234 (0.06)	0.241(2)	0.248(2)
SSB							
Spawning Biomass – tons (CV)	**14673**	**31527(0.32)**	**32757 (0.40)**	**31569 (0.30)**	**12392 (0.61)**	**81466 (0.43)**	**15138 (0.62)**

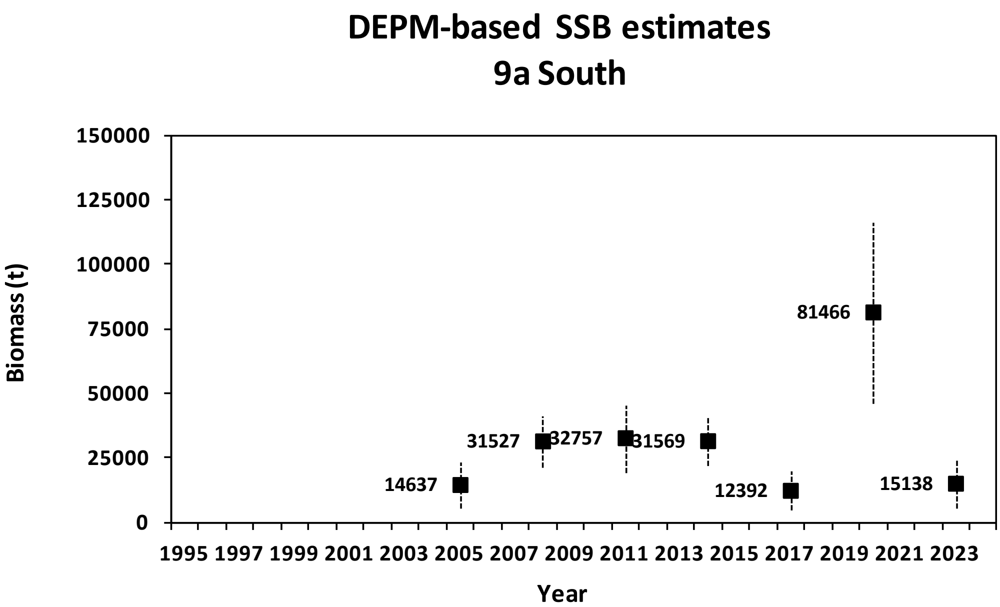


Figure 5.7.1.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *BOCADEVA* DEPM surveys series. Time series of SSB (t) estimates. 2014 SSB computed with the 2011 Spawning fraction estimate; 2020 and 2023 SSB estimates computed with the time-series average Spawning fraction estimate available those years. Sources: ICES WGHANSA and WGACEGG.

Figure 5.7.1.2 shows a comparison between biomass estimates from those surveys estimating the GoC anchovy population with different methods. At first sight, DEPM point estimates seem to be quite consistent with the acoustic estimates. However, this surprisingly coincidence should be considered with caution because the high CV associated to the DEPM-based estimates and the lack of information about the associated errors to the acoustic estimates. In any case, these different sources of information provide estimates about the same order of magnitude indicating some consistency.

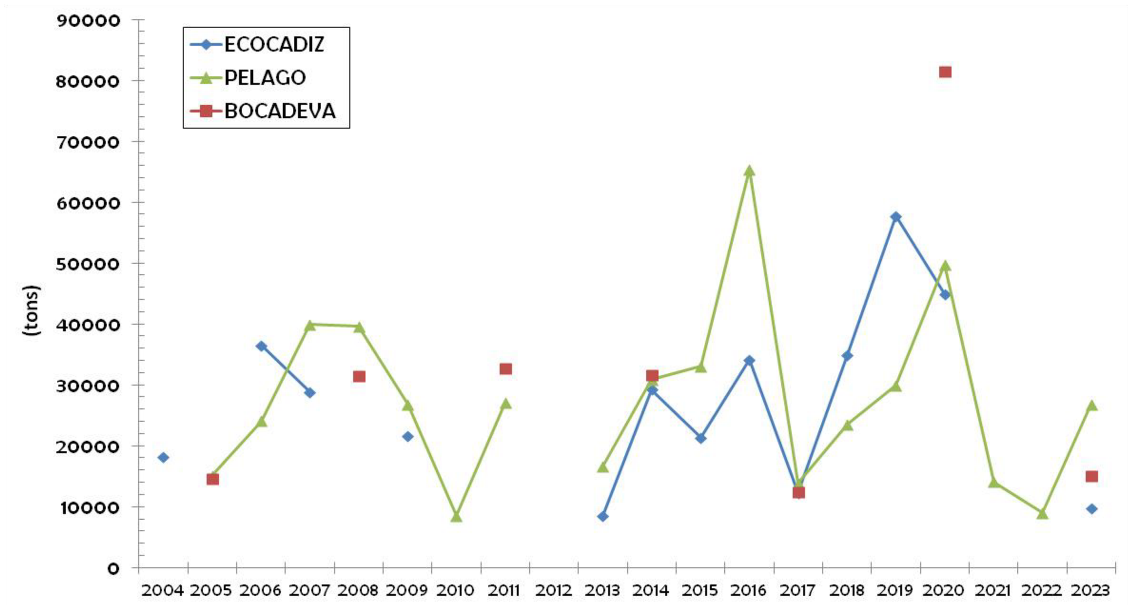


Figure 5.7.1.2. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *BOCADEVA* DEPM surveys series. Between-survey comparison of GoC anchovy biomass estimates (t) in spring-summer. Sources: ICES WGHANSA and WGACEGG.

Despite being only based in 7 observations, the *BOCADEVA* DEPM survey series will be tested as tuning series in the Gadget model, at least to provide information on the past history of the stock until 2023. Reasons for the inclusion in the model are: i) there is one observation available for 2023; ii) these DEPM SSB estimates are relatively consistent with the *PELAGO* and *ECOCADIZ* acoustic estimates for years 2005, 2008, 2014, 2017 and 2023; iii) it is the only series reporting a reliable estimate in 2011 (recall that the null *PELAGO 2011* estimate has been rejected by the ICES WGACEGG; see **Section 5.5.1**) and iv) *BOCADEVA* series also represents an independent source of data in relation to the others acoustic-based sources of direct information on the stock. Notwithstanding the above, the continuity of this survey series by IEO in the next years is not totally guaranteed because of unavailability of ship-time for collecting adult samples, the shortage of technical staff required for the histological processing of those samples and the inability of providing adult estimates in due time (whenever the current dates of the survey – late July-early August – are still maintained).

5.8. Autumn acoustic-trawl survey series, *ECOCADIZ-RECLUTAS*.

5.8.1. Acoustic estimates.

The highest total NASC values allocated to anchovy were recorded in the 2015-2016 and 2019-2021 periods, and the lowest ones in 2014, 2018 and 2023. Although widely distributed, GoC anchovy mainly occurred in autumn in the mid-outer shelf between Isla Cristina and the Bay of

Cádiz, with the hotspots being located in front of the Guadalquivir river mouth, the main GoC anchovy recruitment area (**Figure 5.8.1.1**). The lowest anchovy NASC values were recorded in 2014, 2018 and 2023.

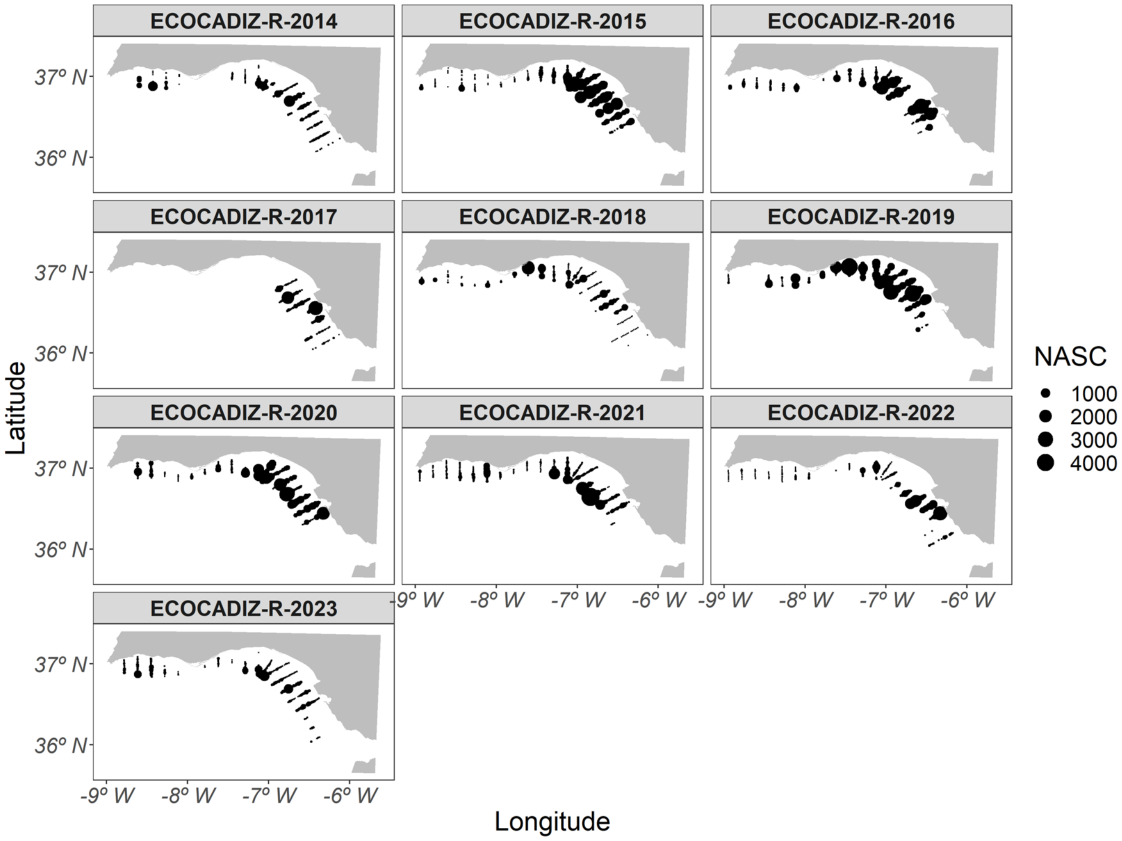


Figure 5.8.1.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Mapping of the distribution of NASC allocated to anchovy. The 2012 survey only surveyed the Spanish waters and under a not standardized sampling scheme and has not been included in the figure. The 2017 survey only surveyed the 7 easternmost transects of the Spanish waters. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

Figures 5.8.1.2 and **5.8.1.3** show the time series of total and regional biomass estimates. **Figure 5.8.1.4** shows the time-series of estimates for the whole population and age-0 fish. The estimated abundances for the whole GoC oscillated between 816 (2023) and 5518 (2019) million fish (time-series average: 2686 million fish). The range of biomass estimates oscillates between 8113 t (2014) and 48 398 t (2019), (time-series average: 21 276 t). Estimates for Age 0 anchovies ranged between 543 (2018) and 5117 (2015) million fish (time series average: 2347 million fish) for abundance and between 3834 (2018) and 36 405(2019) t (time series average: 15 467 t) for biomass.

Spanish waters, excepting in 2018 when 60% of the population biomass was distributed in Algarve waters, usually concentrate more than 80% of this total estimated biomass. The anchovy population inhabiting the GoC during autumn 2023 was the lowest of the time series and it showed a large decrease in abundance (55%) and in biomass (38%) when compared to last year's estimates. The current estimates are well below than the time-series average. The observed recent strong decreasing trend for the whole population seemed to continue in 2023.

Size composition of the estimated population ranged between 2.0 and 19.0 cm size classes (**Figure 5.8.1.5**). The time series of LFDs of the estimated population usually shows bi-modal LFDs, with the smallest, and usually the dominant mode at around 7.5 – 10.5 cm size classes and the largest one at around 14.0 - 15.0 cm size classes depending on the year.

Age-structure of the estimated population is shown in **Figure 5.8.1.6**. The surveyed population in autumn is almost exclusively composed by 0 to 2 years old anchovies, with the occurrence of anchovies older than 2 years being incidental. The bulk of the population, excepting in 2018, is usually composed by age 0 juveniles (with contributions of 75-99% in abundance, and 57-98% in biomass). Juveniles in 2018 only contributed with 57% in abundance and 37% in biomass. Only the 2013 year class clearly outstand as a strong cohort (as age 1 anchovies in 2014, since no autumn survey was conducted in 2013). Other year classes that showed a relative strength were those of 2017, 2018, 2019 and 2020. Mean lengths and weights at age in these surveys are shown in **Figure 5.8.1.7**. Those estimates corresponding to age-0 anchovies oscillated between 9.4 (2016) and 11.8 (2014) cm, and 4.6 (2016) and 10.6 (2014) g. Given the dominance of this age group during the survey season the estimates for the whole population were very close to the former ones.

The size composition and age structure of GoC anchovy throughout the surveyed area confirms the usual pattern exhibited by the species during the survey season, with the largest (and oldest) fish being distributed in the westernmost waters and the smallest (and youngest) ones concentrated in the surroundings of the Guadalquivir river mouth and adjacent shallow waters.

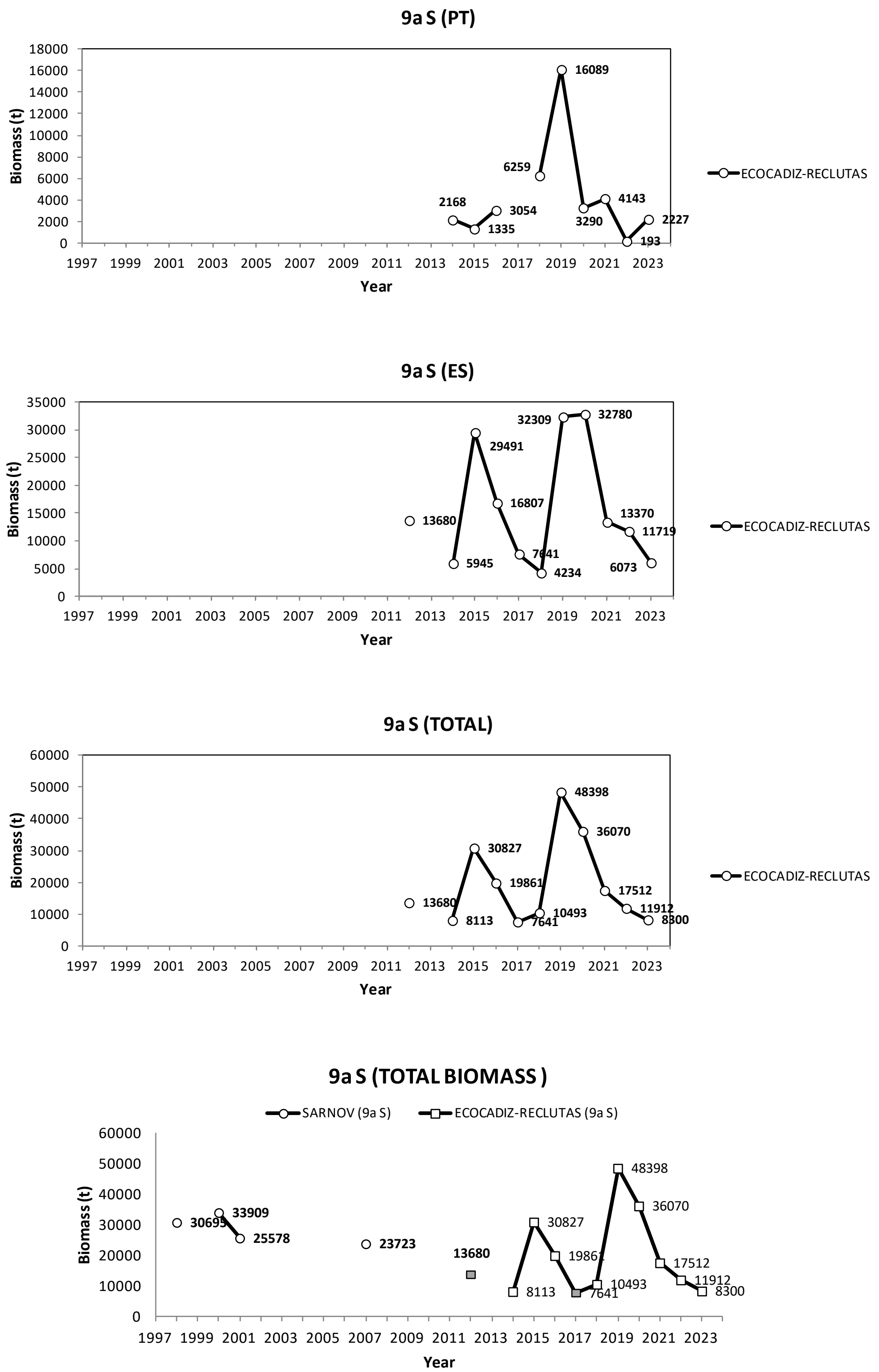
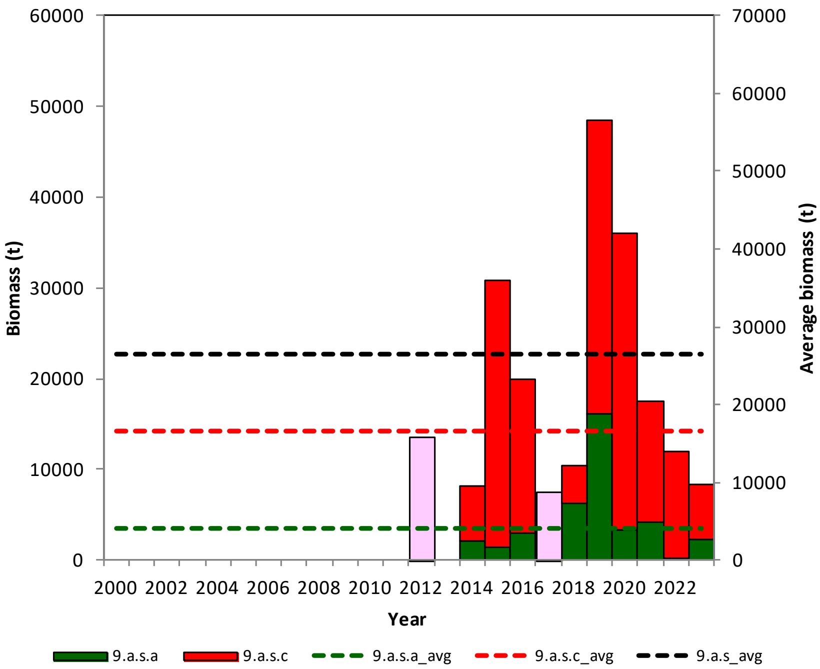


Figure 5.8.1.2. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Historical series of regional acoustic estimates of anchovy biomass (t). The 2012 and 2017 surveys only surveyed the Spanish waters either the whole (2012) or only a part (2017) of these waters. The figure shown in the bottom includes the *SARNOV* autumn Portuguese surveys. Note the different scale of the y-axis. Sources: IEO, ICES WGACEGG, ICES WGHANSA.



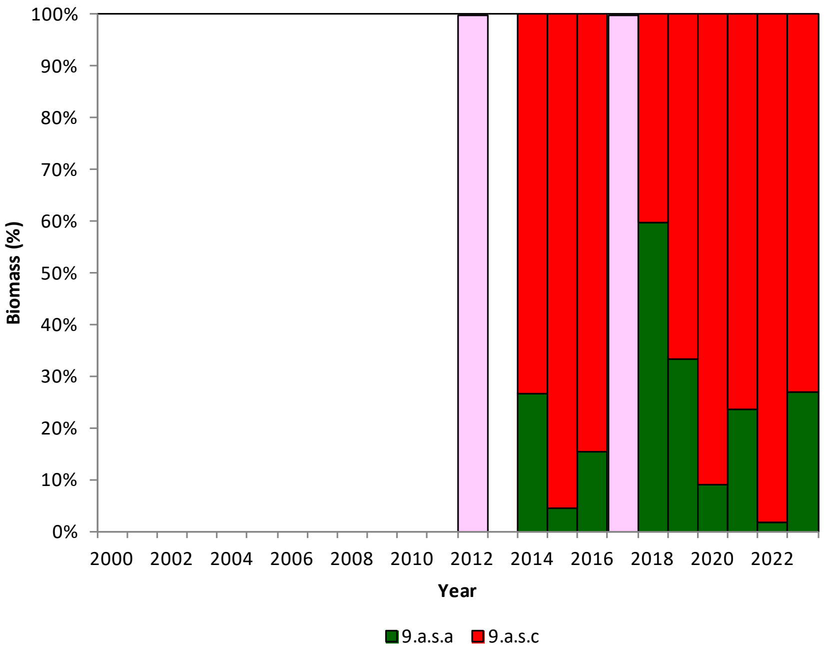
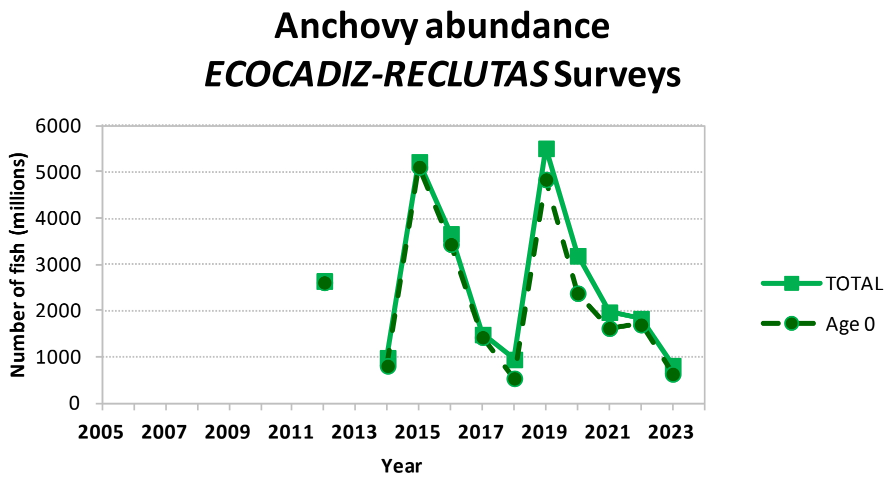


Figure 5.8.1.3. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Top: historical series of regional acoustic estimates of anchovy biomass (t) with indication of the respective time-series averages (9.a.s.a: Portuguese waters; 9.a.s.c: Spanish waters; dotted lines indicate the respective historical regional average estimates). Bottom: relative importance of the regional biomass estimates. Pink colour denotes the incomplete coverage in the 2012 and 2017 surveys, when only the whole or only a part of the Spanish waters were surveyed. Sources: IEO, ICES WGACEGG, ICES WGHANSA.



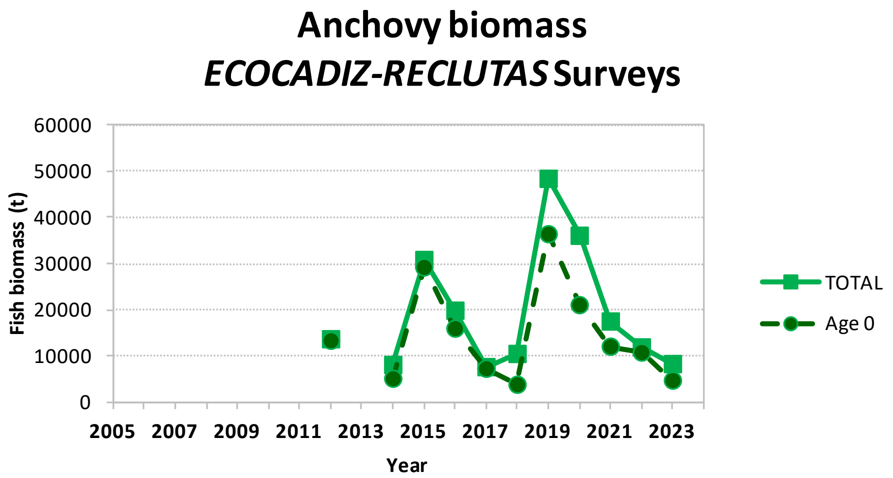


Figure 5.8.1.4. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Time series of abundance (millions; upper panel) and biomass (t; bottom panel) acoustic estimates for the whole population and age 0 fish. The 2012 and 2017 estimates are partial ones: the 2012 survey only surveyed the Spanish waters of the Gulf of Cadiz. The 2017 survey only surveyed the 7 easternmost transects of the Spanish waters. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

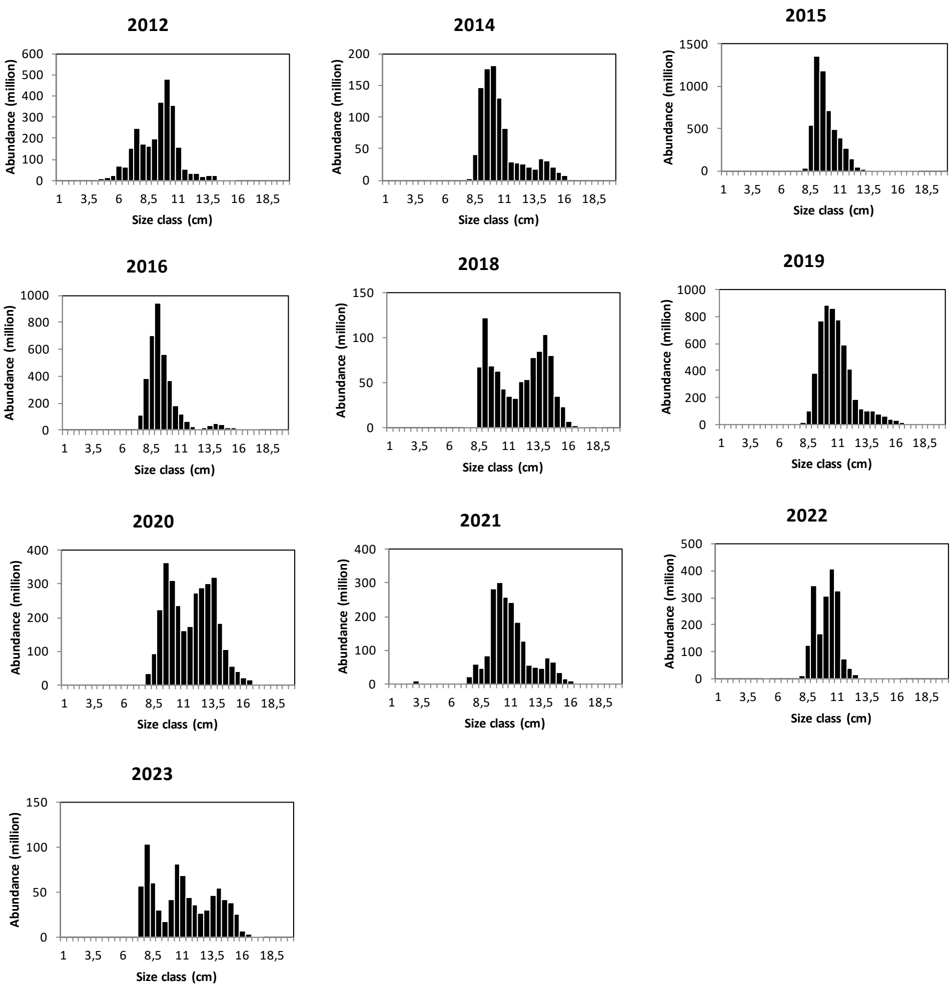


Figure 5.8.1.5. Anchovy in 9a South. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Size composition (0.5 cm size classes) of the estimated population (millions). Note the different scale of the y axis and the occurrence of gaps through the series. The 2012 survey only surveyed the Spanish waters of the Gulf of Cadiz. The 2017 survey only surveyed the 7 easternmost transects of the Spanish waters (not shown). Sources: IEO, ICES WGACEGG, ICES WGHANSA.

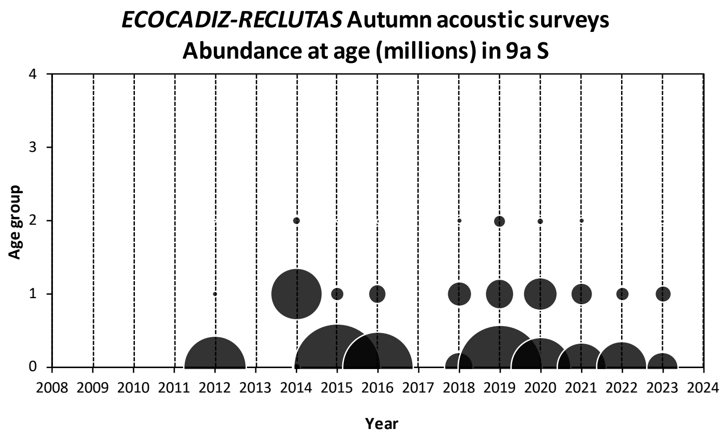


Figure 5.8.1.6. Anchovy in 9a South. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Age structure of the estimated population (millions). The 2012 survey only surveyed the Spanish waters of the Gulf of Cadiz. The 2017 survey only surveyed the 7 easternmost transects of the Spanish waters (not shown). Sources: IEO, ICES WGACEGG, ICES WGHANSA.

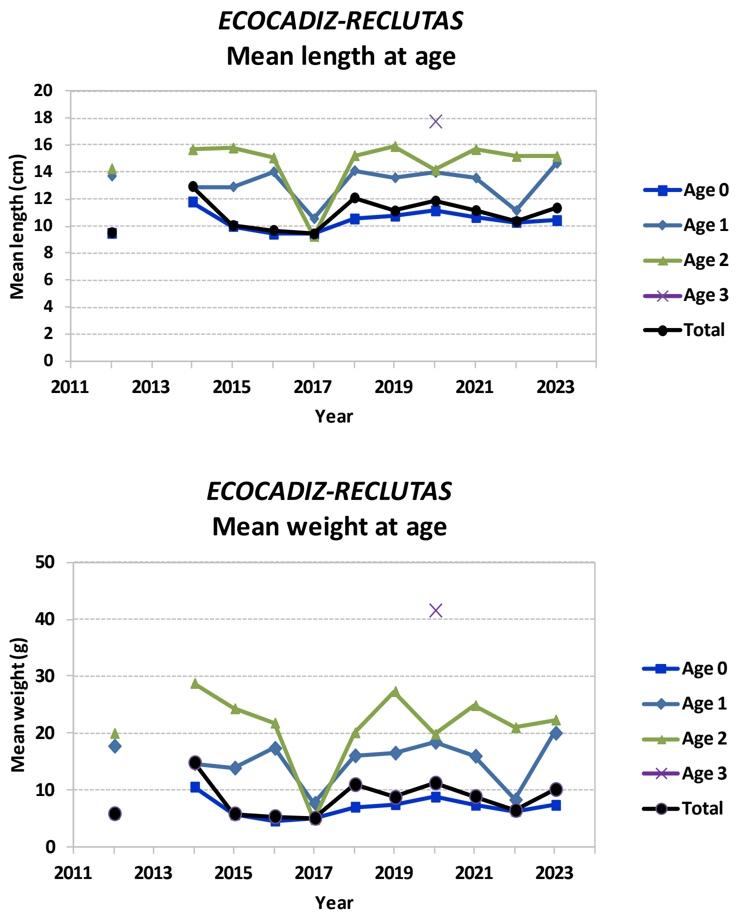


Figure 5.8.1.7. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. *ECOCADIZ-RECLUTAS* survey series (autumn Spanish acoustic-trawl survey in Subdivision 9.a South). Mean length (TL, in cm) and weight (g) at age in the GoC anchovy estimated population. Note that the 2012 survey only surveyed the Spanish waters of the Gulf of Cadiz and the 2017 survey only surveyed the 7 easternmost transects of the Spanish waters. Sources: IEO, ICES WGACEGG, ICES WGHANSA.

6. Biological parameters.

6.1. Mean length and mean weight in catches.

Estimates are only available from the Spanish fishery in 9a S (ES). **Figure 6.1.1** shows the recent history of the evolution of such estimates. Anchovy mean length and weight at age in the Spanish annual catches have oscillated as follows:

- Age 0: 5.8 cm (1996) – 11.3 cm (2016); 1.3 g (1996) – 10.0 g (2018).
- Age 1: 8.9 cm (1996) – 12.6 cm (2022); 6.4 g (1996) – 14.2 g (2021).
- Age 2: 12.3 cm (2021) – 16.9 cm (1989); 14.9 g (1998) – 33.5 g (1989).
- Age 3: 10.8 cm (2017) – 16.9 cm (1992); 21.5 g (2010) – 30.2 g (1992).

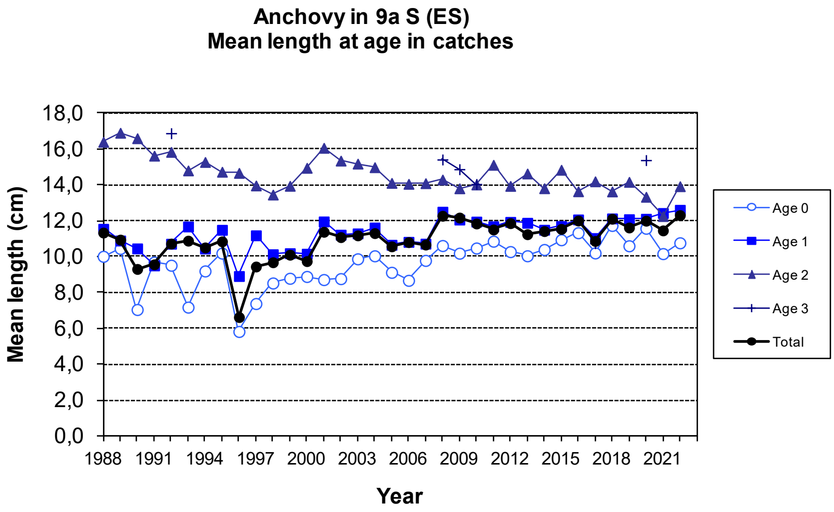
Age 0 and age 1 anchovies have showed a noticeable increasing trend in both estimates in the most recent years, with the 2008-2022 estimates of mean size in catches being between the highest ones in the historical series. Conversely, since 2005 on age 2 anchovies experienced a remarkable decreasing trend in mean size and weight in catches, excepting the punctual relative increases observed in 2011 and 2015. Three year olds were firstly recorded in the sampled landings in 1992. New occurrences of these anchovies have been observed only from 2008 to 2010, 2017 and 2020.

6.2. Maturity ogives.

Previous biological studies based on commercial samples of GoC anchovy (9a S (ES)) indicate that the species' spawning season extends from late winter to early autumn with a peak spawning time for the whole population occurring from June to August (Millán, 1999). Length at first maturity was estimated in that study at 11.09 cm in males and 11.20 cm in females. However, it was evidenced that size at maturity may vary between years, suggesting a high plasticity in the reproductive process in response to environmental changes.

Maturity stage assignment criteria were agreed between national institutes involved in the biological study of the species during the *Workshop on Small Pelagics (Sardina pilchardus, Engraulis encrasicolus) maturity stages* (WKSPMAT; ICES, 2008b).

Annual maturity ogives for anchovy in 9a S (ES) for both sexes pooled has been routinely provided to ICES (since 1988). They are fishery data-based and represent the estimated proportion of mature fish at age in the total catch during the spawning period (second and third quarters) after raising the ratio of mature-at-age by size class in commercial monthly samples to the monthly catch numbers-at-age by size class (**Table 6.2.1**). This approach was adopted because the absence of direct information from surveys during the first 12 years of the available time-series and the discontinuity in this kind of information (*i.e.* occurrence of some years without survey) during the remaining years. The % mature at age 0 in these annual fishery-based ogives need to be checked since these anchovies may also contribute to the (first-) spawners' population fraction during the third quarter in the year. The annual length-based ogives from this data set have not been updated since those provided by Millán (1999). Because of such inconsistencies found in those maturity ogives at age, not noticed during WKPELA 2018, it was assumed that all individuals with age 1 or older (B1+), are mature for assessment purposes.



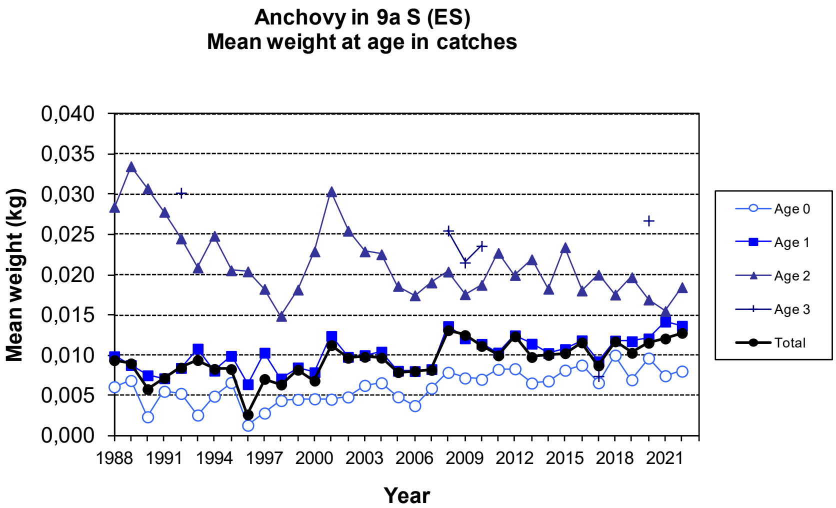


Figure 6.1.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Spanish fishery (all métiers). Annual mean length (TL, in cm) and weight (kg) at age in the Spanish catches of Gulf of Cadiz anchovy (1988-2022). Source: ICES WGHANSA.

The macroscopic maturity scale used by IPMA (Soares *et al*., 2009) for anchovy from the western component has been validated with histology (microscopic identification of macroscopic maturity stages; Costa *et al*., 2019). Results, also applicable to the southern component, show that only histology allows the correct identification of mature and immature individuals macroscopically identified as stage 1 (Immature or Resting); therefore, the maturity ogive of this species must be obtained during the spawning season with histology.

The potential of the maturity data from the different surveys series surveying the southern component either in spring (*PELAGO*) or summer (*ECOCADIZ* and *BOCADEVA*) also needs to be explored.

Table 6.2.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Maturity ogives (ratio of mature fish at age) for Gulf of Cadiz anchovy. Source: ICES WGHANSA.

Year	Age		
	0	1	2+
1988	0	0.82	1
1989	0	0.53	1
1990	0	0.65	1
1991	0	0.76	1
1992	0	0.53	1
1993	0	0.77	1
1994	0	0.60	1
1995	0	0.76	1
1996	0	0.49	1
1997	0	0.63	1
1998	0	0.55	1
1999	0	0.74	1
2000	0	0.70	1
2001	0	0.76	1
2002	0	0.72	1
2003	0,32	0,69	1,00
2004	0,71	0,95	1,00
2005	0,52	0,95	1,00
2006	0,52	0,77	1,00
2007	0,54	0,91	1,00
2008	0,70	0,97	1,00
2009	0,80	0,97	1,00
2010	0,66	0,97	0,98
2011	0,91	0,96	1,00
2012	0,69	0,81	1,00
2013	0,87	0,94	1,00
2014	0,78	0,91	0,98
2015	0,76	0,92	0,93
2016	0,97	0.97	0.98
2017	0,89	0,91	0,99
2018	0,97	0,99	0,99
2019	0,91	0,95	0,96
2020	0,91	0,92	0,98
2021	0,76	0,97	0,97
2022	0,58	0,96	0,97

6.3. Mean weight at age in the stock.

Weights at age in the stock are not required as input data in the Gadget model. Nevertheless, such parameters are estimated for the GoC anchovy and they correspond to yearly estimates calculated as the weighted mean weights-at-age in the catches for the second and third quarters (*i.e.* throughout the spawning season; **Table 6.3.1**).

Survey-based estimates, especially those ones coming from the DEPM *BOCADEVA* survey are also available, but the data points only correspond to 2005, 2008, 2011, 2017, 2020 and 2023. *ECOCADIZ* acoustic surveys may also provide estimates since 2004 for those years not sampled by the DEPM survey but 2012, 2021 and 2022. However, no direct information is available for the period 1989-2003. The potential of these estimates needs to be explored if they were finally required.

6.4. Growth parameters.

Length-based estimates of VBGF parameters (ELEFAN) for GoC anchovy (9a S (ES)) were estimated by Bellido *et al*. (2000). An asymptotic length, L_∞= 19 cm estimated by the above authors (with lower and upper bounds set at 15 and 20 cm), was adopted for the Gadget assessment model finally accepted in the past benchmark (ICES, 2018). The growth rate, k, is estimated by the model. More specifications about how the model simulates the fish growth are described in Rincón *et al*. (2018).

6.5. Natural mortality.

Before the WKPELA 2018 benchmark, natural mortality, M, was unknown for this stock component. For the Bay of Biscay anchovy stock the parameter estimates considered in its assessment are 0.8 y^{-1} for age 1; 1.2 y^{-1} for age 2+. Torres *et al*. (2013) developed an *Ecopath with Ecosim* Model for the Gulf of Cadiz which provided estimates of natural mortality for anchovy caused both by predation (1.397 y^{-1}) and other causes (0.101 y^{-1}), with a total M of 1.498 ≈ 1.5 y^{-1} for all ages.

The following approaches regarding M were firstly explored with the Gadget assessment model during the WKPELA 2018 benchmark (Rincón *et al*., 2018):

- M0 = 1.17 y^{-1}; M1= 0.43 y^{-1} (*i.e.* values used in the assessment of the Alborán Sea anchovy (Giráldez *et al*., 2009)). M values for ages 2 and 3 were chosen higher enough (M2= 0.80 y^{-1}; M3= 1.00 y^{-1}) to be coherent with catches at age data, where there is rarely to find individuals older than two years.
- M0=1.5 y^{-1}; M1=1 y^{-1}; M2+=1.5 y^{-1}.
- M values to be estimated by the model.

Finally, a constant M value was preferred to be selected from classical indirect formulations based on life-history parameters. The R package *FSA* was used to obtain 13 different empirical estimates of M, and a value of M=1.3 was finally adopted (midway between the median and the mean of the available estimates for a maximum age of four years). Currently, it is generally accepted that M may decrease with age, as far as it is presumed to be particularly greater at the juvenile phase. WKPELA 2018 agreed to adopt for the adult ages of anchovy (ages 1 to 4) the constant M estimated before (1.3), but for the juveniles (age 0) a greater one, in proportion to the ratio of natural mortality-at-ages 0 and 1 (M0/M1) resulting from the application of the Gislason *et al.* (2010) method, that presents natural mortality as a function of the growth parameters. The resulting ratio was M0/M1 = 1.7 and, therefore, M0=1.3*1.7= 2.21. Therefore, the following estimates for M at-age were finally adopted: M0=2.21; M1=1.30; M2+=1.30 (similar at any older age; see ICES, 2018). Rincón *et al*. (2018) provide a description of the whole process for deriving the above estimates

Table 6.3.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Mean weight at age in the stock (in g). Source: ICES WGHANSA.

Year	Age 0	Age 1	Age 2	Age 3
1989	4,3	9,9	33,5	
1990	5,1	8,4	32,3	
1991	7,5	11,0	27,5	
1992	5,2	9,6	23,5	
1993	1,7	11,1	21,1	
1994	5,1	9,6	25,1	
1995	7.0	10.7	22.6	
1996	1.1	6.3	20.0	
1997	2.6	11.1	20.9	
1998	2.6	7.4	20.4	
1999	3.2	12.8	20.0	
2000	3.1	10.0	23.8	
2001	6.2	13.3	31.8	
2002	3.3	10.5	26.3	
2003	6.0	10.6	26.8	
2004	6.6	12.0	21.9	
2005	4.9	9.2	22.6	
2006	3.6	8.2	21.0	
2007	5.4	9.4	20.4	
2008	7.2	14.9	21.8	23.1
2009	4.1	12.2	20.3	24.2
2010	6.9	11.3	19.1	23.0
2011	8.2	10.3	22.7	
2012	8.3	14.3	22.5	
2013	6.4	11.9	21.8	
2014	6.6	10.9	19.0	
2015	7.7	10.5	20.7	
2016	8.7	12.9	18.2	
2017	6,7	9,1	19,9	
2018	10,0	12,0	18,5	
2019	10,0	11,9	20,0	
2020	9,6	12,5	22,0	
2021	7,4	12,9	21,8	
2022	9,5	13,5	16,3	

7. Management technical measures.

No EU management plan exists for the anchovy fisheries in Division 9.a. The recent history of the regulatory measures in force for the anchovy fishery in the Division (with a special reference to the Spanish fishery in the Gulf of Cadiz) are described in the ane 27.9a Stock Annex (see also pil.27.8c9a Stock Annex for the Portuguese fishery). Updated information of the Spanish technical measures is given in the 2014 WGHANSA report (ICES, 2014b).

The regulatory technical measures in force for the Spanish (ES) and Portuguese (PT) anchovy purse-seine fishing in the Division 9a (since mid 1980's) are summarized as follows:

- Minimum landing size:
  - 9a N (ES), 9a CN-9a CS-9a S (PT): 12 cm. But see implementation in 20213 of the MCRS below.
  - 9a S (ES): 10 cm. But see implementation in 20213 of the MCRS below.
- Minimum vessel tonnage: of 20 GRT with temporary exemption (ES).
- Maximum engine power: 450 hp (ES).
- Purse-seine maximum length: 450 m (9a S, ES); 600 m (9a N, ES); 800 m (PT).
- Purse-seine maximum height: 80 m (9a S, ES); 130 m (9a N, ES) 150 m (PT).
- Minimum mesh size: 14 mm (ES); 16 mm (PT).
- Fishing time: 5 days per week (PT, ES).
- Seasonal closures:
  - PT (for sardine): 1.5-2 months (winter/spring) in 9a CN. Since 2015 in 9a CN-9a CS-9a S.
  - ES (for anchovy): voluntarily 3 months (Dec-Feb; until 1997), 1.5 months (Nov-Dec 2004-2005), 2 months (Nov-Dec 2006), 3 months (Nov-Feb 2007-2008), 1 month (Dec 2009-2010), 2 months (Dec-Jan 2011 on) in 9a S, under different GoC purse-seine fishery management plans.
- Spatial closures:
  - PT: ¼ nm distance to the coastline. 1 nm if below 20 m depth.
  - ES: inside bays and estuaries and internal waters in 9a N and 9a S. A Marine Protected Area, MPA (the Guadalquivir River mouth fishing reserve) was created in June 2004 in 9a S (**Figure 7.1**). The protected area corresponds to the main nursery area of fish (including anchovy) and crustacean decapods in the GoC. Fishing in the reserve is only allowed (with pertinent regulatory measures) to gill-nets and trammel-nets, although outside the riverbed. Neither purse-seine nor bottom trawl fishing is allowed all over this MPA.

Between 2006 and 2012 Spain implemented successive GoC purse-seine fishery management plans (9a S, ES). A new regulation approved in October 2006 established that up to 10% of the total catch weight could be constituted by fish below the established minimum landing size (10 cm) but fish must always be ≥9 cm.

Since April 2013 Spain implemented a new management plan for fishing vessels operating in its national fishing grounds, so it affects the purse-seine fishing in Galician (9a N) and GoC waters (9a S (ES)). One of the main measures in this new plan is the introduction of an individual quota (IQ) system to allocate annual national quotas. In the case of the GoC purse-seine fishery this measure involves to shift from a system of a fixed daily catch quota system for all the fleet to a new one based on the implementation of a IQ system managed quarterly by each fishery association after resolution of the National Fishery Administration on the annual allocation of the national quota by association.

By way of from Article 15(1) of Regulation (EU) No 1380/2013, which aims to progressively eliminate discards in all Union fisheries through the introduction of a landing obligation for catches of species subject to catch limits, the purse seine fishery in ICES zones 8, 9. and 10 and in CECAF areas 34.1.1, 34.1.2 and 34.2.0 targeting anchovy has a final *de minimis* exemption to the quantities that may be discarded of up to a maximum of 2% in 2015 and 2016, and 1% in 2017, of the total annual catches of this species. STECF concluded that this exemption is supported by reasoned arguments which demonstrate the difficulties of improving the selectivity in this fishery. Therefore, the exemption concerned has been included in the Commission Delegated Regulation (EU) No 1394/2014 of 20 October 2014 establishing a discard plan for certain pelagic fisheries in south-western waters.

Finally, the joint recommendation includes a minimum conservation reference size (MCRS) of 9 cm for anchovy caught in ICES Subarea 9 and CECAF area 34.1.2 with the aim of ensuring the protection of juveniles of that species. The STECF evaluated this measure and concluded that it would not impact negatively on juvenile anchovy, that it would increase the level of catches that could be sold for human consumption without increasing fishing mortality, and that it may have benefits for control and enforcement. Therefore, the MCRS for anchovy in the fisheries concerned should be fixed at 9 cm.

Figure 7.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Anchovy fishery in subdivision 9a South. Limits of the Fishing Reserve off the Guadalquivir River mouth (Spanish waters of the Gulf of Cadiz).

8. Ecosystem drivers.

The Gulf of Cadiz (GoC) is a sub-basin between the Iberian Peninsula and the African Continent that connects the Atlantic Ocean and the Mediterranean Sea through the Strait of Gibraltar (**Figure 8.1**). The northern half of the GoC is the southernmost Atlantic European regional sea.

The GoC is placed in the northern area of the *Canary Current Large Marine Ecosystem* and shares many of the oceanographic characteristics typical of the *Eastern Boundary Upwelling Systems* (*EBUS*s) in middle latitudes (*e.g.*, seasonal alternation of a regime of winds favourable to the coastal upwelling, a high biological productivity associated to this process, a system of zonal fronts and currents, and a coastal transition zone with a set of meso-scale structures that deform the fronts favouring the coast-open ocean exchange). Its main distinctive features are (**Figure 8.2**): i) the rupture at Cape São Vicente of the N-S orientation of the coastline typical of the *EBUS*s by an E-W orientated coastline, which frees most of the GoC from the tight control of the upwelling regime off Portugal (Fiúza 1983; Relvas & Barton, 2002). This is particularly true to the east of Cape Santa Maria, where the influence of the Portuguese upwelling vanishes, the shelf widens and waters here reach the highest temperatures in the region; ii) the influence of a northern branch of the Azores Current; iii) the presence of the Strait of Gibraltar with its Atlantic-Mediterranean water exchanges and mixing, and iv) the seasonality, that produces alternant regimes in the surface waters and an intense generation of meso-scale, which modulate and are modulated by the exchange in the Strait (see *e.g.*, García-Lafuente & Ruiz, 2007; Sánchez *et al.*, 2006; ICES, 2012).

Figure 8.1. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Satellite view of the Gulf of Cadiz featuring a high turbidity event that illustrates the influence of the Guadalquivir River. NASA MODIS, 12/11/2012. Source: earthobservatory.nasa.gov. NASA image courtesy Jeff Schmaltz, LANCE MODIS Rapid Response Team at NASA GSFC. Source: Llope (2017).

Cape Santa Maria divides the GoC shelf in 2 sectors that support different oceanographic processes (forcings by mass and energy inputs and tidal processes) causing that the eastern shelf is warmer and more productive than the western one, which is subject to a more permanent upwelling (Navarro & Ruiz, 2006; Prieto *et al*., 2009). In this eastern sector, shallower and with a lower intensity of currents, the Guadalquivir estuary also plays a relevant role (by constant tidal mixing) in the control of the biological activity on the shelf.

The GoC is heavily influenced by the Guadalquivir River, which drains one of the major European catchments areas (650 km, 57 000 km^2) contributing to the area's high productivity. Sediments carried by the Guadalquivir form marshes and wetlands that host a rich diversity of wildlife and are relied upon by commercially valuable species. The estuary of the Guadalquivir River comprises the lower course of the river, a 90 km stretch from its mouth to the first dam at Alcalá del Río, and covers an area of 1800 km^2 (Llope, 2017).

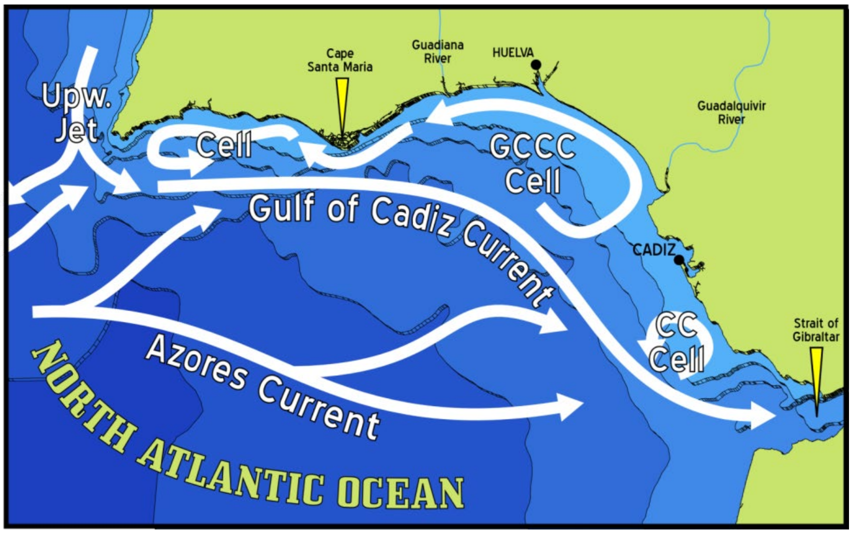


Figure 8.2. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Surface circulation in the GoC. CC Cell: cyclonic cell over the shoals in front of Cape Trafalgar; GCCC Cell: Gulf of Cadiz Counter Current; Upw. Jet: Portuguese upwelling. Source: Sánchez *pers. comm.* (after Folkard *et al*., 1997; Peliz and Fiuza, 1999; Relvas and Barton, 2002; Sánchez and Relvas, 2003; Criado-Aldeanueva *et al.*, 2006; García-Lafuente *et al*., 2006; Sánchez *et al*., 2006; Peliz *et al*., 2009).

The presence of the Guadalquivir estuary and marshes together with the tidal forcing generate a pool of warm water off the river mouth during spring and summer (García-Lafuente *et al*., 2006; García-Lafuente & Ruiz, 2007). This feature systematically appears in satellite imagery analyses (Vargas *et al*., 2003; Navarro & Ruiz, 2006). The tidal forcing and the river flow also contribute to maintaining high nutrient and chlorophyll levels all year round, which is particularly important in the summer, when the rest of the basin is stratified and oligotrophic. These particular conditions make the area off the Guadalquivir the most productive of the GoC (Navarro & Ruiz, 2006). Traditionally, the local cyclonic surface circulation pattern described during spring-summer has been put forward as a favorable meso-scale feature with regard to the maintenance of this warm and productive cell (García-Lafuente *et al*., 2006; Criado-Aldeanueva *et al*., 2006, 2009; Garel *et al*., 2016).

Estuaries are known for their role as nursery areas for many marine species and the Guadalquivir is no exception (Drake *et al.*, 2002; Baldó *et al*., 2006; Ruiz *et al*., 2006; Drake *et al*., 2007). Studies arising from a Guadalquivir estuarine monitoring program since 1997 have described long term changes in anchovy early life stages and other nekton components in relation to salinity and turbidity conditions (Drake *et al.* 2007, González-Ortegón *et al*. 2010, 2012). This nursery function is the main regulating service the region provides in relation to the GoC fisheries. It is this estuarine factor, where terrestrial and marine processes converge, that makes the GoC a unique case study (Ruiz *et al*., 2015; Llope, 2017).

For these reasons, these shelf waters of the NE GoC, mainly those ones in the inner shelf surrounding the Guadalquivir River mouth, offer a favourable environment for the development of anchovy eggs and larvae in spring-summer and become in the main GoC anchovy spawning area (Baldó *et al*., 2006). The outer stretch of the Guadalquivir estuary is used almost synchronously by anchovy post-larvae and juveniles as a nursery area. Recruitment to the estuary occurs when water temperature and salinity are relatively high, but turbidity and rainfall are relatively low. Some studies (Baldó & Drake, 2002; Drake *et al*., 2007; Fernández-Delgado *et al*., 2007; González-Ortegón *et al*., 2010) point out that, within this optimal window, the main factor regulating the nursery function of the estuary is the food availability of key-prey species (copepods for post-larvae, the mysid *Mesopodopsis slabberi* for juveniles).

There is a local upwelling regime to the west of Cape Santa Maria, which is independent of that of the Canary Current and considered a coastal process with a short time response to changes in the wind regime (Criado-Aldeanueva *et al*., 2006). Westerlies are the winds responsible for upwellings while easterlies have the opposite effect leading to a remarkable increase in temperatures (Prieto *et al*., 2009). Furthermore, the westerlies/easterlies regime plays a central role in the continental shelf dynamics of the area, affecting retention within the warm cell. Under westerlies conditions, local upwellings enhance productivity and plankton is confined inside the cyclonic cell. In contrast, easterlies would favor oligotrophy and the westward advection of plankton and larvae (Relvas & Barton, 2002; Catalán *et al*., 2006). Thus, persistent easterlies bursts (preceded and followed by intervals of a lower frequency of this wind) may generate significant modifications in the oceanographic regime in the GoC (*i.e*., decrease of SST, oligotrophy, offshore advection of early stages away from favourable conditions), which can influence markedly the reproductive success of the species. These detrimental conditions were evident during the period 1990-1997 and they seemed to affect to the development conditions of eggs and larvae, which could result in failed recruitments in those years as evidenced by the severe drop of landings in 1995-1996 (Ruiz *et al*., 2006, 2009; **Figure 8.3**). According to the authors, this drop of landings resembled more the easterly signal than the NAO index or precipitation. Conversely, the 1996 rain fall peak (and associated river discharges) –clearly reflecting the dramatic change in the NAO index– may have played a role in the recovery of 1997 anchovy landings.

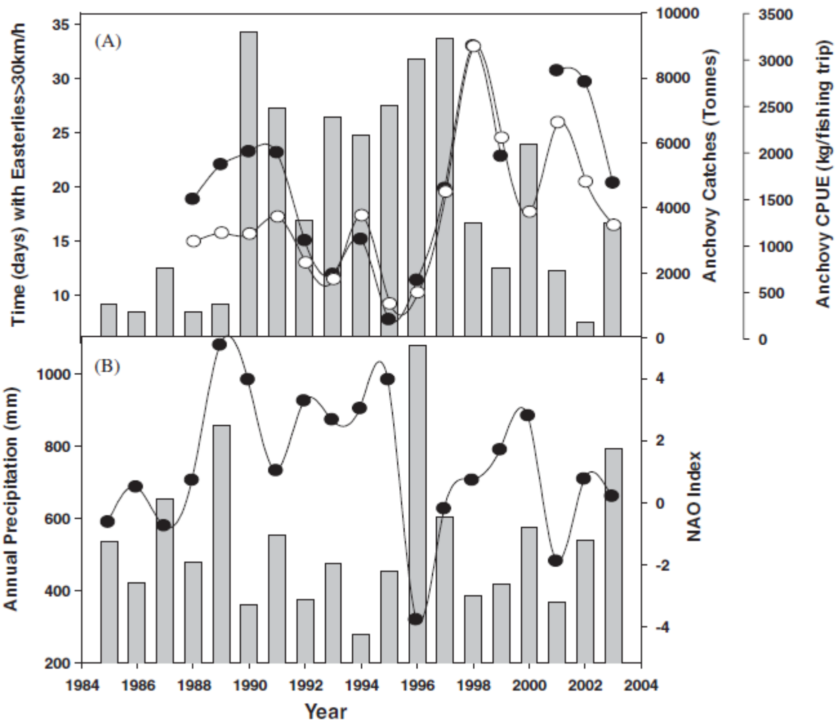


Figure 8.3. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. A. GoC anchovy landings (ICES Subdivision 9a South; black circles) and Barbate's single-purpose purse-seine fleet CPUE (white circles, in kg/fishing trip). Barbate is considered as a reference fleet in the GoC anchovy harvesting. Landing data for 2000 is not included in the graph as catches were not representative due to social conflicts in the fleet. Bars accumulate the time when easterlies stronger than 30 km/h hit Cádiz over the period from March to September. B. Circles and bars indicate North Atlantic Oscillation index and annual precipitation, respectively. Source: Ruiz *et al.* (2006).

The GoC anchovy population has also experienced a noticeable decreasing trend during the period 2008-2010 as a probable consequence of successive fails in the recruitment strength in those years (**Figure 8.4**; ICES, 2011). A man-induced alteration of the nursery function of the Guadalquivir estuary, caused by episodes of highly persistent turbidity events (HPTE; González-Ortegón *et al*., 2010; **Figure 8.1**), during the anchovy recruitment seasons in 2008, 2009 and 2010 could be one plausible explanation. Thus, the control of the Guadalquivir River flow, from the Alcalá del Río dam 110 km upstream, has an immediate effect on the estuarine salinity gradient, displacing it either seaward (reduction) or upstream (enlargement of the estuarine area used as nursery). Also affects to the input of nutrients to the estuary and adjacent coastal areas. The abovementioned HPTEs used to start with strong and sudden freshwater discharges after relatively long periods of very low freshwater inflow and caused significant decreases in abundances of anchovy juveniles and the mysid *Mesopodopsis slabberi*, its main prey (**Figure 8.5**).

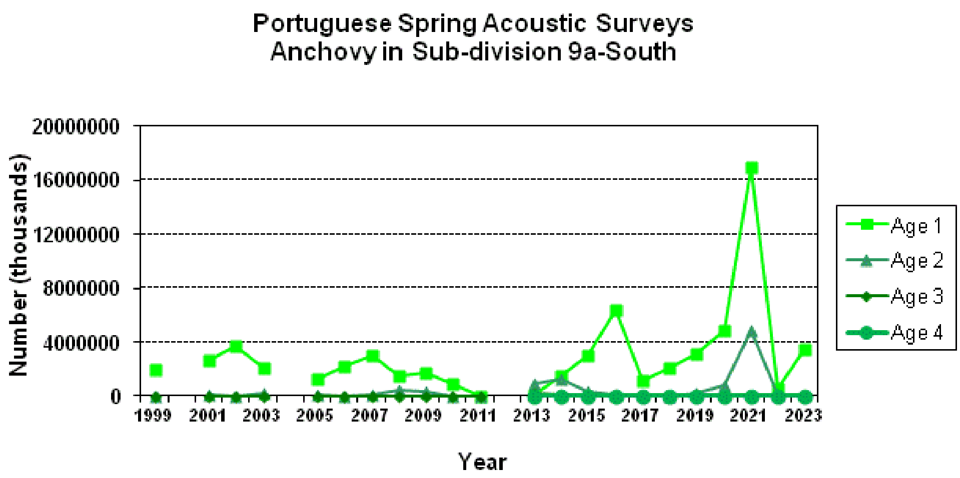


Figure 8.4. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Age structured estimates of GoC anchovy abundance from the Portuguese acoustic survey series. The null estimates for the 2011 Portuguese survey should be considered with caution. Source: ICES (2011).

As a short-lived small pelagic species, anchovy population dynamics are strongly affected by year-to-year fluctuations in environmental processes. As described above, temperature, winds and discharges from the Guadalquivir River have been identified as key factors influencing its recruitment (Ruiz *et al*., 2006, 2009; Rincón *et al*., 2016). Discharges have different effects on the nursery role depending on their volume. Low levels of freshwater discharges constrain primary productivity on the shelf limiting the food supply for juveniles (Prieto *et al*., 2009) while very high discharges cause salinity to drop below the threshold forcing juveniles to leave the protective environment of the estuary (Ruiz *et al*., 2009). However, the combination of both natural (weather) and anthropogenic (discharges) effects, plus the timing and volume discharged, results in a broad range of combinations that makes the ecological response of the ecosystem to freshwater inputs be not unequivocal (González-Ortegón & Drake, 2012; González-Ortegón *et al*., 2012, 2015).

In the last years, models including environmental information have been developed by means of Bayesian simulation techniques (Ruiz *et al*. 2009, 2017, Rincón *et al*. 2016, 2018), GAM empirical modeling (de Carvalho-Souza *et al*., 2016, 2019), as well as mass-balanced models describing the role of GoC anchovy in the marine food web (Torres *et al*. 2013). An ecosystem approach perspective is presented in Llope (2017) (see also ICES, 2017b).

All of these evidences confirm that the GoC anchovy stock relies on recruits to persist and, therefore, is highly vulnerable to ocean processes and controlled by fluctuations in both environmental and anthropogenic variables.

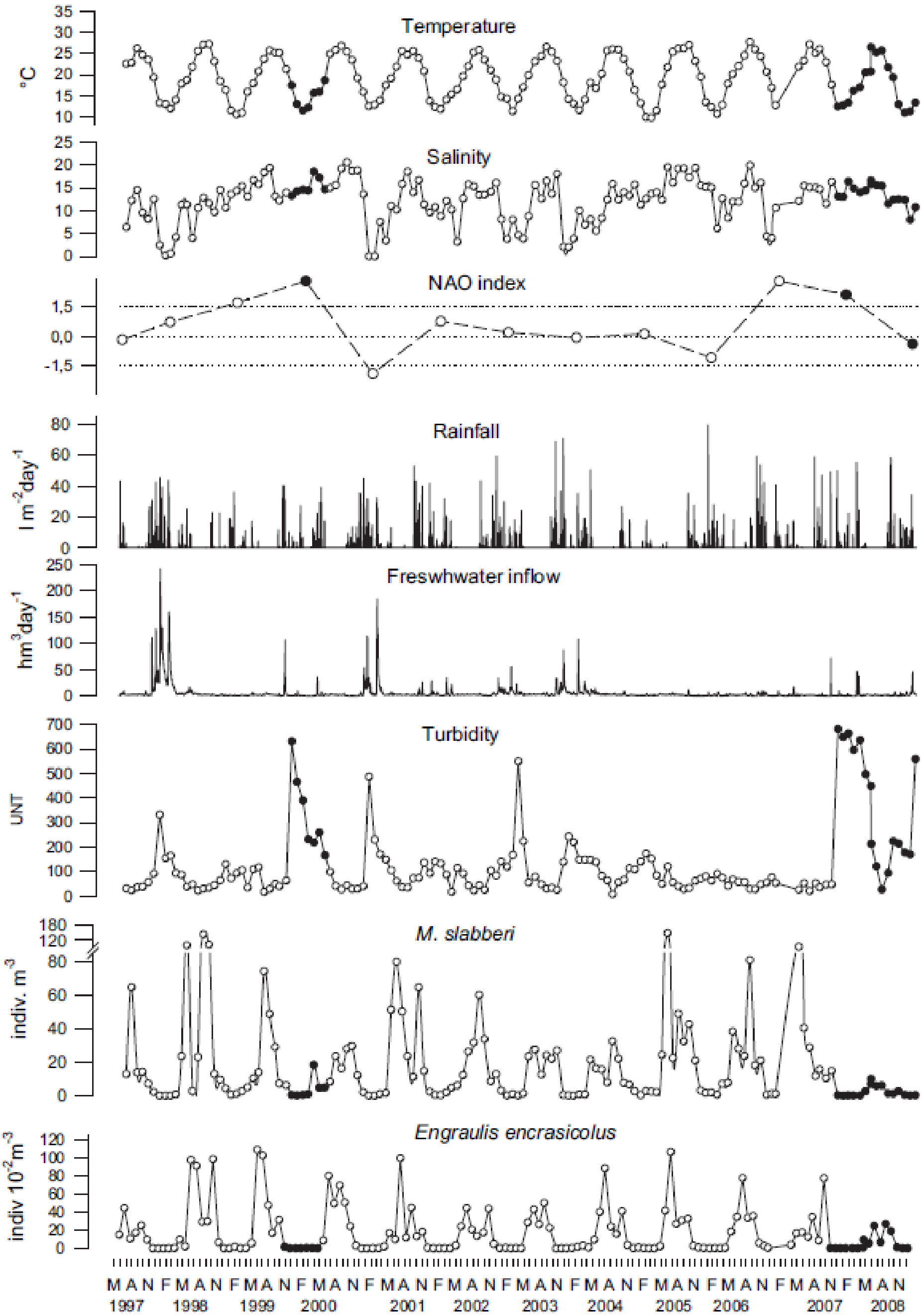


Figure 8.5. Anchovy in Division 9.a. Southern component. Subdivision 9.a South. Monthly/daily mean values of environmental variables (water temperature, salinity, rainfall, freshwater inflow, and turbidity), mysids and anchovy recruits' densities in the Guadalquivir Estuary from May 1997 to February 2009, and winter NAO index values for the same period. F, February, M, May, A, August, N, November. Shaded symbols, samples collected during HPTEs (composite figure from González-Ortegón *et al*., 2010).

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Data consistency analysis of survey age-length data available for the Southern component of anchovy 9a stock

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Introduction

Iberian anchovy stock covers the division 9a, from West Galicia (9aN) to the northern Gulf of Cadiz (9aS). Given the independent dynamics of the populations from the West Iberian coast (9aN, 9aCN and 9aCS) and South Iberian coast (9aS), advice is given separately for the western and southern components of the stock (Figure 1).

Figure 1. ICES Statistical Divisions and Subdivisions in Southern Europe. Western component of anchovy stock distributes in the area identified in blue as 9.a. West (comprising Sub-divisions 9aN, 9aCN, 9aCS). Southern component of anchovy stock distributes in the area identified in blue as 9.a. South (comprising sub-divisions 27.9.a.S -Portugal- and 27.9.a.S - Spain).

This document outlines various tests aimed at assessing the reliability of age-length data from the ECOCADIZ-RECLUTAS, ECOCADIZ, and PELAGO acoustic-trawl surveys performed in the southern component of the anchovy stock in ICES division 9a. It includes analyses of intra- and inter-survey consistency, along with estimates of growth parameters for the datasets under scrutiny. The primary objective is to furnish evidence either endorsing or refuting the incorporation of this data from these surveys in the assessment of the southern anchovy stock.

Methodology

Below, the data obtained from acoustic surveys carried out in the southern component of anchovy stock in division 9a, is presented alongside the two methods used to assess the consistency of age-length data: intra-survey consistency and inter-survey consistency. Additionally, the growth parameters associated to each age-length dataset are estimated.

1. Data available

Table 1 summarizes the available data and reported in ICES (2021, 2024). The historical dataset from the PELAGO spring acoustic-trawl surveys covers a period of 21 years, ranging from 1999 to 2023, with some gaps in 2000, 2004, 2011, and 2012. The survey timing, originally set in March, shifted to April between 2015 and 2019, and in the last four years of the series it reverted to being conducted in March. The historical dataset from the ECOCADIZ summer acoustic-trawl surveys spans 14 years, ranging from 2004 to 2023, with several gaps in 2005, 2008, 2011, 2012, 2021, and 2022. The survey timing originally began in June, transitioned to July between 2007 and 2019, and continued in July in 2023, with occasional surveys conducted in August in the years 2013 and 2020. The historical dataset from the ECOCADIZ-RECLUTAS fall acoustic-trawl surveys covers an 11-year period, from 2012 to 2023, with gaps in 2013 and 2017. The survey timing initially started in November and shifted to October between 2014 and 2023 (Table 1). The following overview of the surveys has been summarized in ICES (2024).

	january	february	march	april	may	june	july	august	september	october	november	december
1999			PELAGO									
2000												
2001			PELAGO									
2002			PELAGO									
2003		PELAGO										
2004						ECOCADIZ						
2005				PELAGO								
2006				PELAGO		ECOCADIZ						
2007				PELAGO			ECOCADIZ					
2008				PELAGO								
2009				PELAGO			ECOCADIZ					
2010				PELAGO			ECOCADIZ					
2011												
2012											ECOCADIZ-RECLUTAS	
2013				PELAGO				ECOCADIZ				
2014				PELAGO			ECOCADIZ			ECOCADIZ-RECLUTAS		
2015				PELAGO			ECOCADIZ			ECOCADIZ-RECLUTAS		
2016				PELAGO			ECOCADIZ			ECOCADIZ-RECLUTAS		
2017				PELAGO			ECOCADIZ					
2018				PELAGO			ECOCADIZ			ECOCADIZ-RECLUTAS		
2019				PELAGO			ECOCADIZ			ECOCADIZ-RECLUTAS		
2020			PELAGO					ECOCADIZ		ECOCADIZ-RECLUTAS		
2021			PELAGO							ECOCADIZ-RECLUTAS		
2022			PELAGO							ECOCADIZ-RECLUTAS		
2023			PELAGO				ECOCADIZ			ECOCADIZ-RECLUTAS		

Table 1 . ane.27.9a stock. Southern component. Available data of age composition for the acoustic surveys carried out in the southern Iberian (Subdivision 9a.S).

The *PELAGO* survey, initiated in 1996 and covering the 9a Division from subdivisions 9aCN to the Gulf of Cadiz, excluding 9aN subdivision, employs acoustic surveying on 71 transects perpendicular to the coast with an 8 nm separation. Conducted by IPMA onboard RV Noruega and, in 2020, onboard Spanish Fisheries General Secretariat (SGPM) RV Miguel Oliver, it focuses on the Portuguese continental shelf and the Spanish Gulf of Cadiz at depths of 20 to 200 meters. The survey utilizes different echo sounders over the years, integrating acoustic signals and conducting fishing hauls for ground-truthing. Co-funded by the European Community Data Collection Framework, *PELAGO* provides biomass estimates without dispersion measures, for anchovy and sardine, presenting population data, size composition, and age structure. The time-series for anchovy in Division 9a dates back to 1999, with intermittent gaps, and includes fish egg sampling using the CUFES system and hydrography and zooplankton sampling during inactive acoustic surveying periods. The 2020 survey's abundance and biomass estimations were considered comparable to previous years.

The *ECOCADIZ* survey, conducted by the IEO, initially with RV Cornide de Saavedra (2004-2013) and later with RV Miguel Oliver, focuses on pelagic communities in the Gulf of Cadiz shelf waters (20–200 m depth). The survey, financed by DCF, aims to coincide with the anchovy peak spawning. Beginning in 2004, with gaps in 2005, 2008, 2011, 2012, 2021 and 2022 it provides population estimates without dispersion measures, offering size composition and age structure for sardine and anchovy biomass. The series, starting officially in 2004, followed earlier Spanish surveys in 1993 and 2002 with RV Cornide de Saavedra. Initially targeting Spanish waters, the series expanded in 2004 to cover Portuguese and Spanish areas in ICES Division 9.a South. Carried out annually, the surveys use a systematic parallel grid of 21 transects, spaced 8 nautical miles apart and perpendicular to the shoreline, with changes over time to enhance spatial coverage.

The *ECOCADIZ-RECLUTAS* survey series, conducted by IEO, initially with RV Emma Bardán (2012 survey) and later with RV Ramón Margalef, is focused on the acoustic estimation of Gulf of Cadiz anchovy and sardine juveniles within Subdivision 9a S (20 – 200 m depth). Financed by DCF, the series began in 2012 and continued in 2014, with a gap in 2017 due to technical problems. The survey, conducted in the second fortnight of October, aims to assess the size composition and age structure of anchovy and sardine populations, providing estimates without dispersion measures. The series, initiated in 2009 as a pilot survey, faced technical challenges in the first year and experienced gaps in 2010 and 2011. In 2012, it was restricted to Spanish waters, and technical issues in 2017 impacted the surveyed area and acoustic sampling coverage. At present (2023), and considering 2014 as the starting point of the conduction of standard surveys, the time-series is composed of 9 data points.

2. Survey consistency

Two methods of examining *ECOCADIZ*, *PELAGO* and *ECOCADIZ-RECLUTAS* survey consistency have been used for anchovy in 9a: intra-consistency and inter-consistency. These methods mainly follow those adopted in the 2004 ICES Study Group on Assessment Methods Applicable to Assessment of Norwegian Spring-Spawning Herring and Blue Whiting Stocks (ICES, 2004; Payne et al., 2009).

2.1. Intra-survey consistency

Intra-survey consistency for a given survey, and two consecutive age groups, i and $i + 1$, may be expressed as correlation coefficients calculated over years between $N(i, y)$ and $N(i + 1, y + i)$, where $N(i, y)$ represents the abundance index in millions for age i and year y. These correlation coefficients provide an indication of the ability of surveys to track year class strength effects.

This has been done in the linear domain to allow for zeros as these are often present in the data, if correlation of $log(N)$ is preferred, the $log(N + k)$ would need to be used, where k is a small constant depending on the scaling of N. A value of k of half of the $min(N)$ might be recommended (ICES, 2004). In the current analyses k was set equal to 1.5 ($min(N)$=3).

Visual representations for the correlation in the surveys are also presented, where the numbers at age i are presented versus the numbers at age $i + 1$ in the series. The points are marked as the year class so it is possible to follow the year classes through the time series.

Intra-survey consistency is completed with survey-based catch curves for each of the year classes (i.e. cohorts) present in the assessed population and an analysis of survey's catchabilities at age.

In the first case, the natural logarithm of abundance indices ($ln(N + k)$) for successive ages composing the cohort are presented and a regression line and model is fitted to the right descending limb of the curve.

Outliers were identified using the Cook's distance (Fox and Weisberg, 2019, Cook and Weisberg, 2009); this distance indicates that a point is an outlier if its associated Cook's distance is over 0.1.It was implemented using the R package *car: Companion to Applied Regression* .

2.2. Inter-survey consistency

The approach followed here differs from the described one in ICES (2004). In ICES (2021), the Inter-survey consistency for a given age was analyzed by estimating the correlation between abundance indices for that age provided by two surveys, $s1$ and $s2$. Here, the analysis focused on comparing the numbers of age-0 individuals from the autumn recruitment survey (*ECOCADIZ-RECLUTAS*) to the numbers of age-1 individuals in the subsequent spring (*PELAGO*) and summer (*ECOCADIZ*) surveys.

Subsequently, the numbers of age-0 individuals in the summer survey (ECOCADIZ) were compared to the numbers of age-1 individuals in the subsequent PELAGO and *ECOCADIZ-RECLUTAS* surveys.

Additionally, correlations were computed for the same age group and survey year, including the correlation between age-1 individuals in the *PELAGO* and *ECOCADIZ* surveys, age-0 individuals in the *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys, and age-1 individuals in the *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys.

2.3. Growth parameters

Annual growth has been studied using the mean length at age in the population obtained by each survey. The mean length at age class was integrated into the von Bertalanffy growth equation:

$$L(t) = Linf(1 - exp(- K(t - t0)))$$

where $L(t)$ is the mean fish length at age t and, $Linf$, K and $t0$ are the parameters that determine the shape of the growth curve: $Linf$ is defined as the asymptotic mean length, K the rate at which the curve approaches the asymptote and $t0$ the age at which mean length is zero (Ricker 1975). The von Bertalanffy function (VBGF) was estimated using the R package *FSA: Fisheries Stock Analysis* (Ogle et al., 2020).

Results

1. Biomass and abundance time series

A general overview of the surveys is presented in Figure 2, where it can be observed that the magnitudes and trends are very similar across surveys. The data reveals high interannual variability in both biomass and abundance. Between 2006 and 2013, a decreasing trend was observed, followed by an important increase that peaked in 2016, as evidenced by *PELAGO* data. However, 2017 saw a marked reduction. Starting from 2018, there was an increasing trend, reaching a second peak in biomass in 2019, according to *ECOCADIZ* records. The period from 2020 to 2022 exhibited a declining trajectory. In 2023, both *ECOCADIZ* and *ECOCADIZ-RECLUTAS* estimate decreases in both abundances and biomasses, while *PELAGO* indicates an increase compared to 2022.

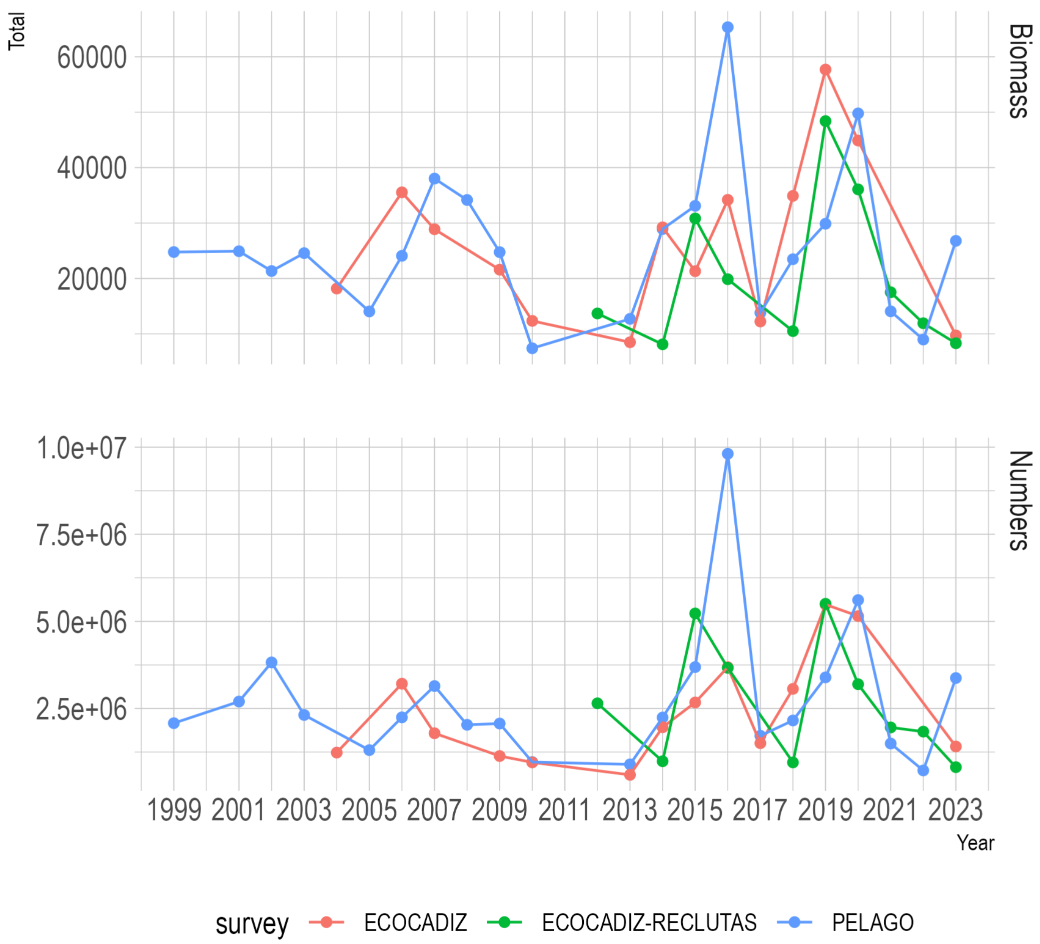


Figure 2. ane.27.9a stock. Southern component. Biomass and abundance time series for *ECOCADIZ, ECOCADIZ-RECLUTAS* and *PELAGO* surveys. Top panel: Estimated biomass time series in tonnes. Bottom panel: Estimated abundance time series in millions.

2. *PELAGO* spring survey data

2.1. Length and age data

As observed in Figure 3 (top right), the 94% of the sampled population in *PELAGO* survey corresponds to age-1 and the 6% to age-2. By convention there is no age-0 at first and second quarters and birthdate is set at January 1st, as *PELAGO* survey is carried out in the second quarter, no age-0 is registered.

Regarding length data, the historical mean length for age-1 is 11.3 cm, while for age 2 is 14.2 cm. Between 2015 to 2023, the mean size for age-1 individuals is below the historical mean (red squares in left and bottom right panels of Figure 3) suggesting that the abundances in this period are predominantly supported by smaller fish.

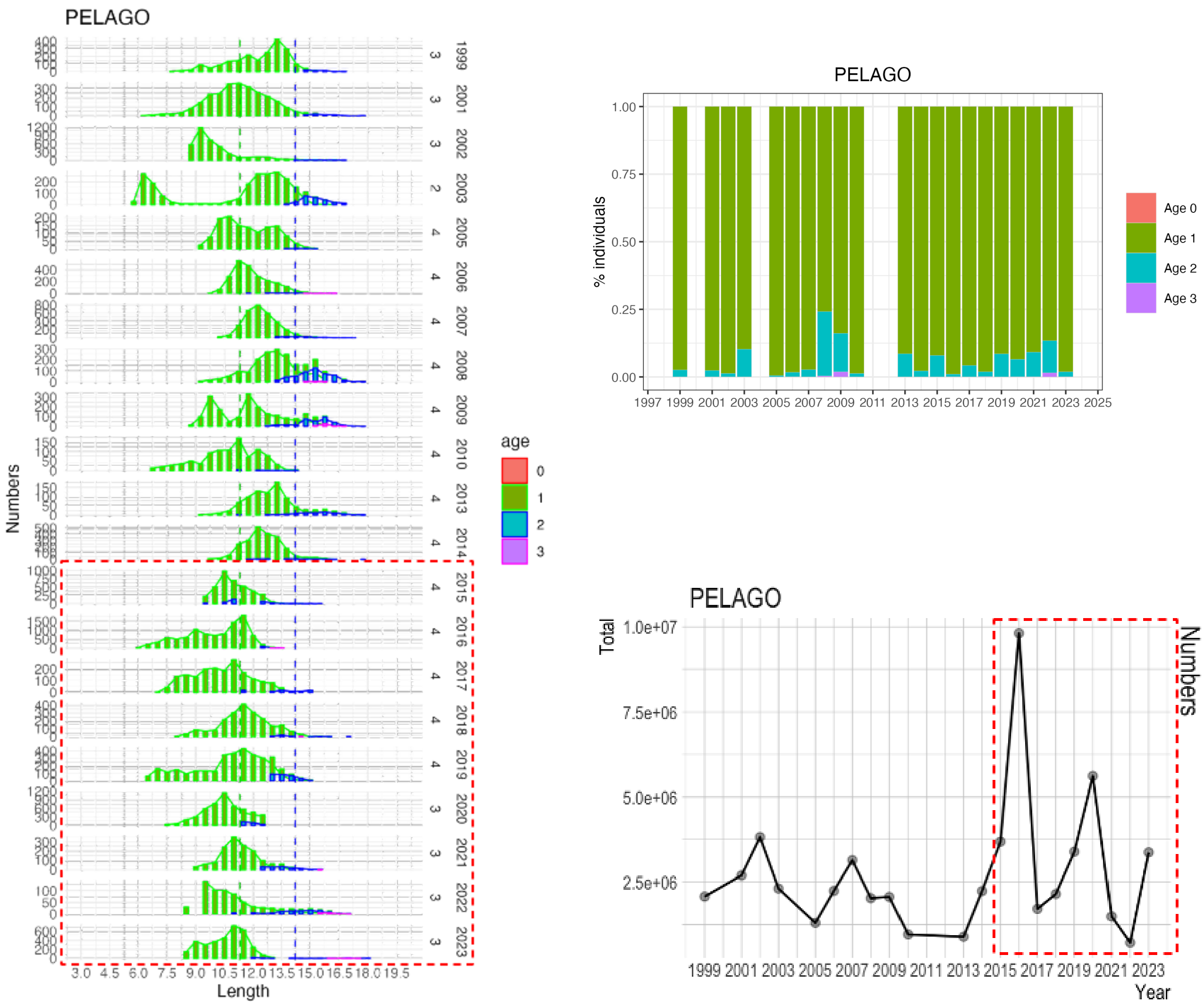


Figure 3. ane. 27.9a stock. Southern component. *PELAGO* spring survey series 1999-2023. Left panel: Length at age structure. Green and blue lines represent the historical mean length for age-1: 11.3 cm and age-2: 14.2 cm, respectively.. Top right panel: Age proportion by year. Bottom right panel: Time series of abundance acoustic estimates.

2.2. Cohort tracking analysis

Figure 4 shows that there is a consistent cohort tracking in PELAGO spring survey series with higher abundances at age-1 decreasing reasonably until age-3.

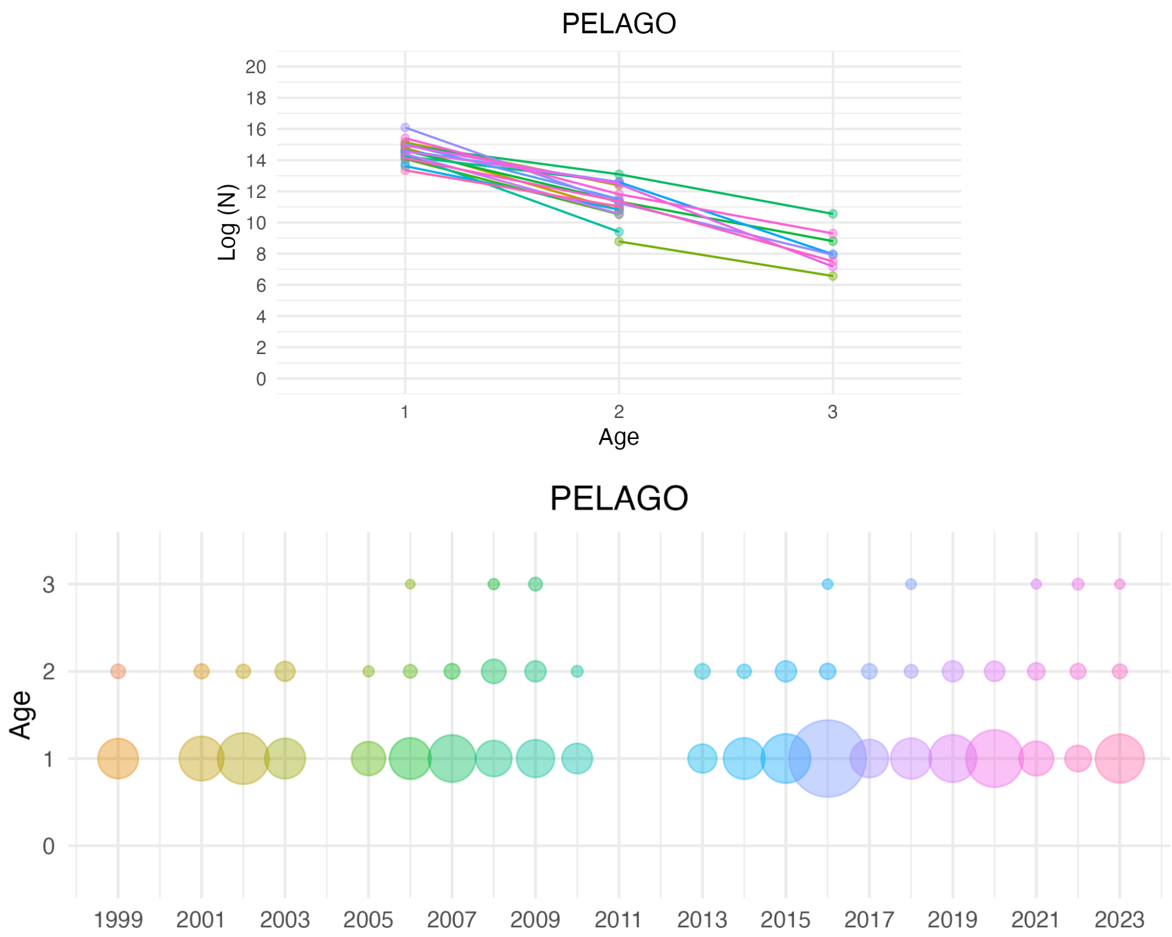


Figure 4. ane. 27.9a stock. Southern component. *PELAGO* spring survey series. Cohort tracking (Log number) by age.

2.3. Intra-consistency analysis

This analysis results in a positive correlation between age-1 and age-2 in consecutive years (age-1 in year-y with age-2 in year-y+1, see Figure 5, left panel). Nevertheless it is not significant (R=0.31, p=0.23). The identified outliers were the cohorts of 2015 (year 2016) and 2021 (year 2022). Correlation without outliers results higher and more significant (R=0.44, p=0.1) (Figure 5, bottom panel).

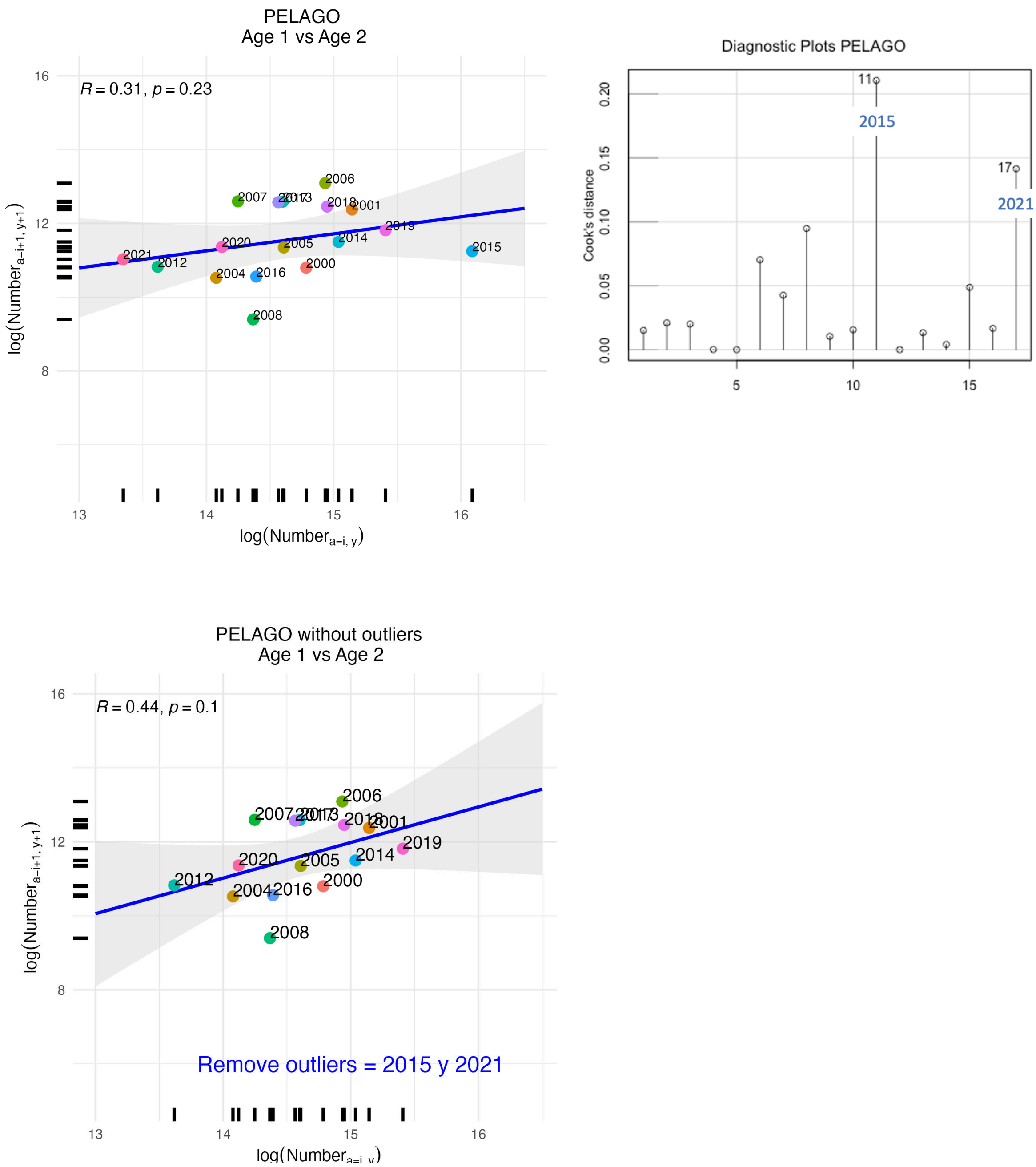


Figure 5. ane. 27.9a stock. Southern component. *PELAGO* spring survey series. Correlation of consecutive ages (age-*i* in year-*y* with age-*i* +1 in year-*y*+1) for Age-1 vs Age-2 (top left panel). Diagnostic cook´s distance for identified outliers (top right panel) and Age-1 vs Age-2 correlation without outliers (bottom left panel).

2.4. Mean length at age and von Bertalanffy growth curves

To assess whether the outliers identified in the pre analysis could be related to age misspecification affecting mean length at age, growth parameters were computed with the whole dataset and the whole dataset without outliers: cohorts 2015 and 2021 (age-1 2016, age-2 2017, age-1 2022, age-2 2023: Figure 6, left panel) for the *PELAGO* spring acoustic survey. The growth parameters estimated considering the whole dataset are Linf=16.03, K=0.88 and t0=-0.39. The corresponding estimates with the dataset excluding outliers are Linf=16.04, K=0.87 and t0=-0.44 (Figure 6, right panel). These estimates align with those reported by Bellido et al (2000) with Linf = 18.95 cm and K = 0.90.

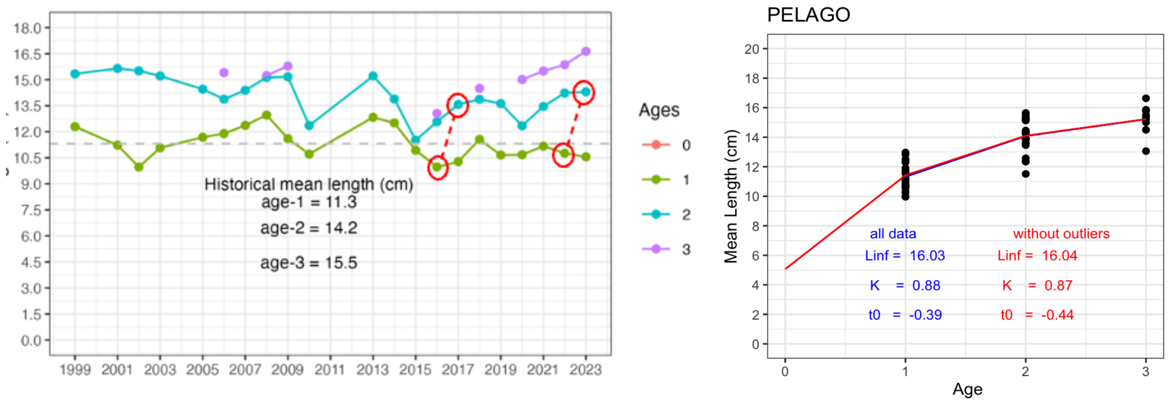


Figure 6. ane. 27.9a stock. Southern component. *PELAGO* spring survey series 2004 - 2023. Left panel: Mean length at age from 1999 to 2023, the red circles joined by dashed lines correspond to the outliers identified, cohort 2015 and 2021. Right panel: von Bertalanffy growth curves fitted to the mean length at age.

2.5. Remarks on *PELAGO* age-length data

- The abundances and biomasses estimated by the *PELAGO* spring acoustic survey are composed of over 90% of age-1 anchovies (adult stock).
- There is a consistent cohort tracking with higher abundances at age-1 decreasing reasonably until age-3.
- There is a positive correlation between age-1 and age-2 in consecutive years, which is more significant when outliers are removed.
- When computing growth parameters with the data set without outliers they are very similar to those estimated with the whole data set.
- Growth pattern with the whole data set is consistent. It is recommended to use the whole data set as an indicator of the adult population.

3. *ECOCADIZ* summer survey data

3.1. Length and age data

As observed in Figure 7 (top right), *ECOCADIZ* survey shows that 54% of the sampled population corresponds to age-1, while 43% corresponds to age-0. By convention there is no age-0 at first and second quarters and birthdate is set at January 1st. As *ECOCADIZ* survey was performed in June for 2004 and 2006, no age-0 is registered. Surveys performed in July consistently identified age-0 fish, except for unexplained absences in 2007 and 2009.

Regarding length data, the historical mean lengths of age-0 and age-1 from 2010 to 2023 were 10.3 cm and 12.7 cm, respectively (Figure 7, left panel).

This survey tracks the juvenile and adult population. Between 2015-2023, the abundances are mainly composed by age-0 individuals (Figure 7, bottom right panel).

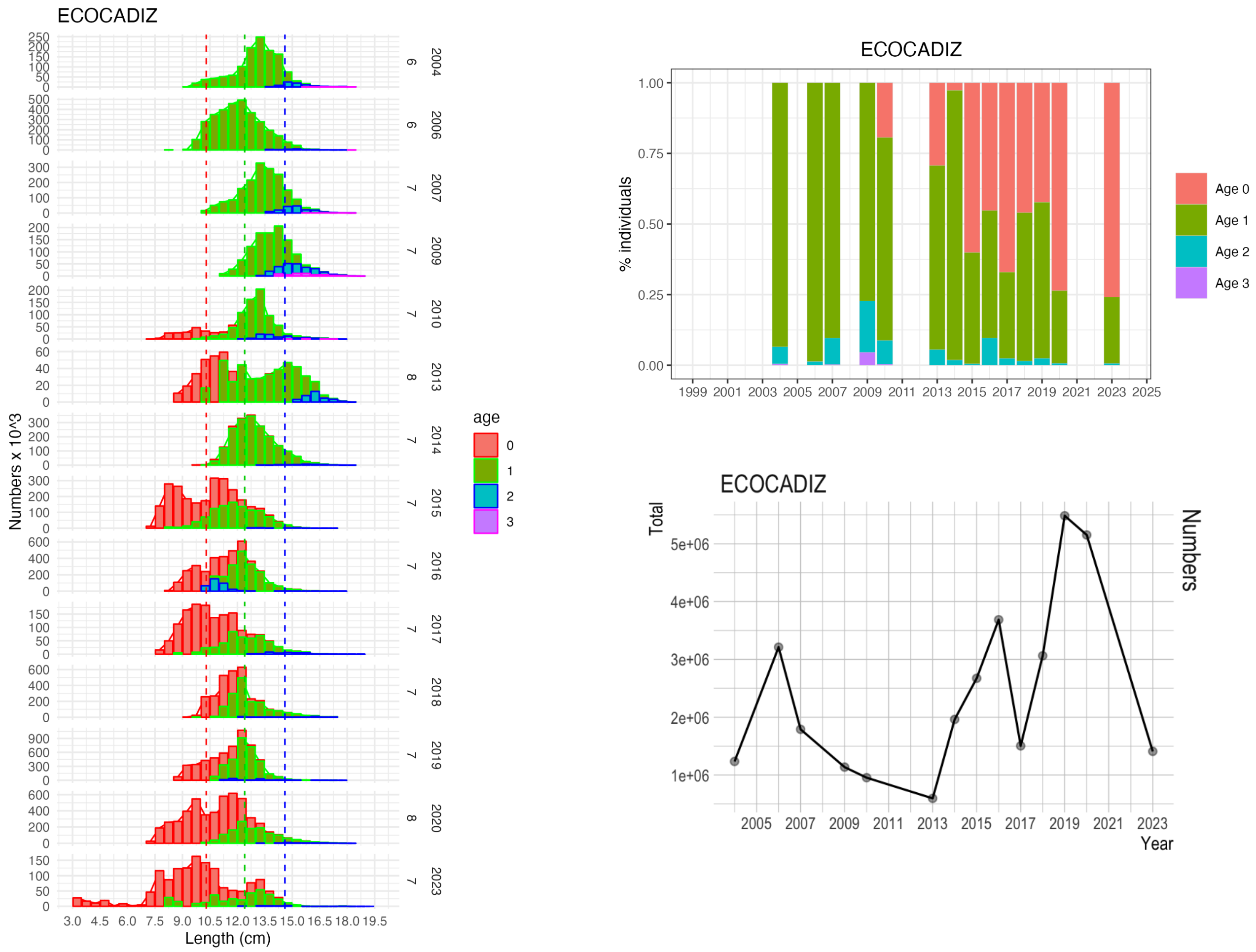


Figure 7. ane. 27.9a stock. Southern component. *ECOCADIZ* summer survey series 2004 - 2023. Left panel: Length at age structure. Red, green and blue lines represent the historical mean length for age-0: 10.3 cm,age-1:12.4 cm and age-2: 14.6 cm, respectively. Top right panel: Age proportion by year. Bottom right panel: Time series of abundance acoustic

estimates.

3.2. Cohort tracking analysis

At the beginning of the *ECOCADIZ* series, from 2004 to 2009, no age-0 fish were observed, which results in a different pattern for cohort tracking compared to the period from 2010 to 2023. The age-0 number of individuals observed was very similar to the age-1 number, not as usually expected in cohort-tracking. Age-2 numbers were lower than the other age groups (age 0 and age 1) as expected in cohort tracking. Due to data gaps, it was not possible to do cohort tracking after 2019 (Figure 8).

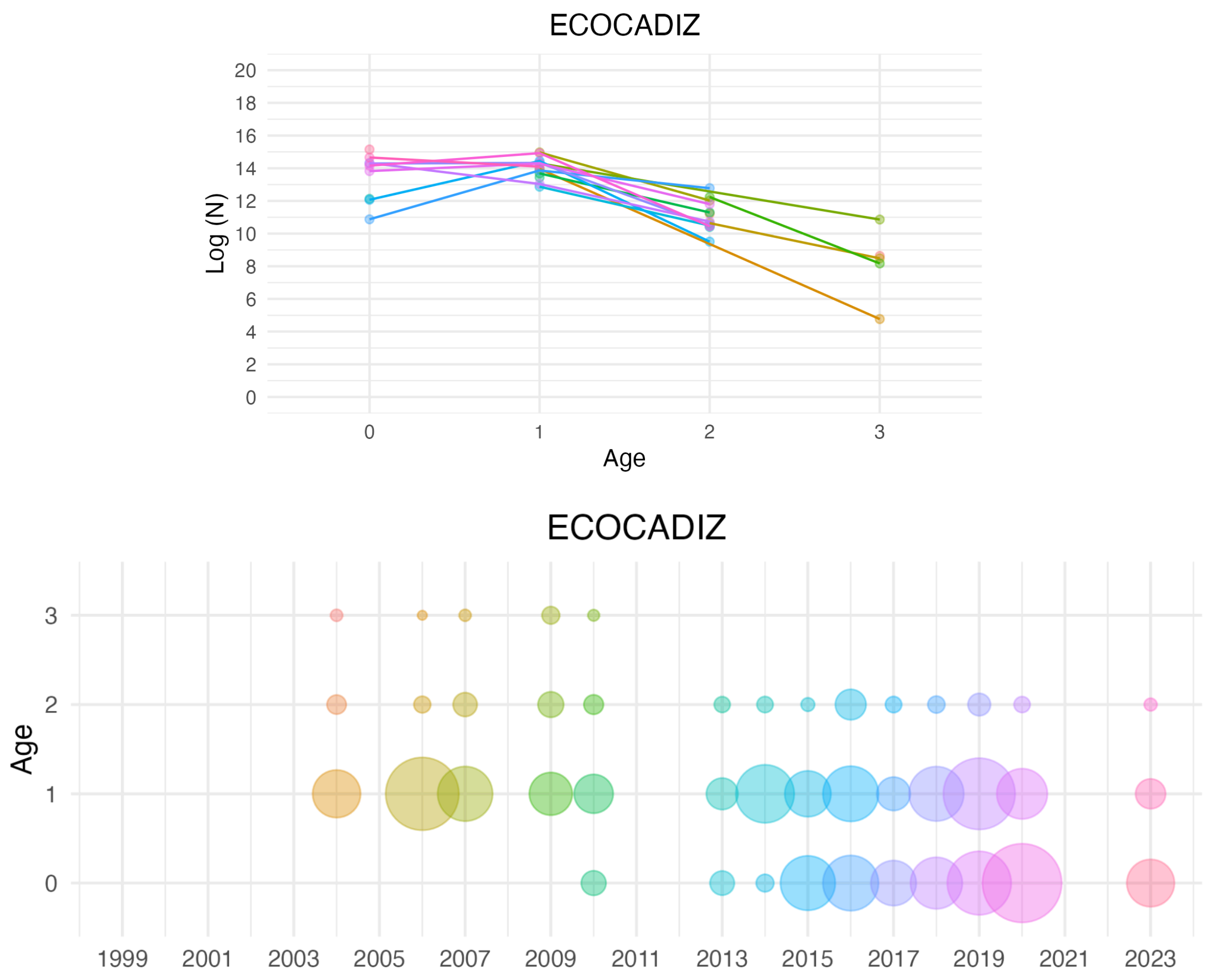


Figure 8. ane. 27.9a stock. Southern component. *ECOCADIZ* summer survey series. Cohort tracking (Log number) by age.

3.3. Intra-consistency analysis

The top left panel of Figure 9 shows that there is no correlation between age-0 and age-1 in consecutive years (R=0.0068, p=0.99). After removing the cohort of 2016, which was identified as an outlier, the Pearson correlation results positive (R=0.43, p=0.39) but not significant (Figure 9, bottom panel).

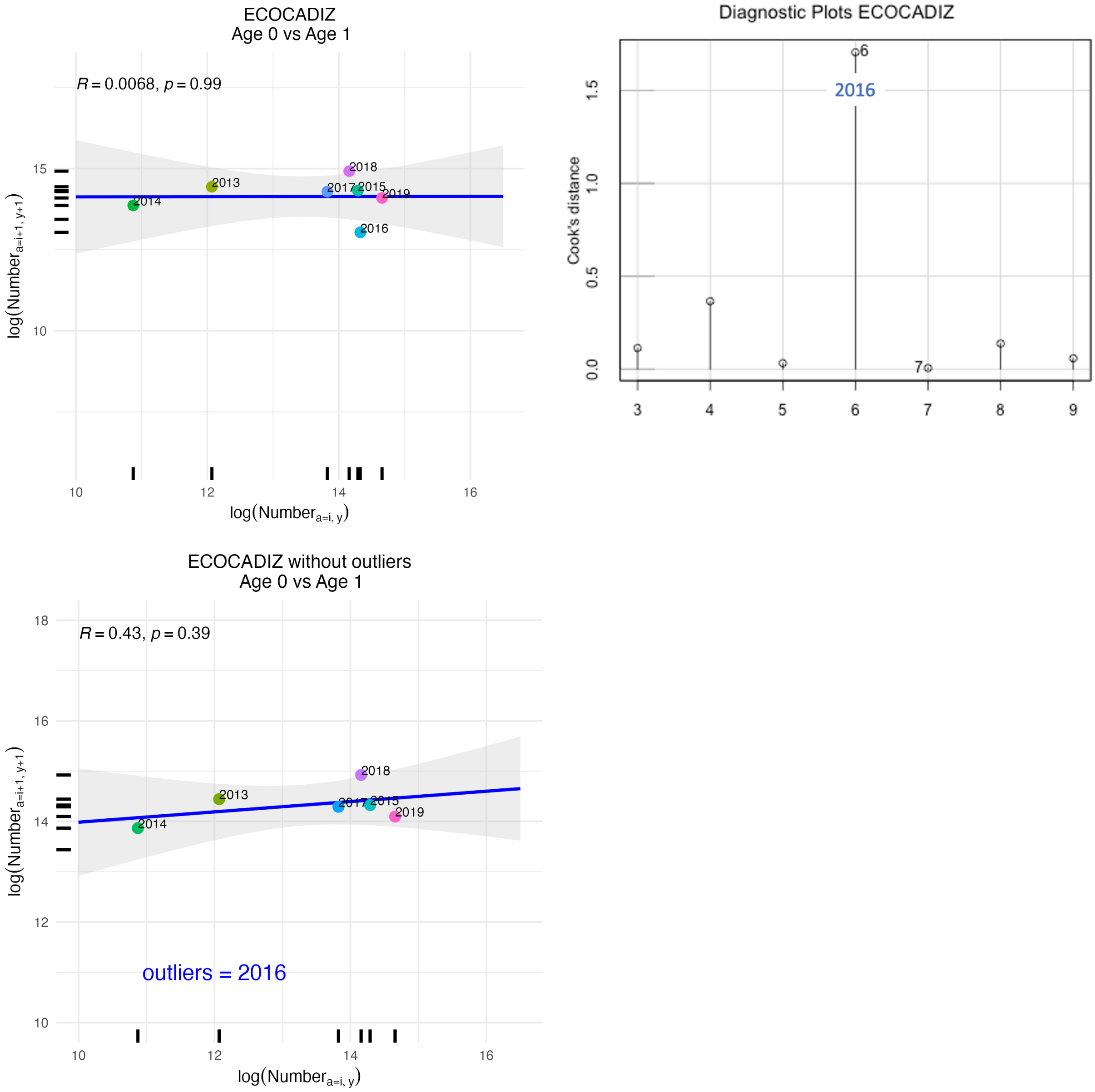


Figure 9. ane. 27.9a stock. Southern component. *ECOCADIZ* summer survey series. Correlation of consecutive ages (age-*i* in year-*y* with age-*i* +1 in year-*y*+1) for Age-0 vs Age-1 (top left panel) . Diagnostic Cook´s distance for identified outliers (top right panel) and Age-0 vs Age-1 correlation without outliers (bottom left panel).

In the left top panel of Figure 10 it can be observed that there is almost no correlation between age-1 and age-2 in consecutive years (R=0.062, p=0.87). The identified outliers were the cohorts of 2005, 2012 and 2013 (top right panel). After removing the outliers from the analysis, the Pearson correlation results negative and not significant (R=-0.18, p=0.73, bottom panel).

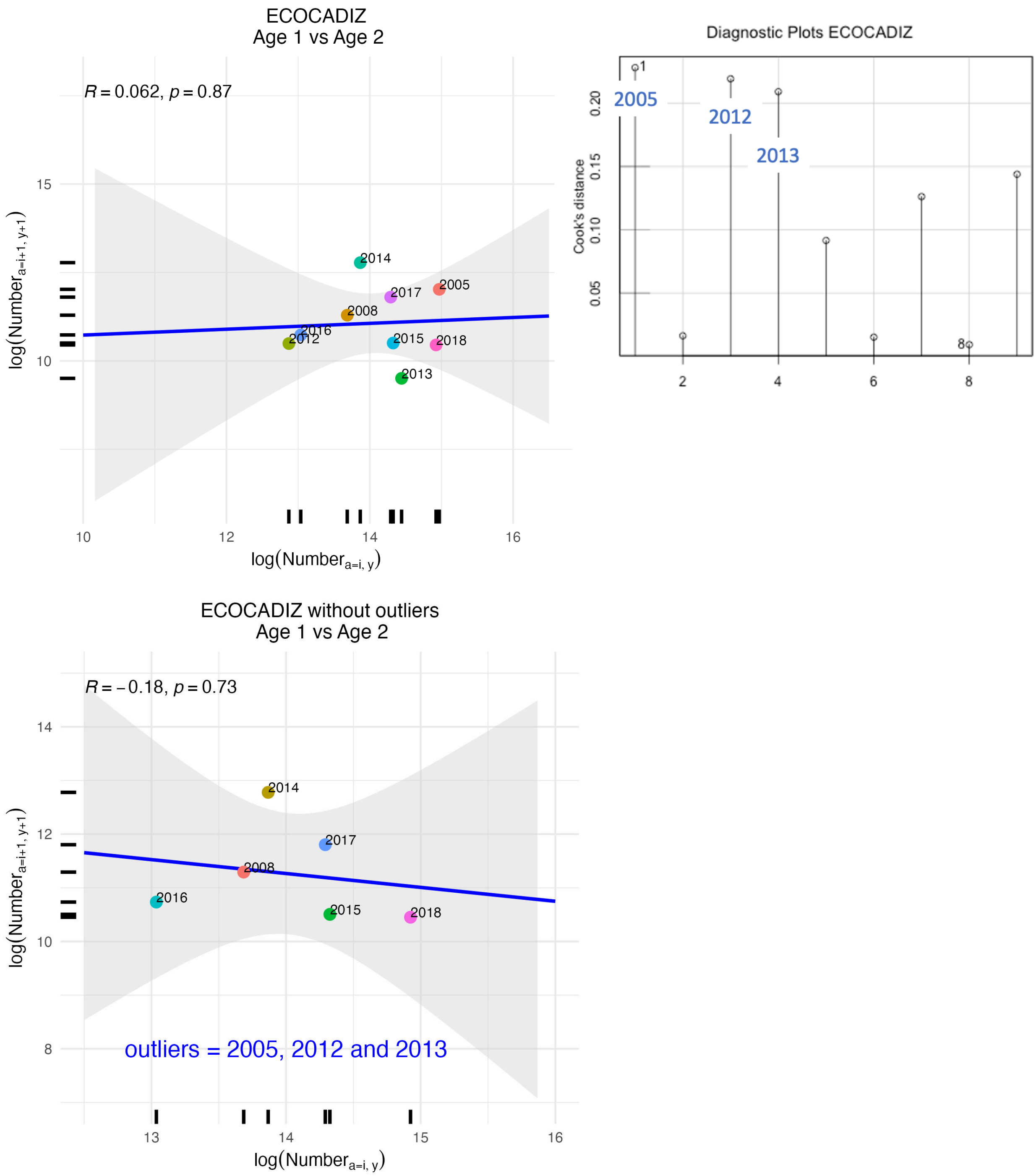


Figure 10. ane. 27.9a stock. Southern component. *ECOCADIZ* summer survey series. Correlation of consecutive ages (age-*i* in year-*y* with age-*i* +1 in year-*y*+1) for Age-1 vs Age-2 (top left panel) . Cook´s distance for identified outliers (top right panel) and Age-1 vs

Age-2 correlation without outliers (bottom left panel).

Regarding consistency between age-1 and age-2 when removing the first years of the series where no age-0 was observed, the top left panel of Figure 11 shows a negative correlation (R=-0.11, p=0.82). The identified outlier was the cohort of 2012 (Figure 11, top right panel). After removing the outliers, no remarkable improvement was observed.

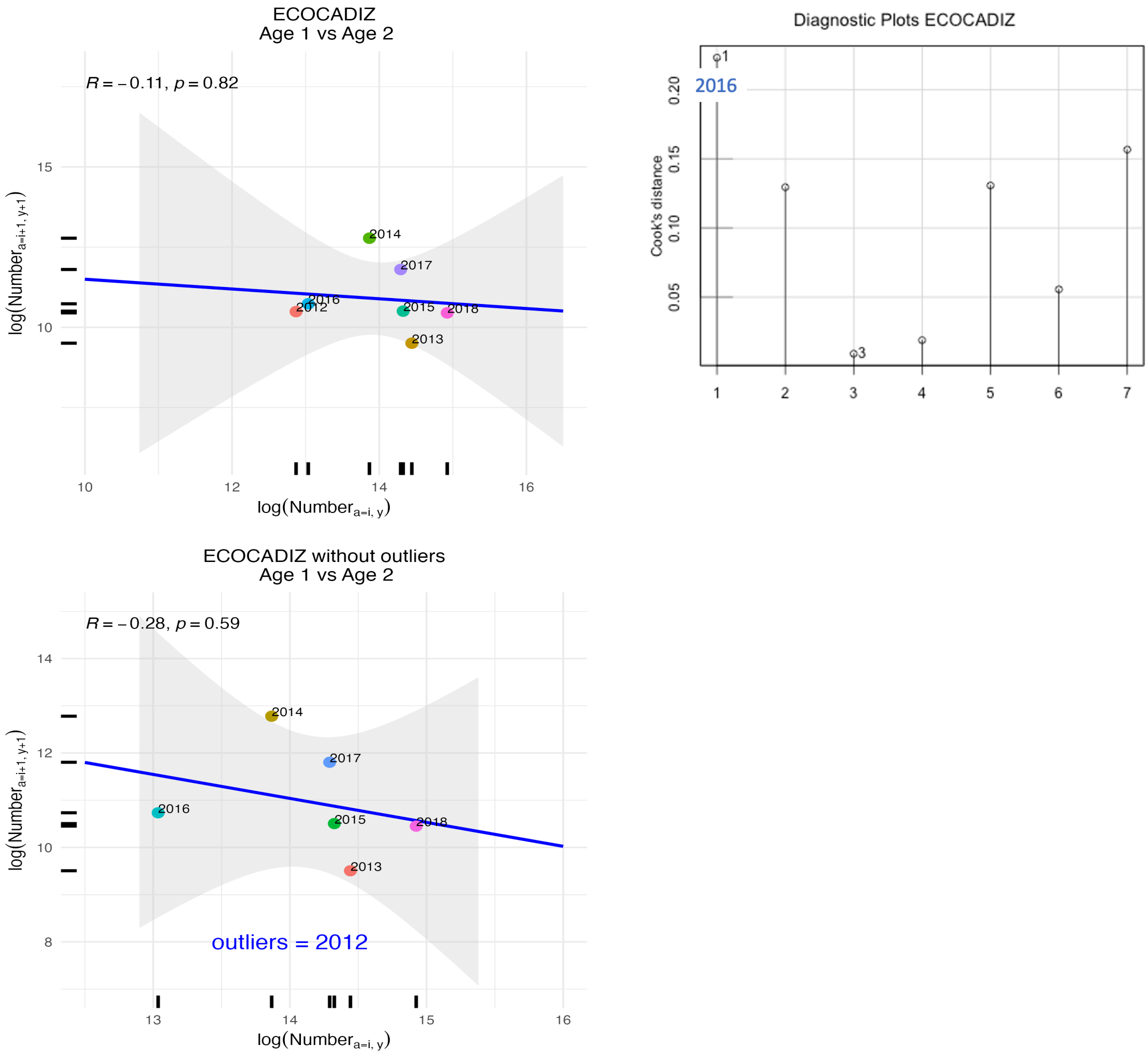


Figure 11. ane. 27.9a stock. Southern component. *ECOCADIZ* summer survey series between 2010-2023. Correlation of consecutive ages (age-*i* in year-*y* with age-*i* +1 in year-*y*+1) for Age-1 vs Age-2 (top left panel). Cook´s distance for identified outliers (top right panel) and Age-1 vs Age-2 correlation without outliers (bottom left panel).

3.4. Mean length at age and von Bertalanffy growth curves

The absence of age-0 individuals in the *ECOCADIZ* surveys during June 2004 and 2006 aligns with convention, but unexplained absences in July 2007 and 2009 raise concerns. To investigate potential age misclassification effects on mean length at age, growth parameters were computed using the complete dataset, including and excluding the all ages from years 2004-2009 (Figure 12, left panel). The growth parameters estimated using the complete dataset are Linf=37.04 cm and K=0.09 (see Figure 10, right panel), while those computed without the period 2004-2009 are Linf=21.02 cm and K=0.23. The Linf estimate derived from the complete dataset deviates from Bellido's estimates (Linf = 18.95 cm and K = 0.90). However, when data from 2010 onwards is considered, the Linf value is similar to Bellido's estimate. Discrepancies in K estimation may be linked to the t0 estimate .

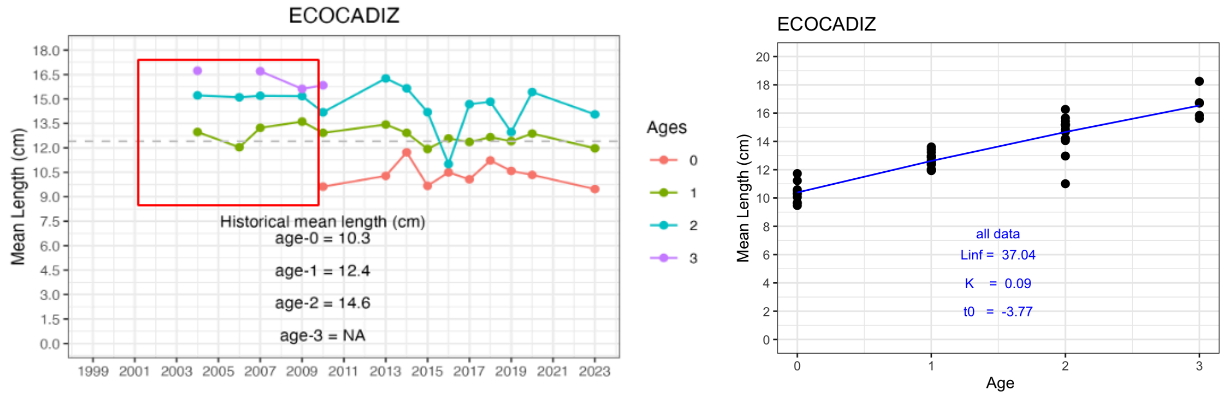


Figure 12. ane. 27.9a stock. Southern component. *ECOCADIZ* summer survey series 2004 - 2023. Left panel: Mean length at age; the red square highlights the period corresponding to years 2004-2009 where no age-0 was observed. Right panel: von Bertalanffy growth curves fitted to the mean length at age.

3.5. Remarks on *ECOCADIZ* age-length data

- At the beginning of the *ECOCADIZ* series, from 2004 to 2009, no age-0 fish were observed, which results in a different pattern for cohort tracking compared to the period from 2010 to 2023.
- Intra-consistency tests for this survey result in low correlations or not correlation at all. Removing outliers did not show any improvement
- If age-length data is used, it is recommended to consider only the 2010-2023 period, due to the earlier years lack of age-0 data. Moreover, the Linf estimate for this period was closer to Bellido's Linf than the one estimated when using the whole data-set.

4. ECOCADIZ-RECLUTAS summer survey data

4.1. Length and age data

The top right panel of Figure 13 shows that in the *ECOCADIZ-RECLUTAS* autumn survey, 85% of the sampled population corresponds to age-0, 14% to age-1 and 1% to age-2. Mean length for age-0 was 10.3 cm and for age-1 was 13.4 cm. The length structure for the age-0 spans from 7 to 13 cm, approximately, except for the year 2012 where age-0 spans from 4.5 to 13 cm. This difference in length range could be related to the fact that in that year the survey was performed only in Spanish waters of the Gulf of Cádiz (Figure 13, left panel).

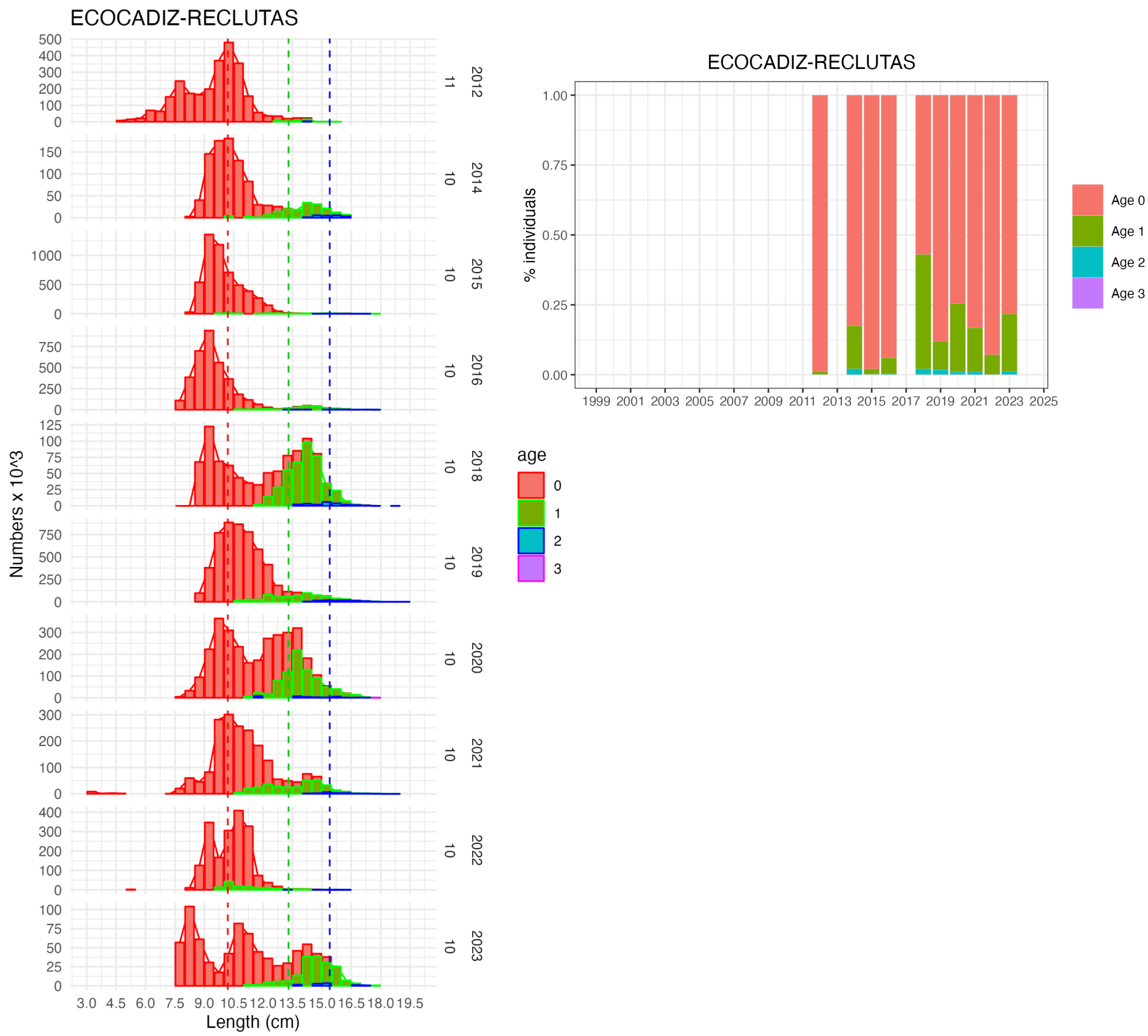


Figure 13. ane. 27.9a stock. Southern component. *ECOCADIZ-RECLUTAS* fall survey series 2012 - 2023. Left panel: Length at age structure. Red, green and blue lines represent the historical mean length for age-0: 10.2 cm, age-1: 13.3 cm and age-2: 15.4 cm, respectively. Top right panel: Age proportion by year.

4.2. Cohort tracking analysis

The Figure 14 shows a consistent cohort tracking with higher abundances at age-0 decreasing reasonably until age-2. Except for the 2018 cohort, where the abundance of age-0 (year 2018) is lower than the abundance of age-1 (year 2019).

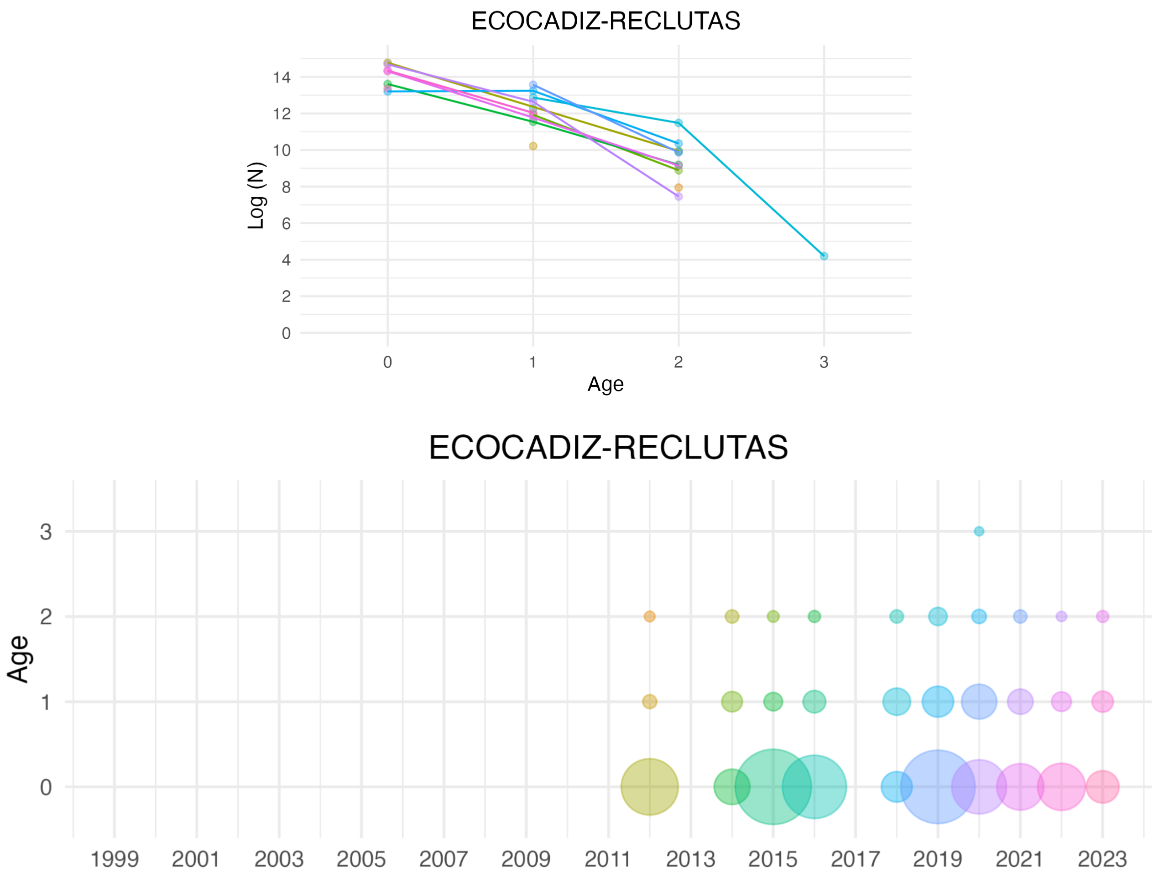


Figure 14. ane. 27.9a stock. Southern component. *ECOCADIZ-RECLUTAS* fall survey series 2012 - 2023. Cohort tracking (Log number) by age.

4.3. Intra-consistency analysis

The analysis shows a lack of correlation (R=0.22, p=0.64) between age-0 and age-1 individuals in consecutive years (age-0 in year-y with age-1 in year-y+1, as seen in Figure 15, left panel). The identified outliers were the cohorts of 2018 and 2019. After excluding these outliers (2018 and 2019 cohorts, as shown in Figure 15 right panel) from the analysis, the Pearson correlation was higher and more significant (R=0.72, p=0.17, as depicted in the bottom left panel of Figure 15).

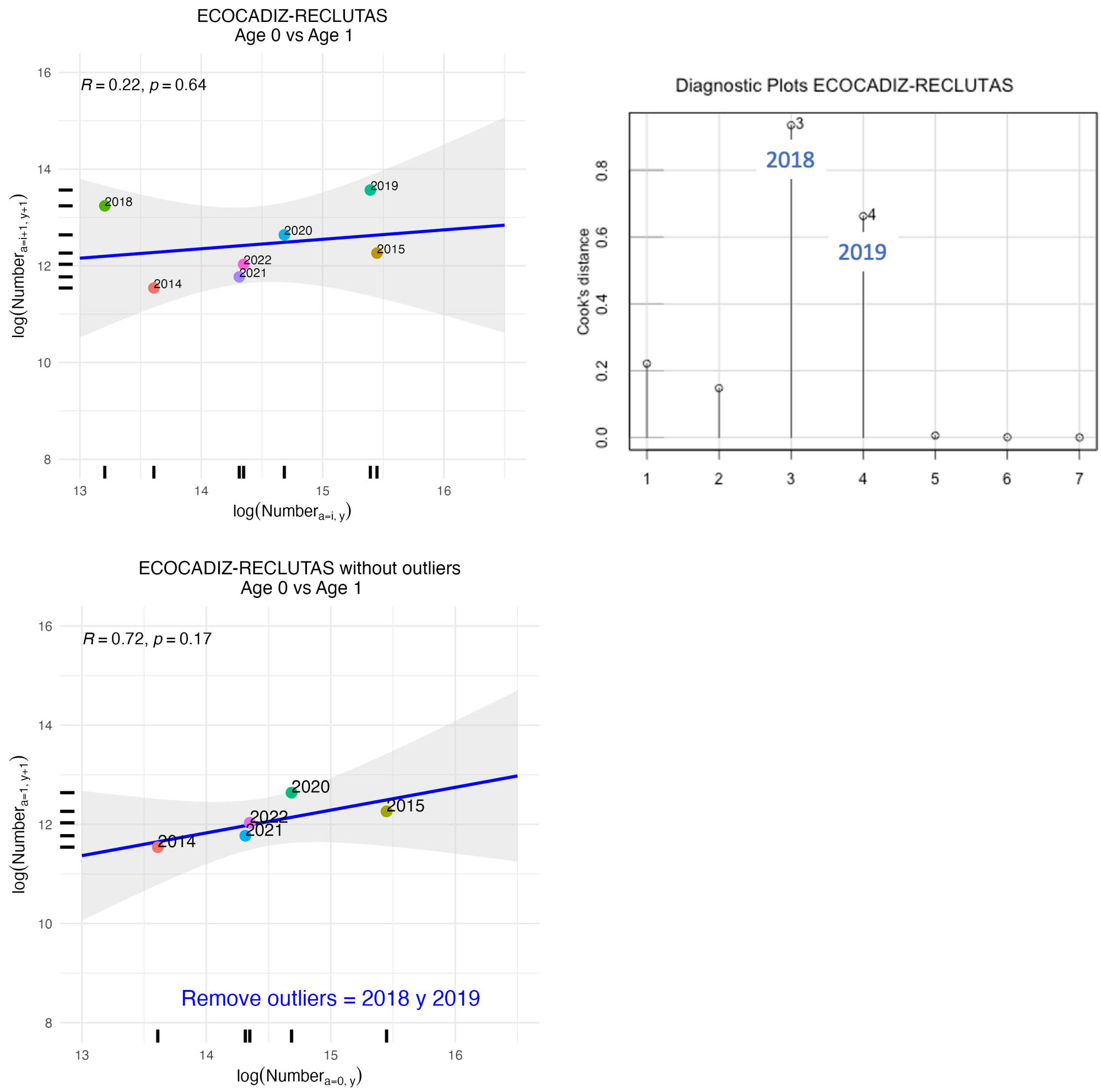


Figure 15. ane. 27.9a stock. Southern component. *ECOCADIZ-RECLUTAS* fall survey series between 2012-2023. Correlation of consecutive ages (age-*i* in year-*y* with age-*i* +1 in year-*y*+1) for Age-0 vs Age-1 (top left panel). Cook´s distance for identified outliers (top right panel) and Age-0 vs Age-1 correlation without outliers (bottom left panel).

The analysis indicates a positive correlation between age-1 and age-2 individuals in consecutive years (R=0.41, p=0.37). The cohort 2020 was identified as an outlier. After removing this outlier from the analysis, the Pearson correlation results in a higher magnitude and increased significance (R=0.65, p=0.16) (Figure 16).

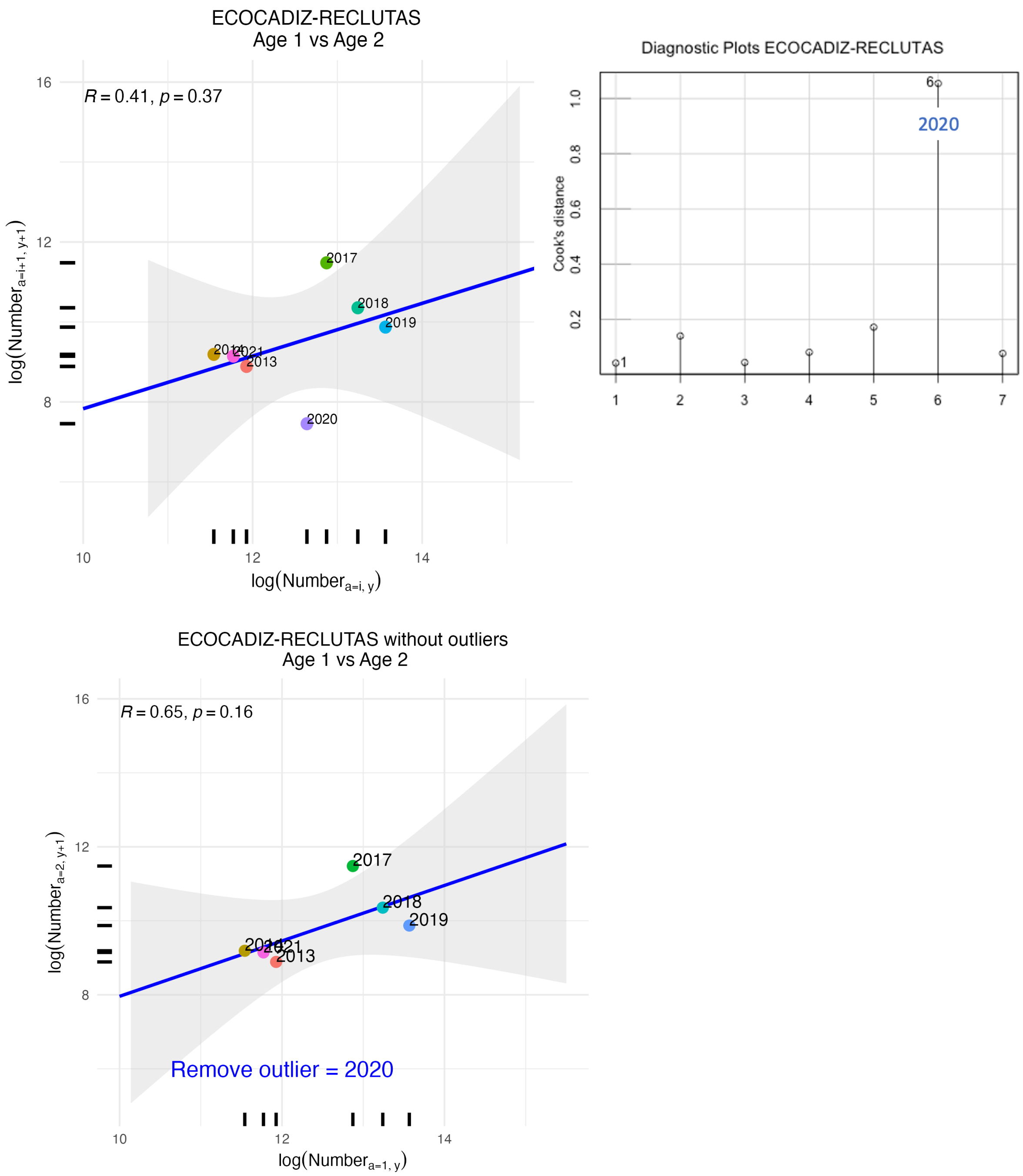


Figure 16. ane. 27.9a stock. Southern component. *ECOCADIZ-RECLUTAS* fall survey series between 2012-2023. Correlation of consecutive ages (age-*i* in year-*y* with age-*i* +1 in year-*y*+1) for Age-1 vs Age-2 (top left panel). Cook´s distance for identified outliers (top right panel) and Age-1 vs Age-2 correlation without outliers (bottom left panel).

4.4. Mean length at age and von Bertalanffy growth curves

To determine if the outliers identified previously may arise from age misclassification impacting mean length at age, growth parameters were computed using the entire dataset and also with outliers removed, specifically focusing on cohorts from 2018 and 2020 (with age-0 individuals in 2018, age-1 individuals in 2019 and 2021, and age-2 individuals in 2022, Figure 17, left panel). When considering the complete dataset, the estimated growth parameters are Linf=19.29, K=0.42, and t0=-1.83, while without outliers, they are Linf=20.41, K=0.35, and t0=-1.97. The Linf estimates align with those reported by Bellido et al. (2000) (Linf = 18.95 cm and K = 0.90) using both the complete dataset and the dataset without outliers. Discrepancies in the estimation of K may be attributed to variations in the t0 estimate (see Figure 17, right panel).

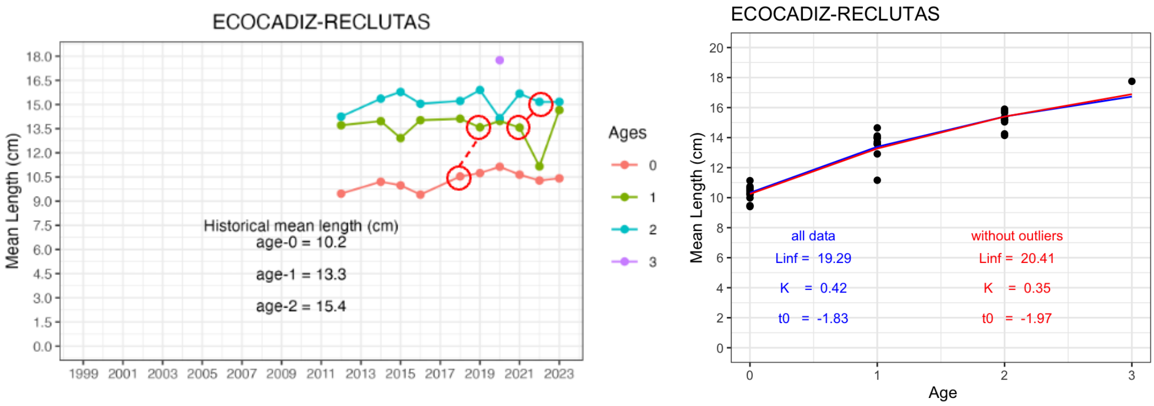


Figure 17. ane. 27.9a stock. Southern component. *ECOCADIZ-RECLUTAS* fall survey series. Left panel: Mean length at age from 2012 to 2023, the red circles joined by dashed lines correspond to the outliers identified, cohort 2018 and 2020. Right panel: von Bertalanffy growth curves fitted to the mean length at age (right panel).

4.5. Remarks on *ECOCADIZ-RECLUTAS* age-length data

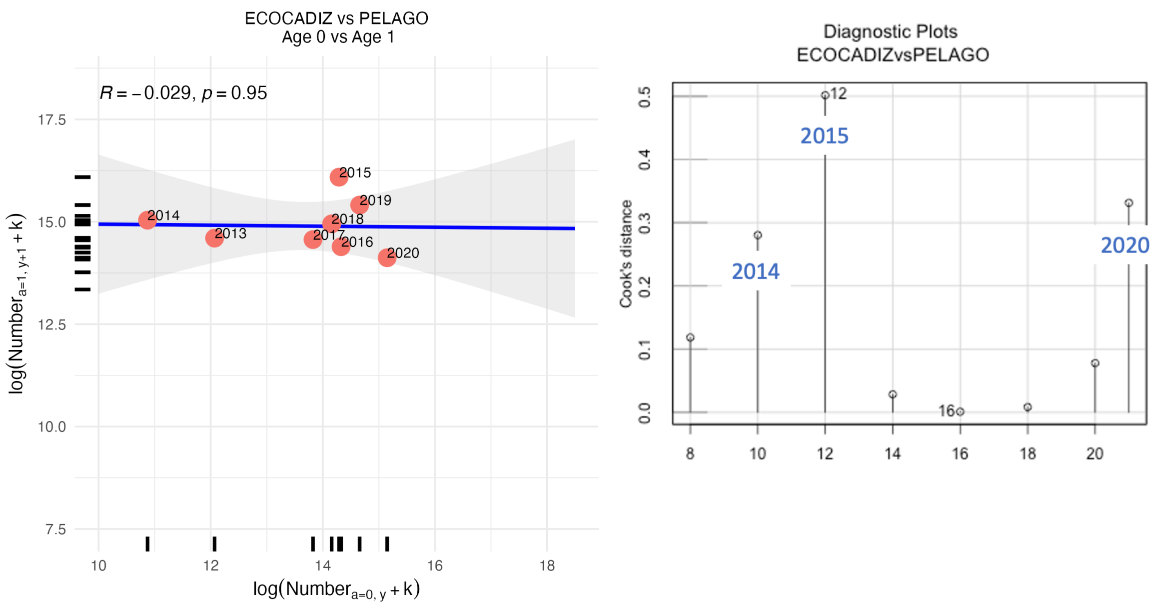
- 85% of the sampled population corresponds to age-0 (juvenile stock).
- There is a consistent cohort tracking with higher abundances at age-0 decreasing reasonably until age-2.
- There is a positive correlation between age-0 and age-1, and between age-1 and age-2 in consecutive years, which is more significant when outliers are removed.
- When computing Linf with the data set without outliers it is very similar to the one estimated with the whole data set.
- Growth pattern with the whole data set is consistent. It is recommended to use the whole dataset as an indicator of the juvenile population.

5. Inter-consistency

Regarding *ECOCADIZ* and *PELAGO* inter-consistency, a positive but not significant correlation between age-0 from *ECOCADIZ* and age-1 from *PELAGO* was observed (R=-0.029, p=0.95, see Figure 18 top left panel). After removing the outliers, no improvement was observed and the significance value was still very high (p almost 0.5) (R=0.43, p=0.47, see Figure 18, bottom panel).

Nevertheless, that is not the case for inter-consistency between age-0 from *ECOCADIZ-RECLUTAS* and age-1 from *PELAGO*, where the correlation coefficient and significance value improve when removing the outliers corresponding to years 2014, 2015 and 2018, going from R=0.18 and p=0.64 to R=0.52 and p=0.29, as can be observed in Figure 19.

There is a positive correlation between age-0 for *ECOCADIZ-RECLUTAS* and age-1 for *ECOCADIZ* when removing the outlier corresponding to year 2018, but the p-value is very high (p> 0.5) (R=0.16, p=0.8) (Figure 20).



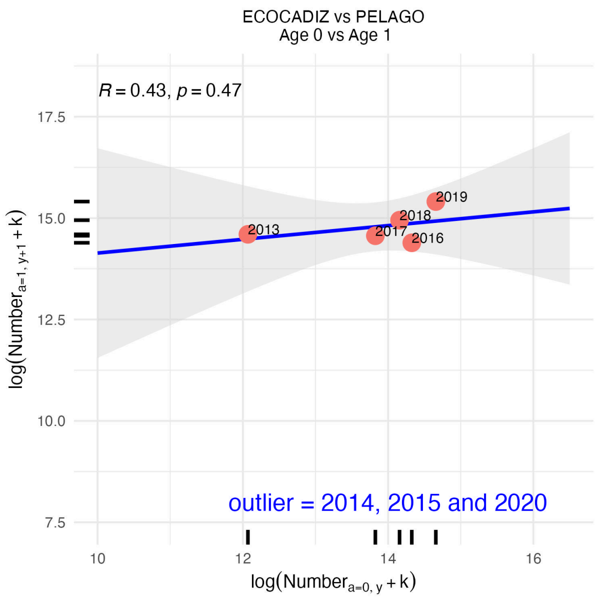


Figure 18. ane. 27.9a stock. Southern component. Correlation of the abundance of anchovy between the *ECOCADIZ* vs *PELAGO* surveys (top left panel) and Cook´s distance for identified outliers (top right panel) and the same correlation without outliers (bottom left panel).

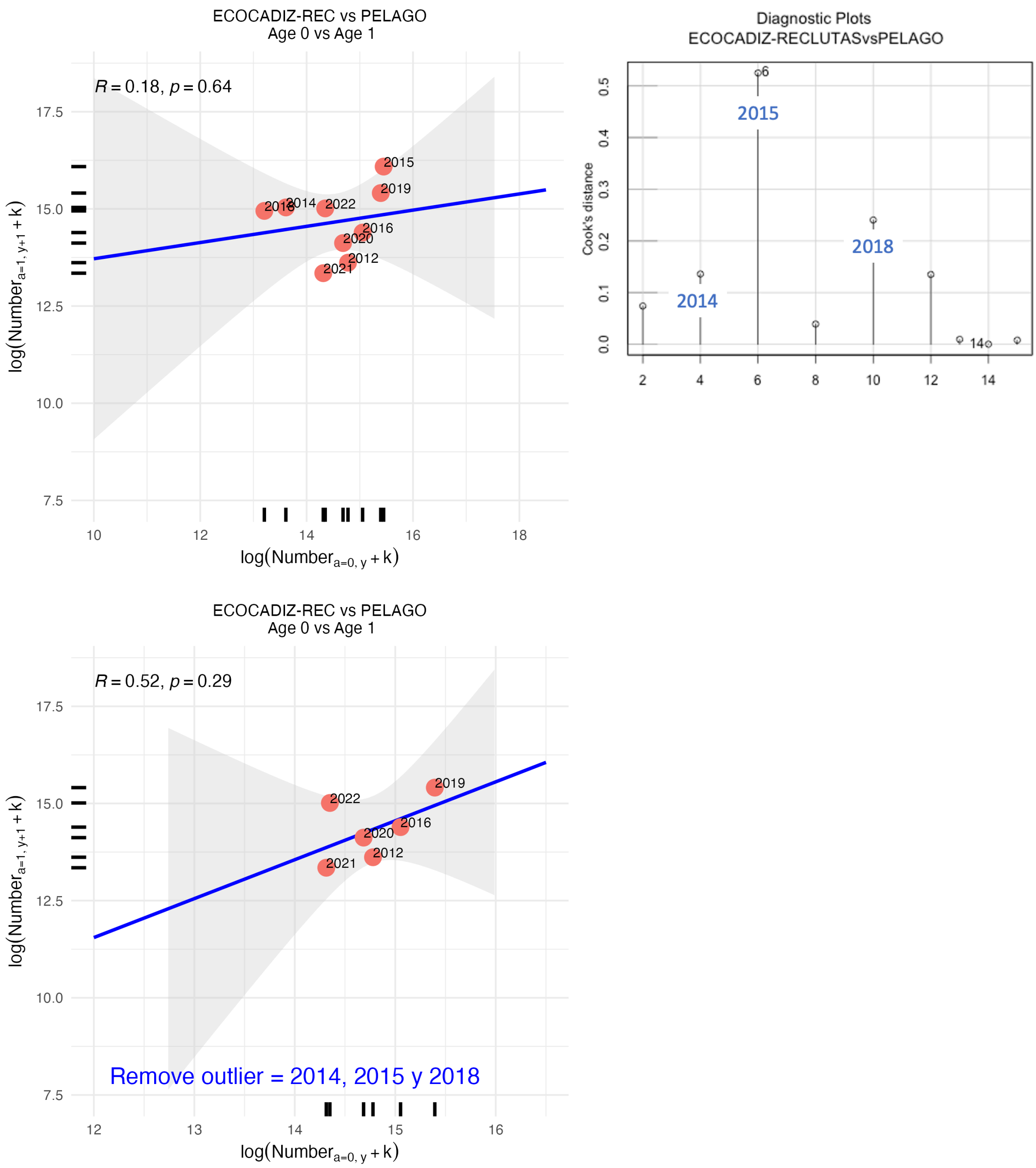


Figure 19. ane. 27.9a stock. Southern component. Correlation of the abundance of anchovy between the *ECOCADIZ-RECLUTAS* vs *PELAGO* surveys (top left panel) and the Cook´s distance for identified outliers (top right panel) and the same correlation without outliers (bottom left panel).

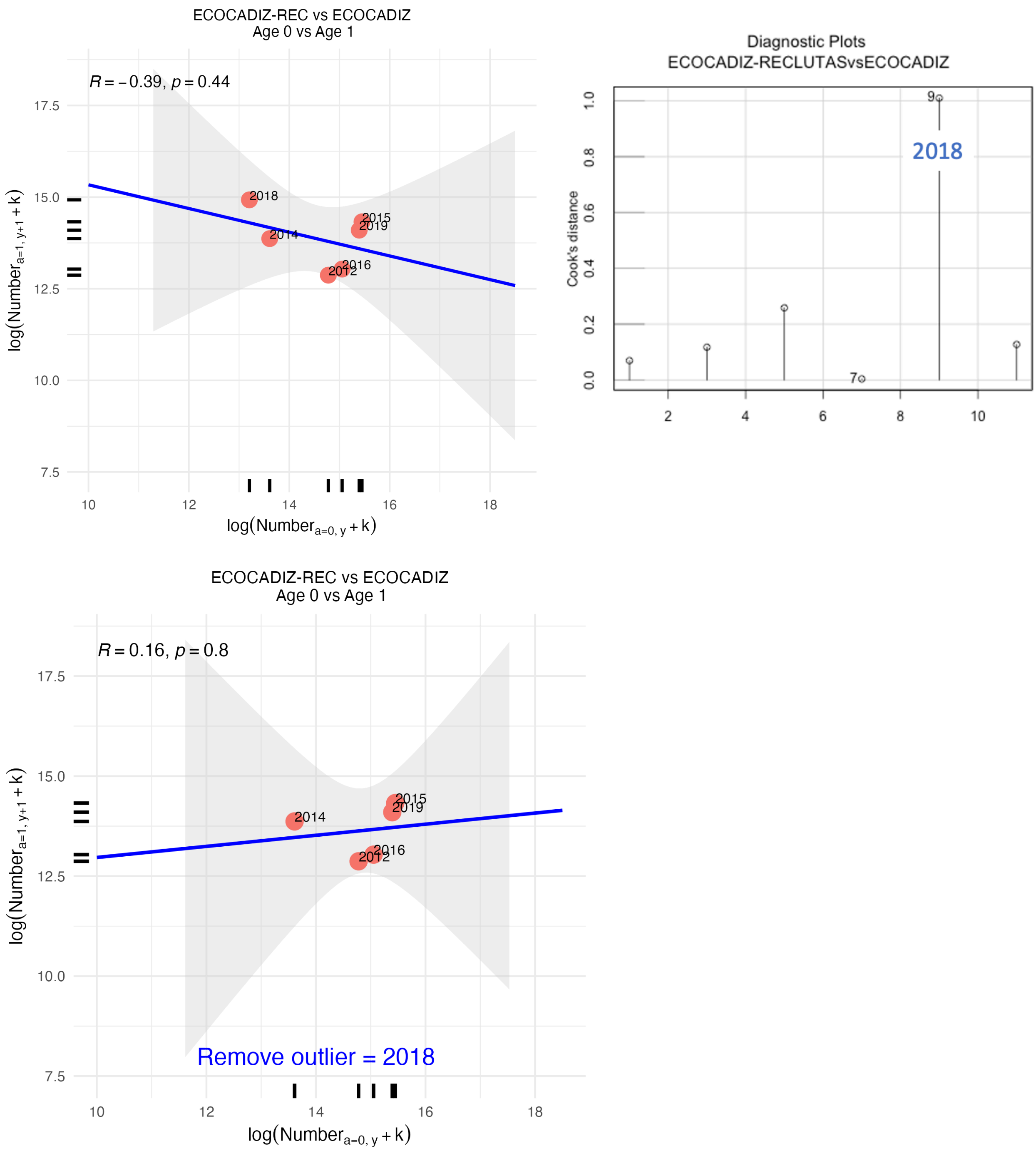


Figure 20. ane. 27.9a stock. Southern component. Correlation of the abundance of anchovy between the *ECOCADIZ-RECLUTAS* vs *ECOCADIZ* surveys (top left panel) and the Cook´s distance for identified outliers (top right panel) and the same correlation without outliers (bottom left panel).

Inter-consistency analysis between *PELAGO* and *ECOCADIZ* surveys for the same age and year results in a positive correlation. Specifically, a positive correlation of R=0.56 (p=0.059) is observed for age-1 in both surveys (top left panel, Figure 20). The inter-consistency analysis between *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys conducted during same year, results in a positive correlation of R=0.53 (p=0.27) between age-0 in *ECOCADIZ* and age-0 in *ECOCADIZ-RECLUTAS* surveys (bottom left panel, Figure 20). However, a lower correlation (R=0.4) is obteined between the age-1 in *ECOCADIZ* and age-1 in *ECOCADIZ-RECLUTAS* surveys conducted in the same year, with a very high p-value of 0.43 (top right panel, Figure 21).

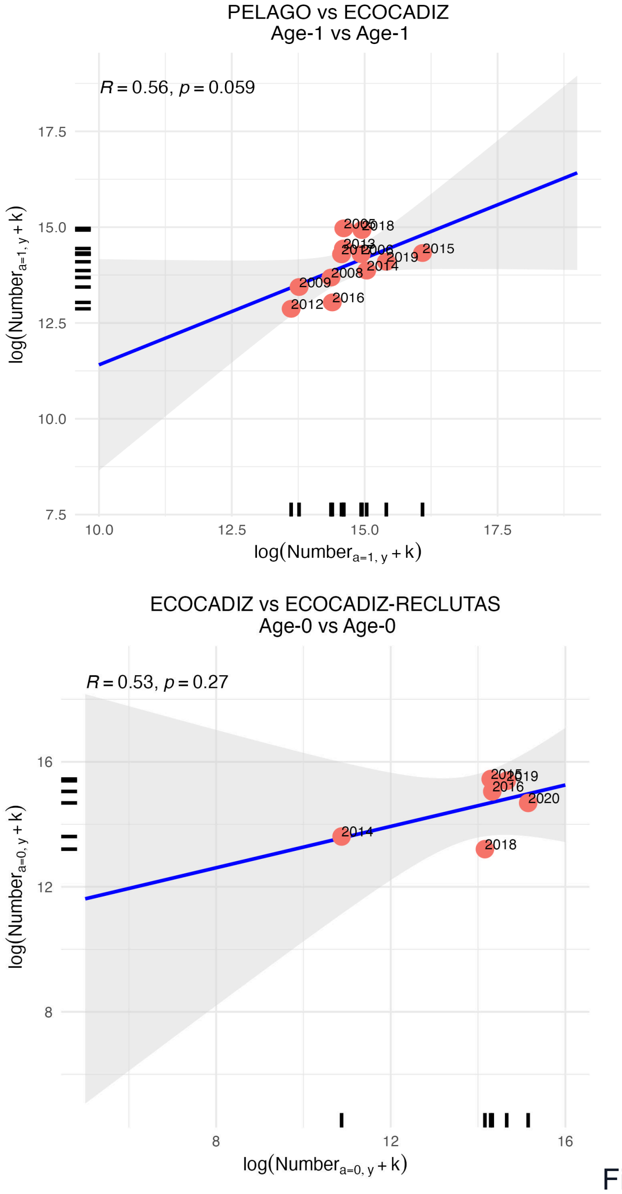


Figure 21. ane. 27.9a stock. Southern component. Correlation of the abundance for the same age and year. *PELAGO* vs *ECOCADIZ* surveys (correlation between age 1 vs age 1: top left panel). *ECOCADIZ* vs *ECOCADIZ-RECLUTAS* surveys (correlation between age 0 vs age 0: bottom left panel). *ECOCADIZ* vs *ECOCADIZ-RECLUTAS* surveys (correlation between age 1 vs age 1: top right panel).

Remarks on inter-consistency

- There is a positive correlation between *ECOCADIZ* and *PELAGO* age-length data when removing cohorts 2014, 2015 and 2020, but significance value is very high (p close to 0.5)(R=0.43, p=0.47).
- There is a higher correlation between *ECOCADIZ-RECLUTAS* and *PELAGO* age-length data when removing cohorts 2014, 2015 and 2018 (R=0.52, p=0.29 compared to R=-0.029, p=0.95).
- There is a higher correlation between *ECOCADIZ-RECLUTAS* and *ECOCADIZ* age-length data when removing outliers but significance value is very high (p> 0.5)(R=0.16, p=0.8).
- A stronger inter-consistency is observed in the abundances of the same age between surveys.
- A stronger positive correlation is evident between the abundances of the same age in the *PELAGO* and *ECOCADIZ* surveys, with a correlation coefficient of R=0.56 and a p-value of 0.059 for the comparison between age 1 in both surveys.
- Additionally, a positive correlation is recorded with R=0.53 and p=0.27 between age-0 in the *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys.
- In the comparison of age-1 between the *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys, a lower correlation is observed with R=0.4 with a high p-value of 0.43.

General conclusions

- *PELAGO* spring survey
    - There is a positive correlation between age-1 and age-2 in consecutive years, which is more significant when outliers are removed. When computing growth parameters with the data set without outliers they are very similar to those estimated with the whole data set. Growth pattern with the whole data set is consistent.
    - It is recommended to use the whole data set as an indicator of the adult population.

- *ECOCADIZ* summer survey
    - Intra-consistency tests for this survey result in low correlations or not correlation at all.
    - The inter-consistency analysis shows there is a positive correlation between *ECOCADIZ* and *PELAGO* age-length data when removing outliers, but significance value is very high. A stronger positive correlation is evident between the abundances of the same age in the *PELAGO* and *ECOCADIZ* surveys.
    - If age-length data is used, it is recommended to consider only the 2010-2023 period, due to the earlier years lack of age-0 data. Moreover, Linf estimate for this period was closer to Bellido's Linf than the one estimated when using the whole data-set.

- *ECOCADIZ-RECLUTAS* fall survey
    - The intra-consistency shows a positive correlation which is more significant when outliers are removed.
    - Growth pattern with the whole data set is consistent.
    - The inter-consistency analysis shows a higher correlation between *ECOCADIZ-RECLUTAS* vs *PELAGO* and *ECOCADIZ-RECLUTAS* vs *ECOCADIZ* age-length data when removing outliers, but significance value is very high. A positive correlation is recorded between age-0 in the *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys.
    - It is recommended to use the whole data set as an indicator of the juvenile population.

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Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)

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Fish body weight is essential for converting modeled numbers-at-age into metrics such as total catch biomass or a biomass-based abundance index (Methot and Wetzel, 2013). Stock Synthesis (SS3) uses a file called `"wtatage.ss"` to incorporate empirical weight-at-age observations (SS3, Methot *et al.*, 2024). For anchovy in the Gulf of Cádiz, mean weight by age data is available from - The commercial fleet (*SEINE*): Figure 1)

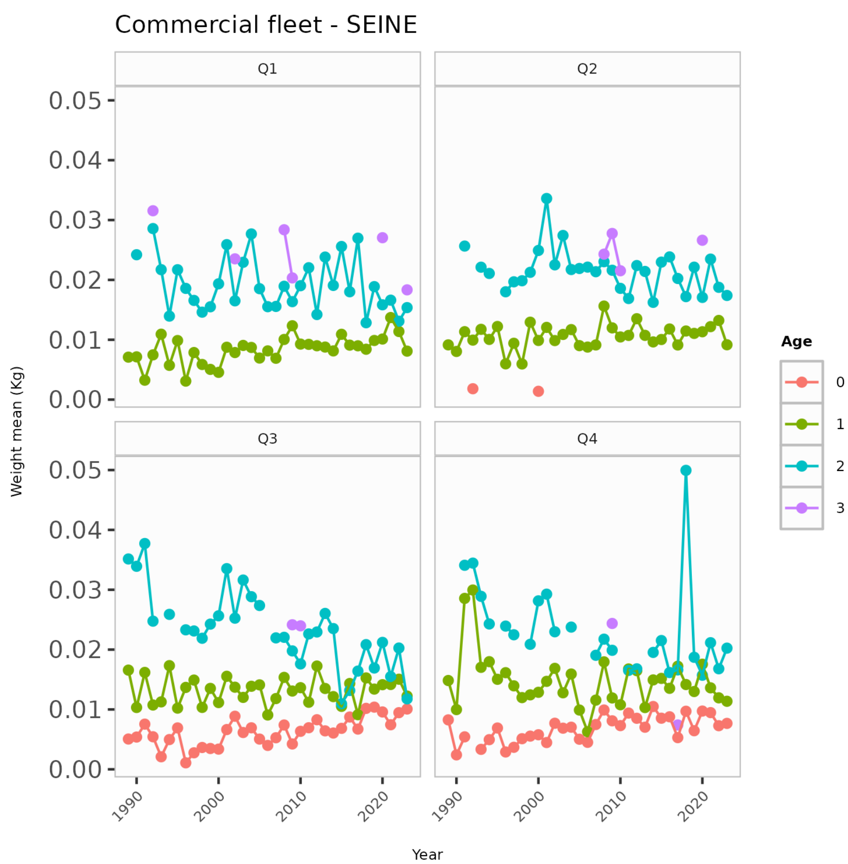

Figure 1: ane.27.9a stock. Observed mean weights (in kilograms) for commercial fleet (*SEINE*) by age group (0 to 3 years) for four quarters (Q1, Q2, Q3, Q4) over the period 1989 to 2024.

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- Three acoustic surveys (*PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS*: Figure 2).

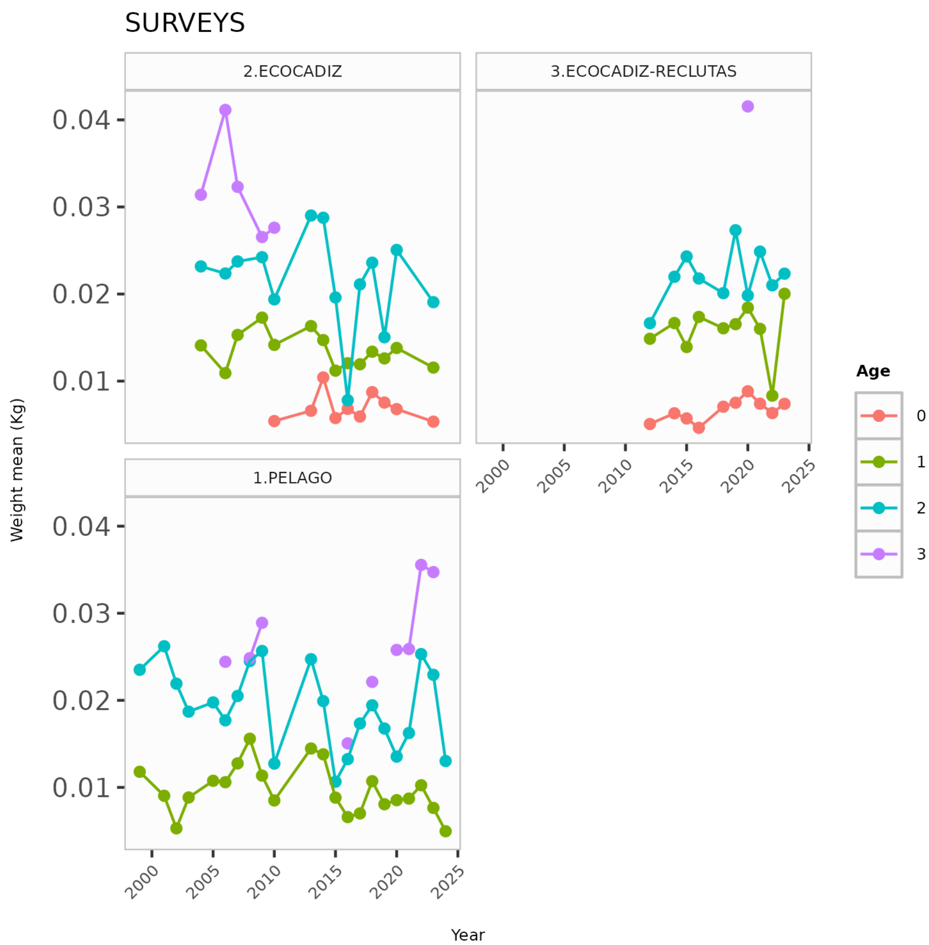

Figure 2: ane.27.9a stock. Observed mean weights (in kilograms) for acoustic surveys (*PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS*) by age group (0 to 3 years).

Out-of-range values were removed based on specific criteria:

- Weights below 15 grams for ages 2 and 3.
- Age 0 individuals were removed in quarters 1 and 2.
- Weights less than or equal to 2 grams across all quarters.
- Weights above 40 grams were discarded.
- Weights below 20 grams for age 3 in quarter 4.

This procedure was applied to each dataset prior to merging them into a single unified dataset (Taylor *et al.*, 2014). Missing values were removed, and weight was transformed using the natural logarithm. In order to account for both fixed and random variability in the data, for each quarter and each subset, a linear mixed model was fitted, with log-transformed weight as the dependent variable and age as the fixed effect. Additionally, a random effect for year was incorporated to capture interannual variability. Estimated datasets were generated for combinations of year (1989–2024) and age (0–3), and log-transformed weight estimates were calculated accordingly as can be seen in Figure 3, where the resulting estimates are presented compared to observed values for each quarter.

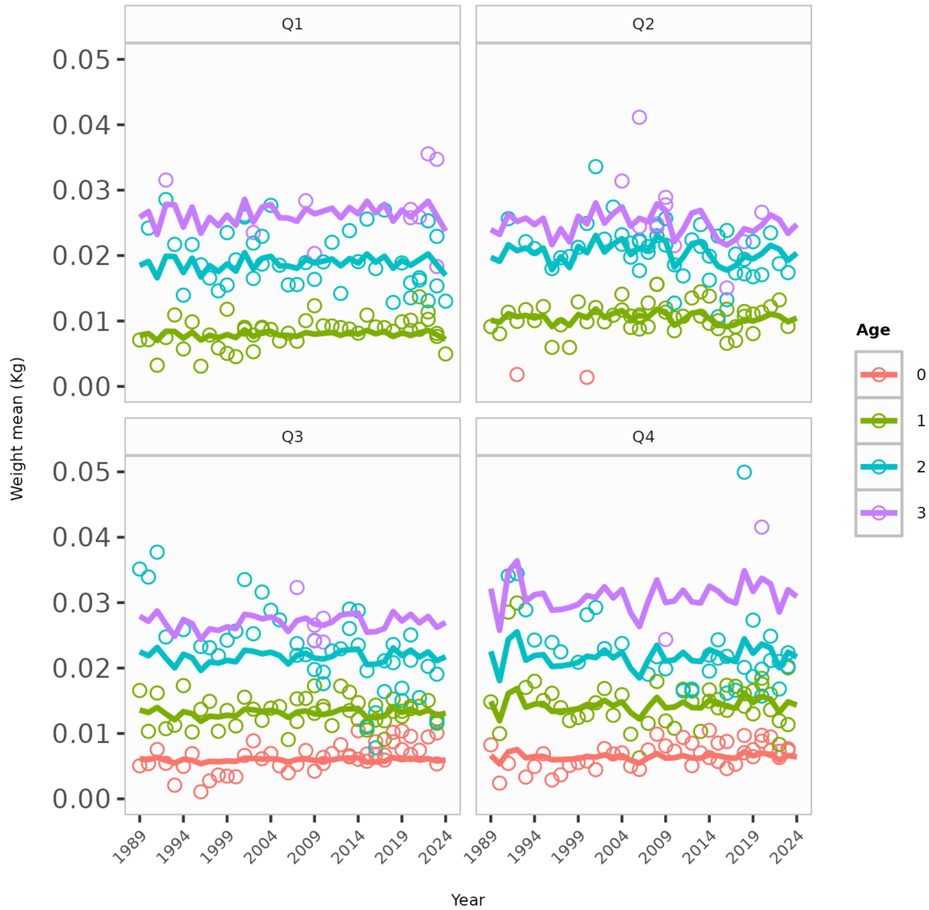

Figure 3: ane.27.9a stock. Observed and predicted mean weights (in kilograms) by age group (0 to 3 years) for four quarters (Q1, Q2, Q3, Q4) over the period 1989 to 2024. Circles represent observed data points, while solid lines indicate estimates from the linear mixed-effects model. Each panel corresponds to a specific quarter. Data were obtained from the commercial fleet (SEINE) and acoustic surveys (*PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS*).

The mean weights estimates from the linear mixed-effects model were used to populate the `"wtatage.ss"` file, which requires mean weight data for ages 0 to 3, covering the period 1989-2023. These weights were specified for both the beginning and mid-point of each quarter and are used for all data sets included in the model.

Nonlinear mixed-effects models were implemented using the nlme R package, version 3.1-164 (Lindstrom and Bates, 1990; Pinheiro and Bates, 1996; Pinheiro and Bates, 2002).

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Growth and natural Mortality parameters estimation for anchovy 9a South, 2024

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Growth parameters estimation

The description of the estimation of the growth parameters given below is a summary of the work presented in a manuscript that was already submitted (Rincón et al. submitted).

The parameters L_∞, k, and t_0 were estimated by fitting the Von Bertallanfy Growth Function (VBGF) to the observed length-age data using nonlinear regression and nonlinear mixed-effects techniques. Initially, a nonlinear regression technique was implemented. Two scenarios were explored: in the first, the parameters were estimated independently, while in the second, the parameter t_0 was fixed at zero. Subsequently, a nonlinear mixed-effects (mixed-effects hereafter) model was fitted to the data. Six different scenarios were evaluated, varying the combinations of random effects among the parameters L_∞, k, and t_0.

The estimated parameters and Akaike Information Criterion (AIC) values were used to select the most suitable method framework and scenario for anchovy growth data.

The comparison of parameter estimates and model fit for nonlinear and mixed-effects models is presented in Table 1. That comparison shows that allowing t_0 to be estimated freely by nonlinear models results in a higher estimate of L_∞. In contrast, fixing t_0 results in lower estimates of L_∞ and higher estimates for k. Among these approaches, the mixed-effects model assuming random effects for t_0 and k provides the best fit to the data, as indicated by the lowest AIC value. This suggests that incorporating random effects may effectively capture the variability in the data.

Table 1: Comparison of growth parameter estimates and model fit between nonlinear and nonlinear mixed-effects models. Additionally, the AIC (Akaike Information Criterion) values are provided for each model

method	Random effect	Linf (mm)	k (1/year)	t0 (years)	AIC
Nonlinear free t0	-	427.17	0.10	-1.99	781165
Nonlinear fixed t0	-	149.65	1.34	0	795342
Mixed-effects	t0	226.62	0.31	-1.15	776750
Mixed-effects	k	251.55	0.24	-1.40	777271
Mixed-effects	Linf	274.37	0.20	-1.55	777465
Mixed-effects	t0 and k	199.58	0.46	-0.74	775272
Mixed-effects	t0 and Linf	208.93	0.40	-0.86	775424
Mixed-effects	Linf and k	243.11	0.30	-1.13	775817

Natural mortality estimation

Natural mortality selection is justified by the following arguments:

- The Gislason et al. (2010) method for modelling natural mortality, M, at age as a function of the growth parameters was applied. For that, the length-at-age vector for ages 0-3 years derived from the VBGF was used. The value of the parameters for this function ($L_\infty = 19.95, k = 0.46, t_0 = -0.74$), as explained before, were obtained from Rincón et al. (submitted). The resulting values are presented in Figure 1.

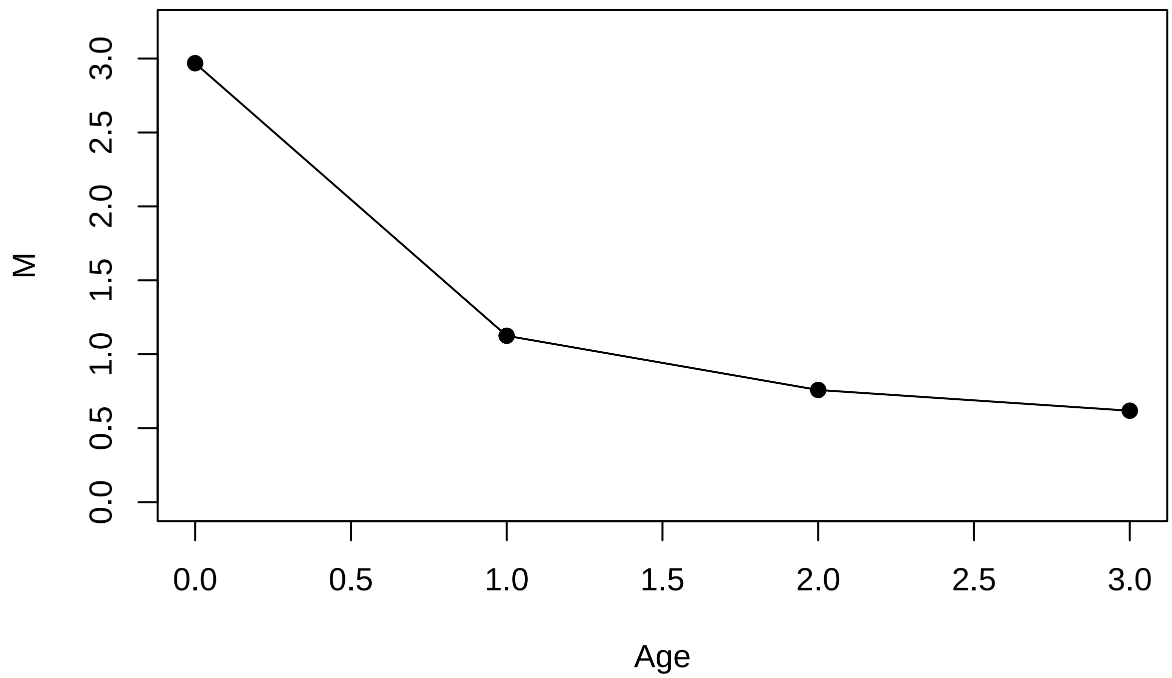

Figure 1: Estimated natural mortality using Gislason et al. (2010) approach, modelling M as a function of the growth parameters

- As anchovy is a short-lived species, Gislason et al. (2010) methodology estimates ($M_0 = 2.97, M_1 = 1.13, M_2 = 0.759$ and $M_3 = 0.618$) were not very accurate for ages 1^+, if we assume that M in older ages may be similar to the one of the Bay of Biscay anchovy. Results from Uriarte et al. (2016) suggest that mortality at these older ages should be higher because senescence might be occurring, in accordance with the expectation of observable senescent mortality affecting short-lived cupleoids (Beverton 1963).

- For the estimation of M_{1^+}, empirical estimates based on life history parameters were calculated. A total of 13 estimators were produced using as input the VBGF parameters from (Rincón et al. submitted) and the maximum age for anchovy in 9a South (Gulf of Cádiz). For the maximum observed age, estimators were calculated assuming age 3 and 4 as the maximum age (Table 2), nevertheless, age 3 was considered adequate because there were only few individuals for age 4 which were considered as outliers (3 and 4 individuals in *ECOCADIZ 2009* and *ECOCADIZ-RECLUTAS 2017* surveys, respectively). The mean value of those estimators following the assumption of age 3 as maximum age, $M = 1.33$, is suggested as the best choice (Table 3).

Table 2: M estimates according to different methods and different maximum age assumptions

method	M.age3	M.age4
tmax1	1.70	1.28
PaulyLNoT	0.87	0.87
HoenigO	1.43	1.08
HoenigOF	1.42	1.06
HoenigO2	1.69	1.24
HoenigLM	1.84	1.37
HoenigNLS	1.79	1.38
HewittHoenig	1.41	1.05
K1	0.78	0.78
K2	0.81	0.81
JensenK1	0.69	0.69
JensenK2	0.89	0.89
AlversonCarney	2.00	1.36

Table 3: Summary for M estimates by maximum age assumptions

	M.age3	M.age4
	Min. :0.690	Min. :0.690
	1st Qu.:0.870	1st Qu.:0.870
	Median :1.420	Median :1.062
	Mean :1.332	Mean :1.066
	3rd Qu.:1.703	3rd Qu.:1.277
	Max. :2.002	Max. :1.376

- As it was done in the 2018 benchmark (ICES 2018), the overall likelihood scores were compared for different implementations changing the value of M but following the same pattern, $M_0 = M+0.9, M_1 = M$ and $M_{2+} = M$, and the results are presented in Figure 2 where it can be observed that the goodness-of-fit remain similar for $1.2 < M < 2.3$.

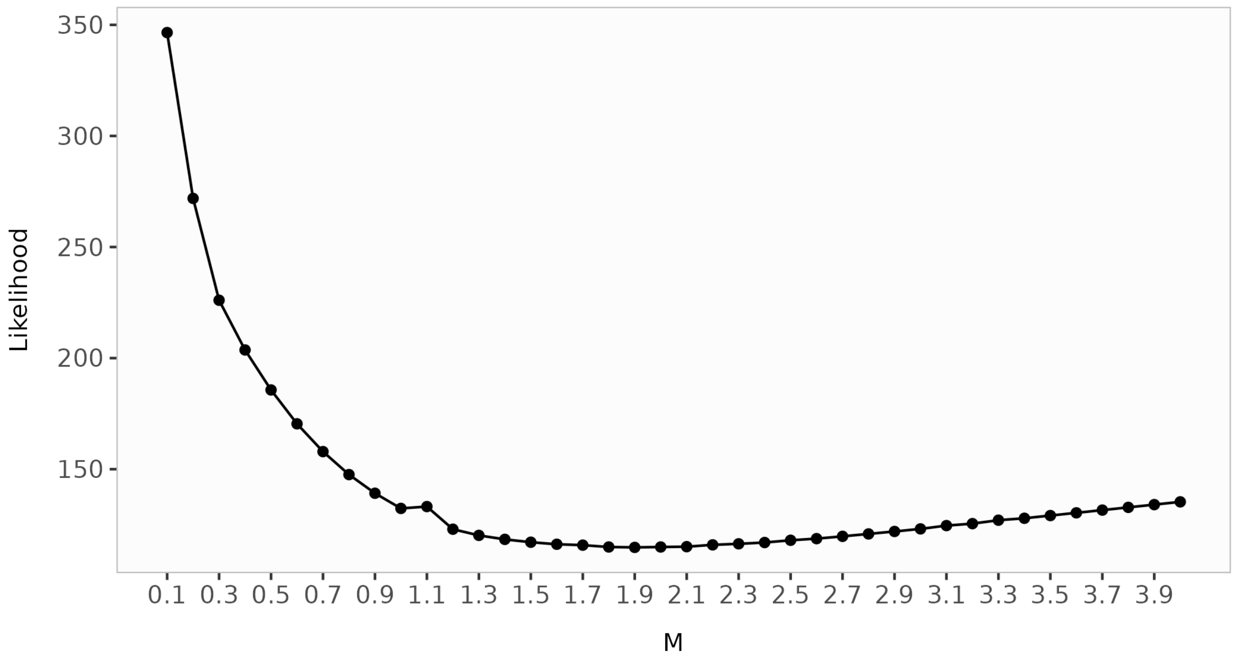

Figure 2:

Figure 2. Comparison of overall likelihood score for model implementations changing the M value, where $M_0 = M + 0.9, M_1 = M$ and $M_2^+ = M$.

- In summary, the following M at age values are recommended for 9a South anchovy: ($M_0 = 2.97, M_1 = 1.33, M_2 = 1.33$ and $M_3 = 1.33$)

Implementation

The Simple Fisheries Stock Assessment Methods FSA R package, version 0.9.5 (Ogle et al. 2023) was used for calculation of M and M at age estimators, as well as for non linear estimation of VBGF parameters.

Additionally, nonlinear mixed-effects models were conditioned through the nmle R package, developed by Pinheiro and Bates (2006), version 3.1-164 Pinheiro and Bates (1996).

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Comparison of Gadget implementations with the same data input as the age-based SS3 model plus length distributions

Margarita María Rincón Hidalgo*

September 10th, 2024

The following are the corresponding model specifications for the results presented in Table 1:

- Models 1 to 3: Model until the end of 2023, including all acoustic surveys information and DEPM surveys estimations, growth parameters fixed.
- Models 4 to 6: Model until the end of 2023, including all acoustic surveys information and DEPM surveys estimations, growth parameters fixed and mortality at age fixed with updated values
- Model 7 to 9: Model until the end of 2023, including all acoustic surveys information and DEPM surveys estimations, growth parameters unfixed.
- Model 10 to 12: Model until the end of 2023, including all acoustic surveys information and DEPM surveys estimations, growth parameters unfixed and mortality at age fixed with updated values.

Table 1: Summary for biomass estimates

model	year	total.biomass	recruitment	likelihoodscore
1	2023	3620944	880579224	12467.46
2	2023	3805788	881313455	11723.17
3	2023	4361354	1183287316	11914.20
4	2023	3249201	1341104444	11820.81
5	2023	3940215	1281851622	11490.39
6	2023	4299340	675976977	12056.30
7	2023	8836439	1772025652	13631.53
8	2023	15990536	3867785156	14021.75
9	2023	12861312	5584252112	13953.40
10	2023	11756288	2198869148	13884.78
11	2023	12684416	3420580428	13562.04
12	2023	13886405	2717473618	14260.36

For each of the groups describe before, the model with better likelihood score were chosen to illustrate how the assumptions affect the results (i.e, models 2, 5, 7 and 11). Thus, hereafter the model numbers for the Figures below correspond to the following description:

- Model 1: Model until the end of 2023, including all acoustic surveys information and DEPM survey estimations, growth parameters fixed.

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- Model 2: Model until the end of 2023, including all acoustic surveys information and DEPM surveys estimations, growth parameters fixed and mortality at age fixed with updated values.
- Model 3: Model until the end of 2023, including all acoustic surveys information and DEPM surveys estimations, growth parameters unfixed.
- Model 4: Model until the end of 2023, including all acoustic surveys information and DEPM surveys estimations, growth parameters unfixed and mortality at age fixed with updated values.

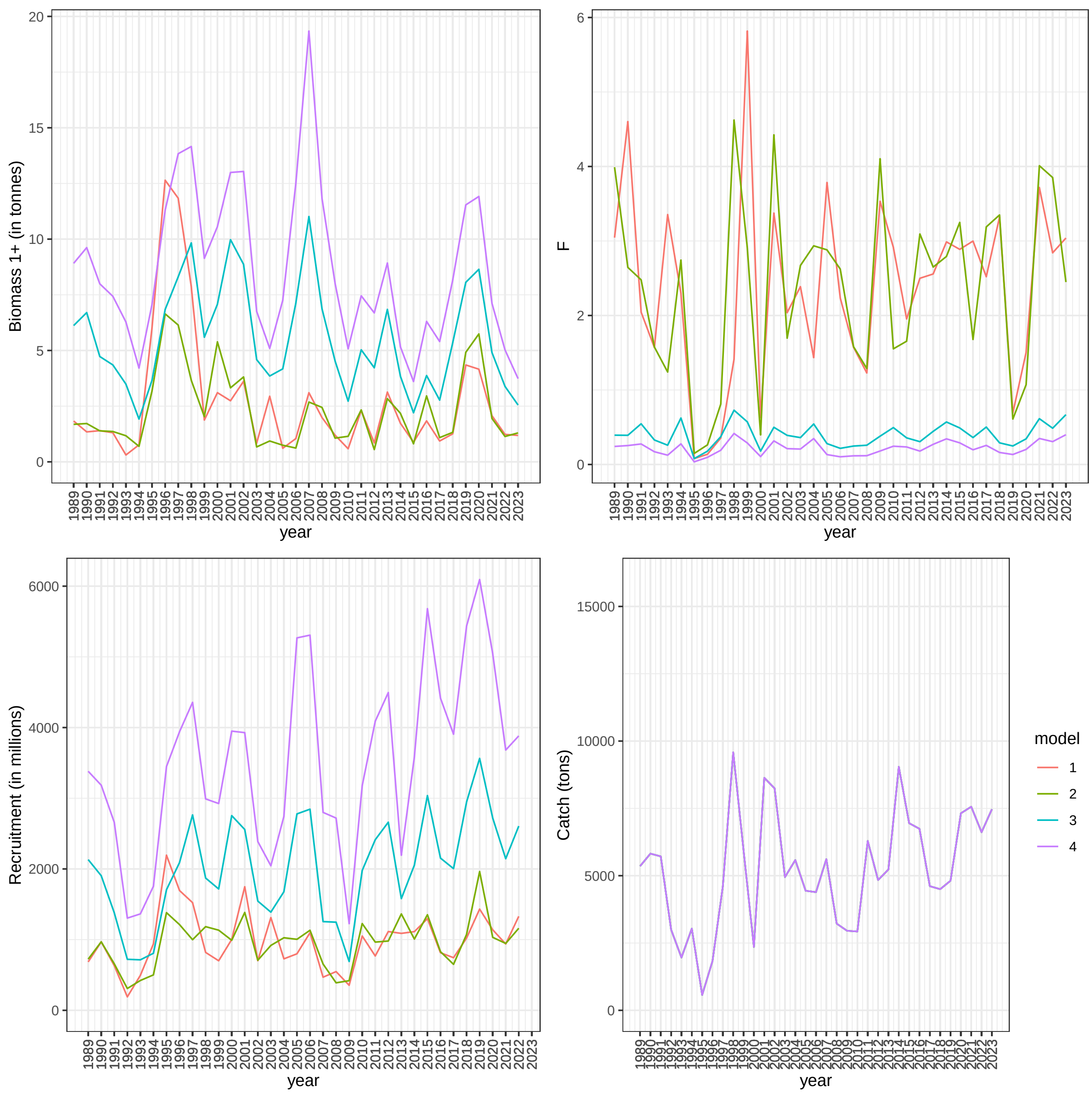

Figure 1. Top and left panel: Absolute values for B_1^+ estimates at the end of the year. Top and right panel: Absolute values for the mean of quarterly F at age 3 for each year. Bottom left panel: Absolute values for recruitment at the end of the year. Bottom right: Observed catches.

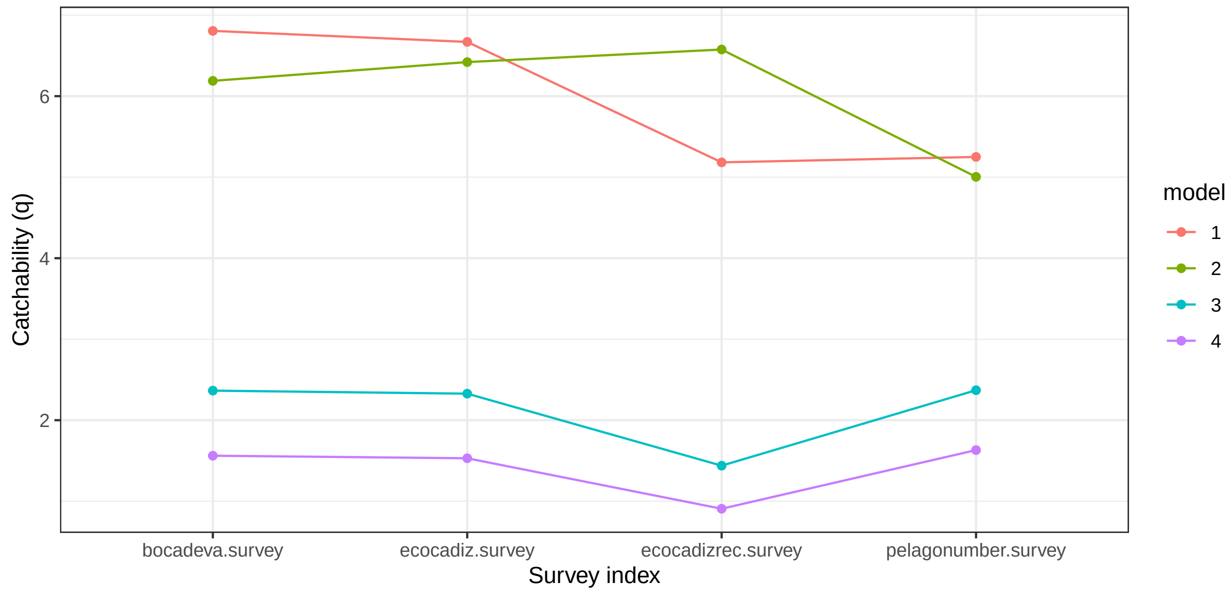

Figure 2. Estimated Catchability for all the surveys by each of the models chosen.

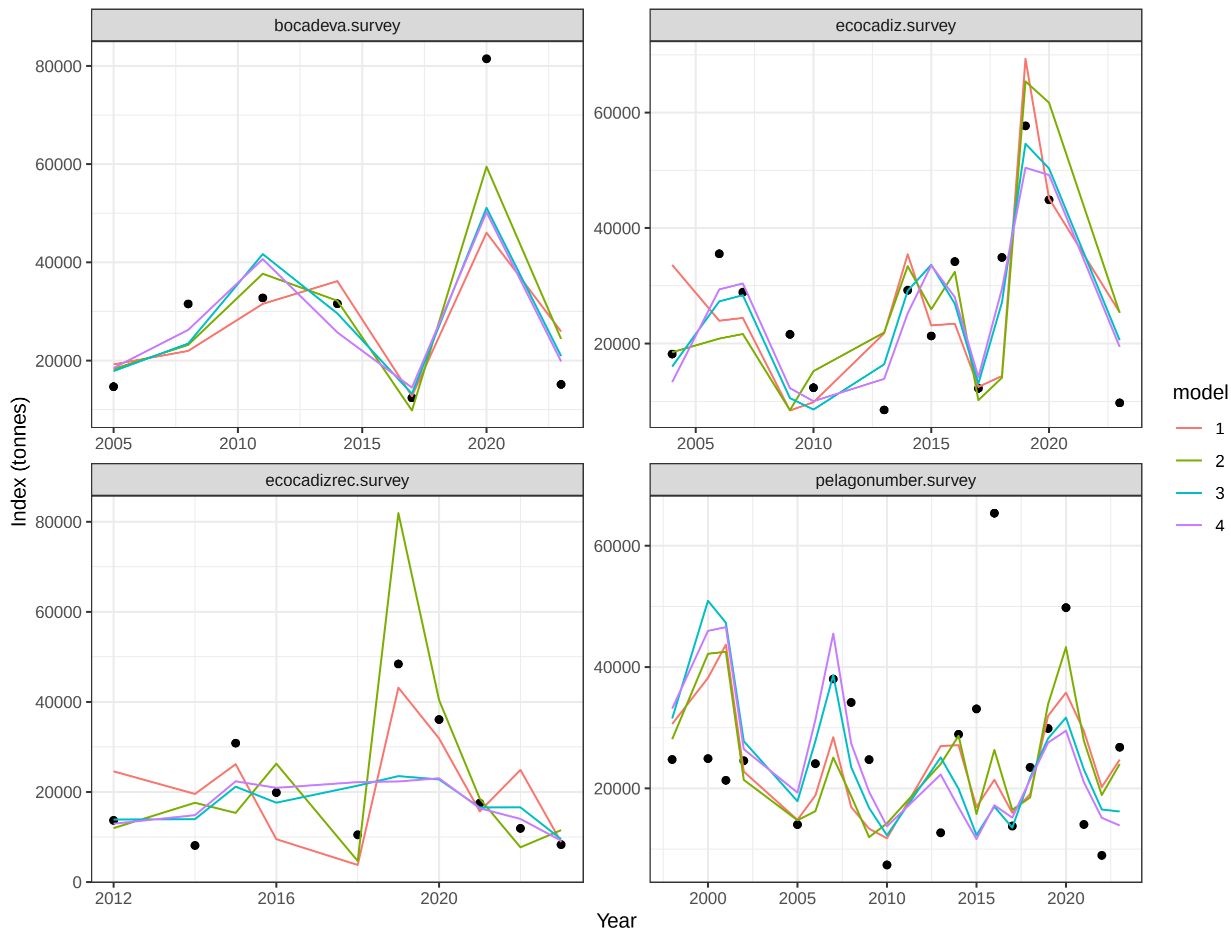

Figure 3. Survey fit by each of the models chosen.

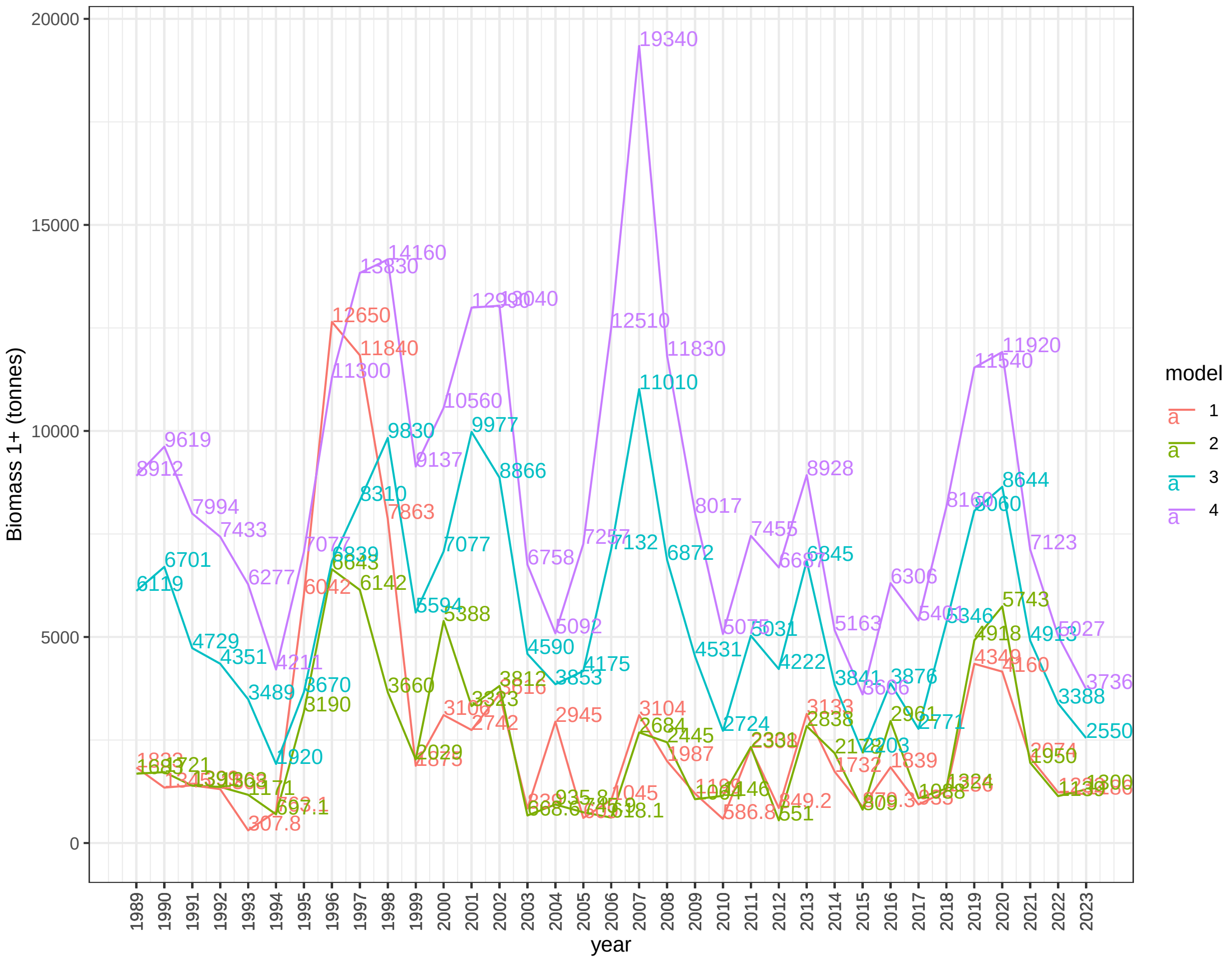

Figure 4. Absolute values for B_1^+ estimates at the end of the year for each of the models chosen.

Table 2: B_1^+ estimates for the last four years in each model

year	B1	model
2020	4160.11	1
2021	2074.40	1
2022	1231.71	1
2023	1185.84	1
2020	5742.61	2
2021	1949.72	2
2022	1138.93	2
2023	1299.61	2
2020	8644.36	3
2021	4912.74	3
2022	3388.09	3
2023	2550.43	3
2020	11916.06	4
2021	7123.25	4
2022	5027.14	4
2023	3736.48	4

Scenario *S1.0_4FLEETS*: Assessment for WKBANSP 2024 using age-structured data in SS3: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)

María José Zúñiga*, Margarita María Rincón†, Fernando Ramos‡

Assessment model

The assessment of the anchovy in ICES division 9a, southern component was performed in Stock Synthesis software, version 3.30.22.1 (SS3, Methot *et al.*, 2024) under the Linux platform. SS3 is a generalized age and/or length-based model that is very flexible with regard to the types of data that may be included, the functional forms that are used for various biological processes, the level of complexity and number of parameters that may be estimated. The model is coded in C++ with parameter estimation enabled by automatic differentiation (www.admb-project.org) and available at the NOAA Fisheries integrated toolbox: https://noaa-fisheries-integrated-toolbox.github.io/SS3. A description and discussion of the model can be found in Methot and Wetzel (2013).

The model is defined quarterly between 1989 and 2023, for one area and it is age-based, where the population is comprised of 3+ age-classes (with age 3 representing a plus group) with sexes combined (male and females are modelled together).

Data

The input data includes total catch (in biomass) and age composition of the catch (in proportion) for the commercial *SEINE* fleet, as well as abundance (in biomass) and age composition from the *PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys. Age composition data from *PELAGO* was included only for the period 2014–2023, when age-length keys were available, as specified by WKPELA 2018. Spawning stock biomass (SSB) estimates are derived from the triennial *BOCADEVA* survey using DEPM. To account for seasonal variability in catches, the *SEINE* fleet has been subdivided into four quarterly fleets.

The Figure 1 provides a visual representation of the input data used in the model, categorized into three main types: catches, abundance indices, and age compositions. These data are displayed over time (years) and are represented by circles, with the size of each circle reflecting the magnitude of the data.

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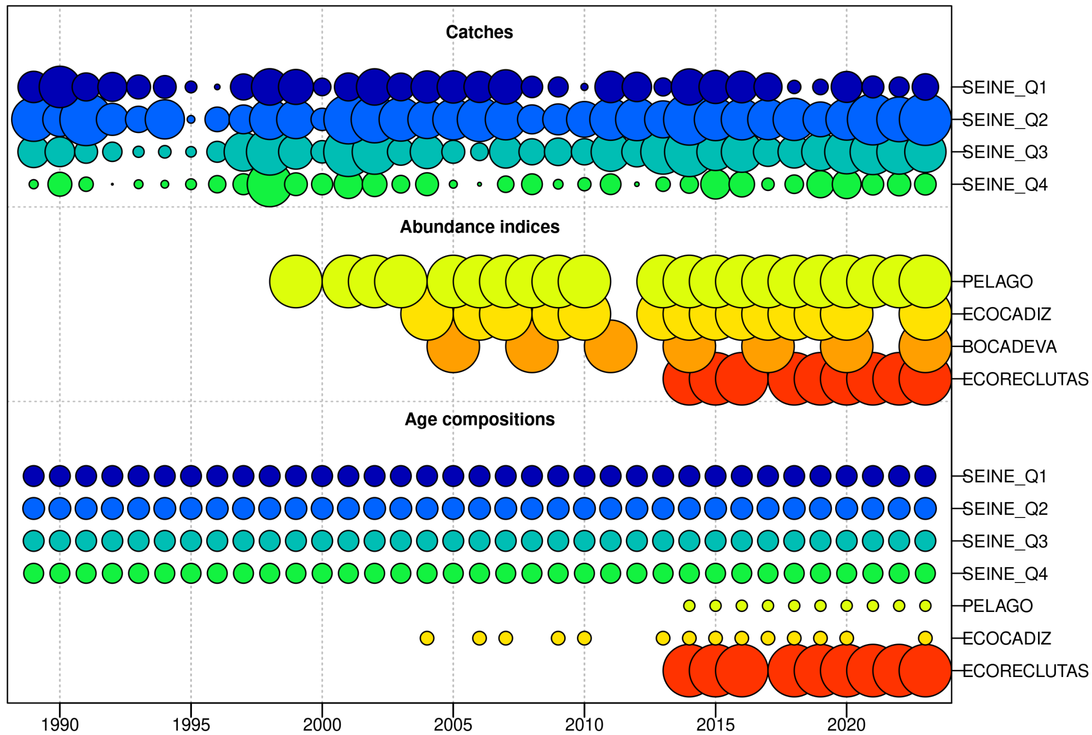

Figure 1: ane.27.9a Southern stock. Summary of model data input by year, where circle area is relative within a data type. Circles are proportional to total catch for catches, to precision for indices and to total sample size for age compositions.

Catches

Anchovy catches in the Gulf of Cádiz exhibit seasonality, with 40.61% concentrated in the second quarter (Q2), averaging 2120.26 tons historically, followed by the third quarter (Q3) with 29.60% (1545.23 tons), the first quarter (Q1) with 19.39% (1012.42 tons), and the fourth quarter (Q4) with 10.39% (542.61 tons). In 2023, first-quarter catches were 7.84% lower than the historical average, while second, third, and fourth-quarter catches increased by 71.03%, 48.06%, and 14.70%, respectively (Figures 2 and 3).

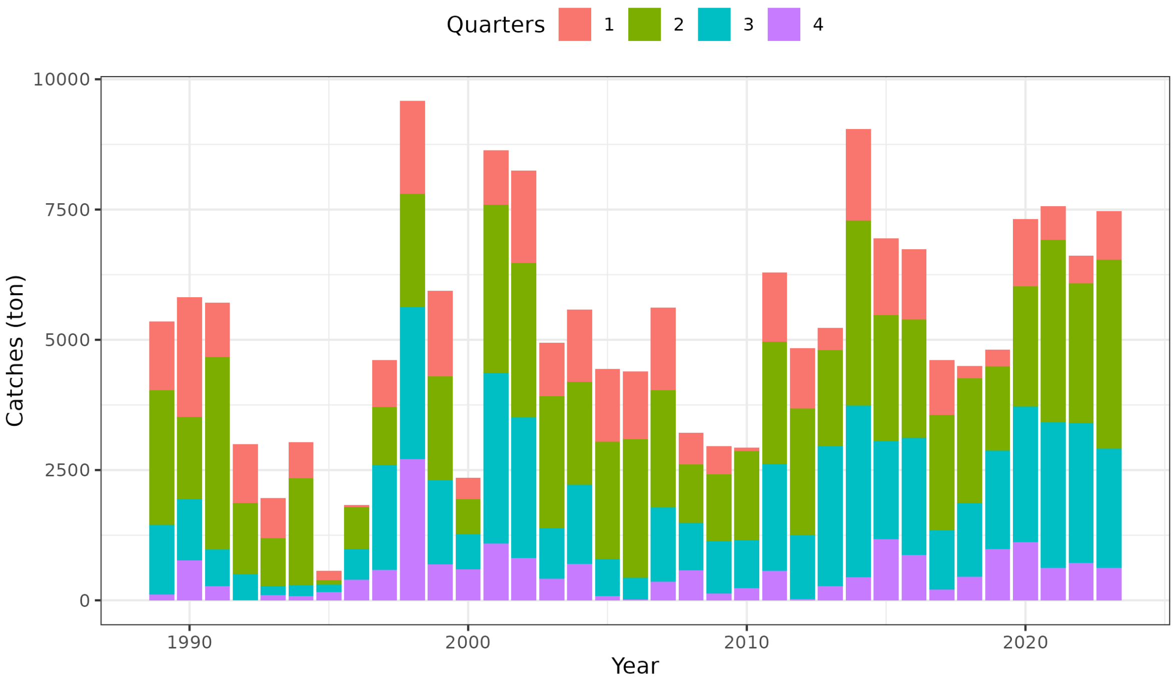

Figure 2: ane.27.9a Southern stock. Time series of quarterly catches.

	Catches (ton)				
Year	Q1	Q2	Q3	Q4	Total
1989	1318	2589	1336	111	5354
1990	2300	1571	1182	765	5818
1991	1049	3693	702	274	5718
1992	1125	1368	500	4	2997
1993	767	921	167	105	1960
1994	690	2055	210	80	3035
1995	185	80	148	157	570
1996	41	807	586	398	1832
1997	908	1110	2007	588	4613
1998	1781	2176	2909	2716	9582
1999	1638	1995	1616	691	5940
2000	412	668	673	600	2353
2001	1046	3227	3275	1089	8637
2002	1772	2957	2699	816	8244
2003	1027	2539	965	416	4947
2004	1384	1976	1522	699	5581
2005	1398	2252	706	85	4441
2006	1297	2657	416	19	4389
2007	1581	2251	1423	361	5616
2008	613	1121	910	576	3220
2009	533	1280	1016	126	2955
2010	67	1709	920	232	2928
2011	1326	2343	2051	571	6291
2012	1159	2433	1220	26	4838
2013	434	1837	2683	277	5231
2014	1754	3553	3300	439	9046
2015	1471	2425	1880	1174	6950
2016	1352	2267	2254	869	6742
2017	1051	2213	1140	206	4610
2018	236	2391	1414	458	4499
2019	322	1621	1889	982	4814
2020	1286	2315	2603	1113	7317
2021	644	3500	2794	623	7561
2022	532	2682	2679	722	6615
2023	933	3626	2288	622	7469

Figure 3: ane.27.9a Southern stock. Time series data of quarterly catches

Abundance indices

The abundance indices *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS* exhibit interannual variability over time (Figure 4). *PELAGO*, with data from 1999 to 2023, shows fluctuations with a peak in 2016 at 65,345 tons, followed by a decline, but with a slight recovery in 2023 to 26,786 tons. *ECOCADIZ*, covering the period from 2004 to 2023, reaches its maximum in 2019 at 57,700 tons, followed by a significant decrease to 9,714 tons in 2023. *BOCADEVA*, with data from 2005 to 2023, shows a steady increase to its peak in 2020 at 81,466 tons, followed by a reduction to 15,138 tons in 2023. *ECOCADIZ-RECLUTAS*, recorded from 2014 to 2023, shows a sustained increase until 2019 at 48,398 tons, followed by a decrease to 8,300 tons in 2023.

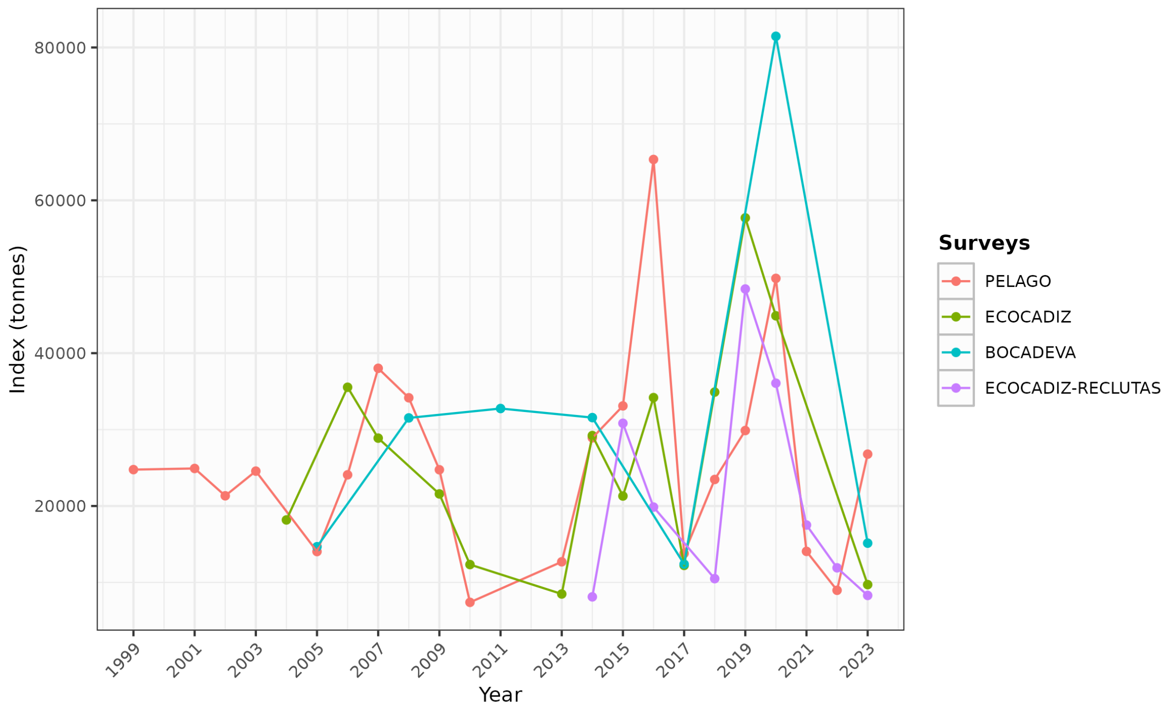

Figure 4: ane.27.9a Southern stock. Biomass estimates from *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS surveys*.

As it can be observed also in the raw data (Figure 5), these patterns reflect a high variability in abundance over time with periods of increase followed by declines in the later years of each series.

Acoustic Biomass (ton) by surveys				
year	PELAGO	ECOCADIZ	BOCADEVA	ECOCADIZ-RECLUTAS
1999	24763			
2001	24913			
2002	21335			
2003	24565			
2004		18177		
2005	14041		14673	
2006	24082	35539		
2007	38020	28882		
2008	34162		31527	
2009	24745	21580		
2010	7395	12339		
2011			32757	
2013	12700	8487		
2014	28917	29219	31569	8113
2015	33100	21305		30827
2016	65345	34184		19861
2017	13797	12229	12392	
2018	23473	34908		10493
2019	29876	57700		48398
2020	49787	44887	81466	36070
2021	14065			17512
2022	8972			11912
2023	26786	9714	15138	8300

Figure 5: ane.27.9a Southern stock. Acoustic biomass (ton) by surveys *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS*.

Age composition

In the model, the age proportion of the commercial fleet (*SEINE*) by quarter from 1989 to 2023, is used (Figure 6). It can be observed that age-0 proportion compared to other ages has been increasing in the last years while age-1 predominates in Q1 and Q2, with a constant proportion over time. Age-0 is not recorded in Q1 and Q2 by convention. In Q3 and Q4, the proportion of age-1 individuals decreases as the proportion of age-0 increases. Additionally, ages 2 and 3 exhibit lower and variable proportions across all quarters over the years, without a defined pattern of change.

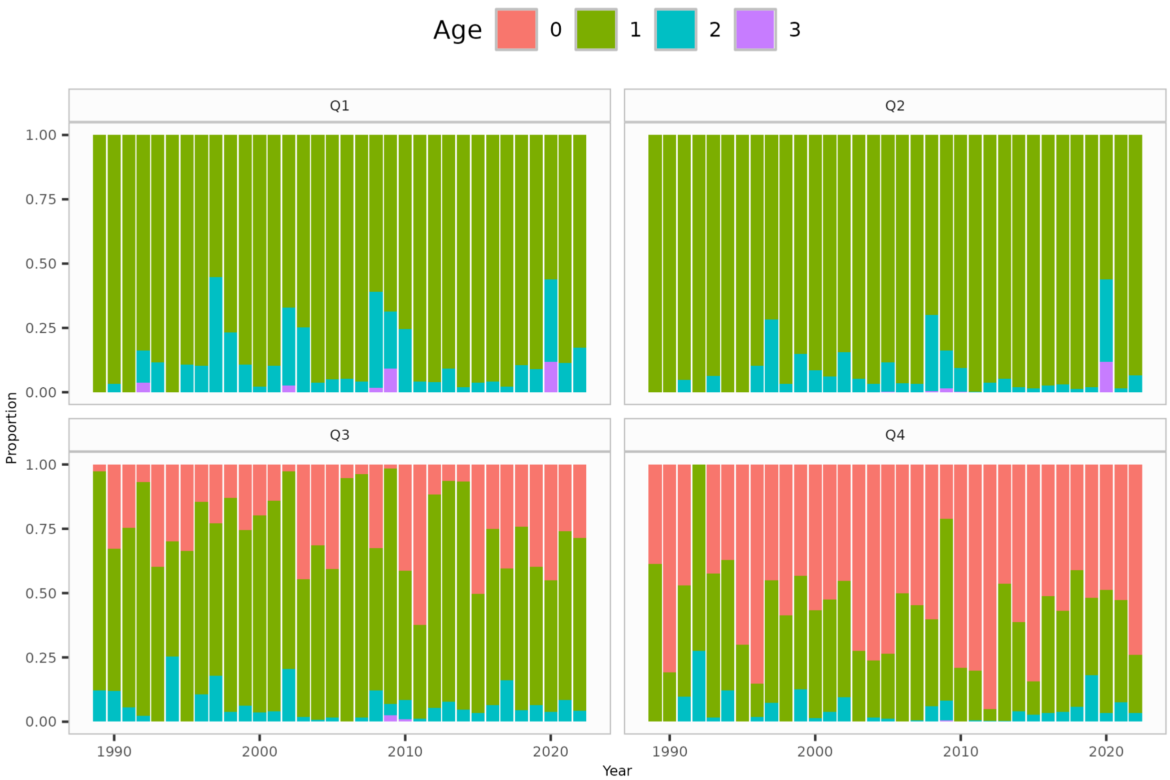

Figure 6: ane.27.9a Southern stock. Age proportion in the commercial fleet catches (*SEINE*) by quarter (1989 to 2023).

Figure 7 shows the yearly age proportions from surveys *PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS* that were used as input for the model. It can be observed that in the *PELAGO* survey, conducted in the second quarter (Q2), age 1 represents the highest proportion over time, with a presence of ages 2 and 3, and no records of age 0 individuals. The *ECOCADIZ* survey, primarily conducted in the third quarter (Q3), shows a predominance of age 1, with an increase in the proportion of age 0 from 2010 onwards; in 2004 and 2006, when the survey was conducted in the second quarter (Q2), no age 0 individuals were recorded by convention. The *ECOCADIZ-RECLUTAS* survey, conducted since 2014 in October (fourth quarter, Q4), shows a higher proportion of age 0, followed by age 1, with lower representation of ages 2 and 3.

In the *SS3* model, age-based data from the *PELAGO* survey were included only for the period 2014-2023, when age-length keys from the surveys were available, as per WKPELA 2018.

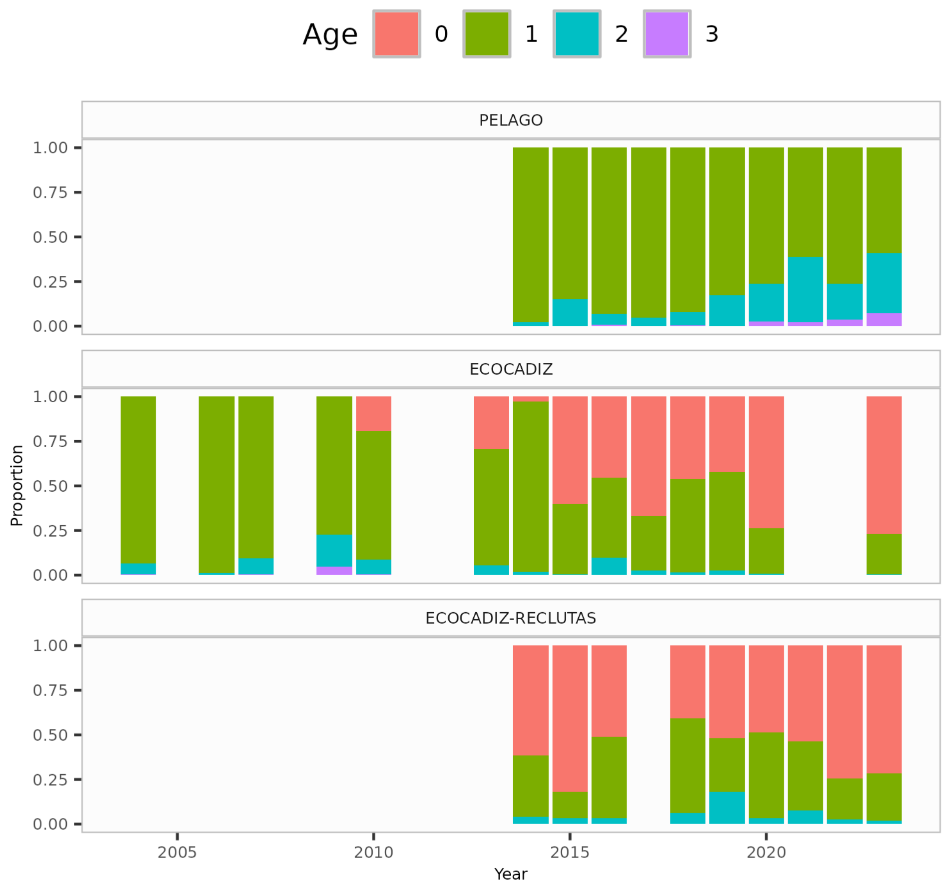

Figure 7: ane.27.9a Southern stock. Age proportion in acoustic surveys estimates (*PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS*).

Weigth-at-age

Figure 8 presents the age-specific weight-at-age values at the start of each season, estimated from external data sources. The figure illustrates that mean weight differences between age groups remain consistent over time, with some variability observed across quarters. Individuals aged 3 show greater variability in mean weight compared to younger age groups. For further details, refer to the working document by *Zuñiga et al.(2024) WD: Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).*

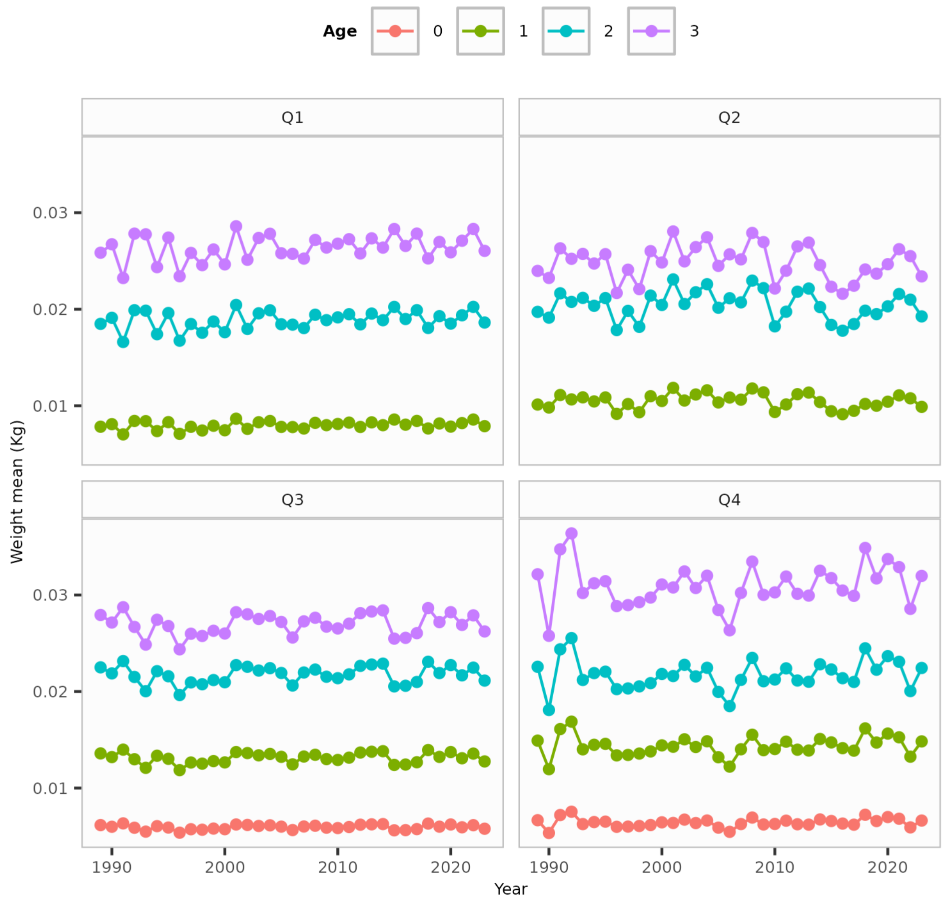

Figure 8: ane.27.9a Southern stock. Weight at age by quarters.

Model settings

Natural mortality

Age-specific natural mortality input values at the beginning of the year were derived from external data sources. For further details, refer to the working document by *Rincón et al. 2024 WD: Growth and natural Mortality parameters estimation for anchovy 9a South.*

Parameter	Age_0	Age_1	Age_2	Age_3
natM1	2.97	1.33	1.33	1.33

Maturity

Due to some inconsistencies in the maturity ogives not noticed during WKPELA 2018, we assume that all individuals with age 1 or higher (B_{1+}), are mature i.e. these abundance estimates result equivalent to spawning stock biomass (SSB) estimates.

Parameter	Age_0	Age_1	Age_2	Age_3
Maturity	0	1	1	1

Growth

It is not modelled explicitly.

Recruitment

Equilibrium recruitment (R_0) was estimated in the base model, and steepness (h) fixed at 0.8, supported by studies from Hsu *et al.* (2024) and Thorson (2020), which are consistent with pelagic species. This value is biologically reasonable for small pelagic species due to their fast growth, early maturity, and short lifespan, allowing them to maintain high reproductive potential at low biomass levels. Standard deviation of log number of recruits was set to 0.6.

The early recruitment deviations for the initial population were estimated from 1985. A recruitment bias adjustment ramp (Methot and Taylor, 2011) was applied to this early period, and bias-adjusted recruitment was estimated for the main period. Recruitment deviations for the main period were estimated for 1991 - 2023.

Fishing mortality

Calculation of fishing mortality is performed by using the hybrid F method that does a Pope's approximation to provide initial values for iterative adjustment of the Baranov continuous F values to closely approximate the observed catch. Total catch biomass by year is assumed to be accurate and precise and the F values are tuned to match this catch.

Catchability

All the surveys are assumed to be relative indices of abundance. The catchability is modelled with a simple q linear model.

Selectivity

The fishery and the surveys selectivity were defined as logistic functions fixed over time, except for *BOCADEVA*, where selectivity was fixed at 1 from age 1 onwards, assuming it is a indicator of spawning biomass.

Data weighting

Constant standard errors of 0.05 and 0.3 were assumed for quarterly catches and surveys, respectively.

The age compositions were adjusted assuming a multinomial error structure with variance described by the sample size, set at 100 for both, the commercial fleet and acoustic surveys. After that, these data was weighted using the Francis method TA1.8 (Francis, 2011), which was adjusted after 5 iterations.

Initial population

It is calculated by estimating an initial equilibrium population modified by age composition data in the first year of the assessment (Methot and Wetzel, 2013). The model starts in 1988 and the equilibrium population age structure was assumed to be in an exploited state with an initial catch of 0 tonnes.

Variance estimates for all estimated parameters are calculated from the Hessian matrix. Minimisation of the likelihood is implemented in phases using standard ADMB process. The phases in which estimation will begin for each parameter are shown in the control file available in the TAF repository for this stock (https://github.com/ices-taf/2024_ane.27.9a_south_benchmark). The R packages r4ss version 1.50.0 (Taylor *et al.*, 2021) and ss3diags version 1.10.3 (Carvalho *et al.*, 2021) were used to process and view model outputs. All analyses were conduction in R version 4.4.1 (2024-06-14).

Diagnostics

The model successfully converged, as evidenced by the Hessian matrix being positive definite and the final gradient being relatively small, with a gradient value of 0.0000088. The "Status" column in Figure 9 shows that the initial model configuration has allowed for adequate optimization of the parameters. Additionally, the gradient for all parameters is relatively small. It is important to note that the bounds imposed on the initial parameters have not restricted the search for optimized values, as reflected in the "Afterbound" column.

Parameter	Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Afterbound
SR_LN(R0)	15.537300	1	1.0	25.0	20.0	OK	0.0202286	-0.000002902400000	OK
LnQ_base_PELAGO(5)	1.181530	2	-30.0	15.0	0.0	OK	0.3354880	-0.000001285890000	OK
LnQ_base_ECOCADIZ(6)	1.339300	2	-30.0	15.0	0.0	OK	0.4701520	0.000000727476000	OK
LnQ_base_BOCADEVA(7)	1.847040	2	-30.0	15.0	0.0	OK	0.1251790	-0.000004784390000	OK
LnQ_base_ECORECLUTAS(8)	1.841860	1	-30.0	15.0	0.0	OK	0.2498140	0.000005941930000	OK
Age_inflection_SEINE_Q1(1)	0.930026	2	0.0	4.0	0.0	OK	0.7851080	-0.000001562900000	OK
Age_95%width_SEINE_Q1(1)	0.198602	2	0.1	0.3	0.2	OK	2.2253600	-0.000000027394300	OK
Age_inflection_SEINE_Q2(2)	0.194172	2	0.1	0.3	0.2	OK	2.2129800	0.000000000998684	OK
Age_95%width_SEINE_Q2(2)	0.206624	2	0.0	4.0	0.5	OK	2.1450700	-0.000000005568720	OK
Age_inflection_SEINE_Q3(3)	0.229521	2	0.0	4.0	0.0	OK	1.3760200	0.000000201413000	OK
Age_95%width_SEINE_Q3(3)	0.187959	2	0.0	4.0	0.5	OK	1.1268200	-0.000000204574000	OK
Age_inflection_SEINE_Q4(4)	0.463384	2	0.0	4.0	0.0	OK	0.2558520	-0.000001398380000	OK
Age_95%width_SEINE_Q4(4)	0.663873	2	0.0	4.0	0.5	OK	0.3095230	0.000001252340000	OK
Age_inflection_PELAGO(5)	0.893223	2	0.0	3.5	0.9	OK	1.4557100	0.000000395900000	OK
Age_95%width_PELAGO(5)	0.246366	2	0.1	0.4	0.3	OK	3.3392600	0.000000014853800	OK
Age_inflection_ECOCADIZ(6)	0.413031	3	-2.0	3.5	0.0	OK	2.8691000	-0.000006196260000	OK
Age_95%width_ECOCADIZ(6)	0.372468	3	-2.0	3.5	0.2	OK	2.5301900	0.000006984250000	OK
Age_inflection_ECORECLUTAS(8)	0.953594	2	-2.0	3.5	0.0	OK	0.1666880	-0.000003069310000	OK
Age_95%width_ECORECLUTAS(8)	1.043370	3	-2.0	3.5	1.0	OK	0.1011620	0.000004294120000	OK

Figure 9: ane.27.9a Southern stock. Parameters estimated by the initial base model.

Model fit and residuals

The Figure 10 shows that the abundance indices from the acoustic surveys exhibit a high level of variability, as reflected by the width of the assumed confidence intervals, with a maximum coefficient of variation of 30%. The model follows the overall trend of the indices, though it encounters some difficulties in accurately fitting the extreme biomass values, both the highest and lowest. However, it adequately reproduces the general trend of variability in biomass levels presented by the survey estimates.

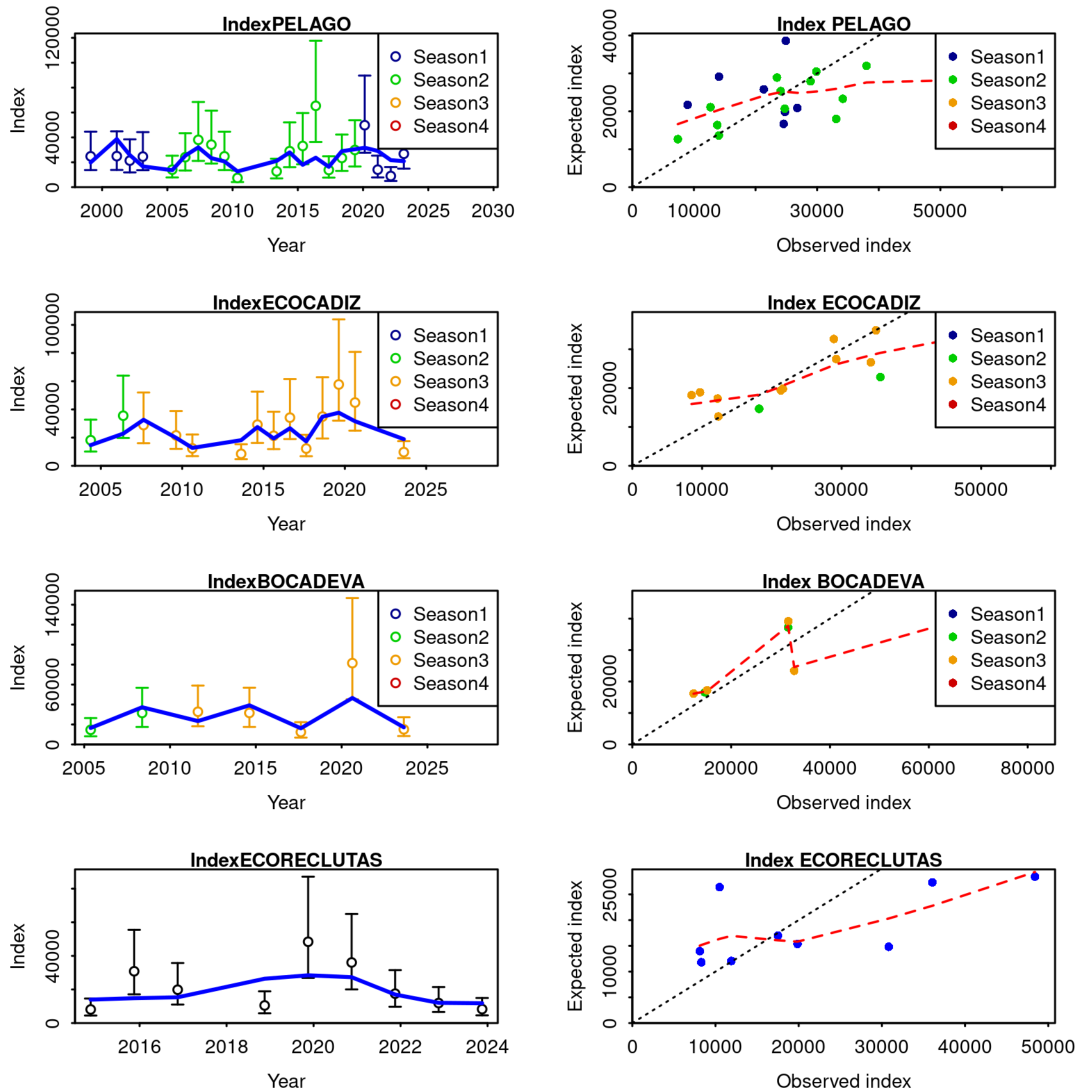

Figure 10: ane.27.9a Southern stock. Model fit to the data (left panel) and observed versus expected values (right panel) of the indices from the surveys *PELAGO*, *ECOCADIZ*, *BOCADEVA* and *ECOCADIZ-RECLUTAS*. The lines indicate a 95% uncertainty interval around the index values based on the lognormal error model assumption.

Figure 11 shows that the residuals from the fit of the biomass indices are randomly distributed, with p-values greater than 0.05 (*PELAGO* = 0.415, *ECOCADIZ* = 0.636, *BOCADEVA* = 0.888, *ECOCADIZ-RECLUTAS* = 0.374). The estimated root mean square error (RMSE) for the joint residual analysis is 41.7%.

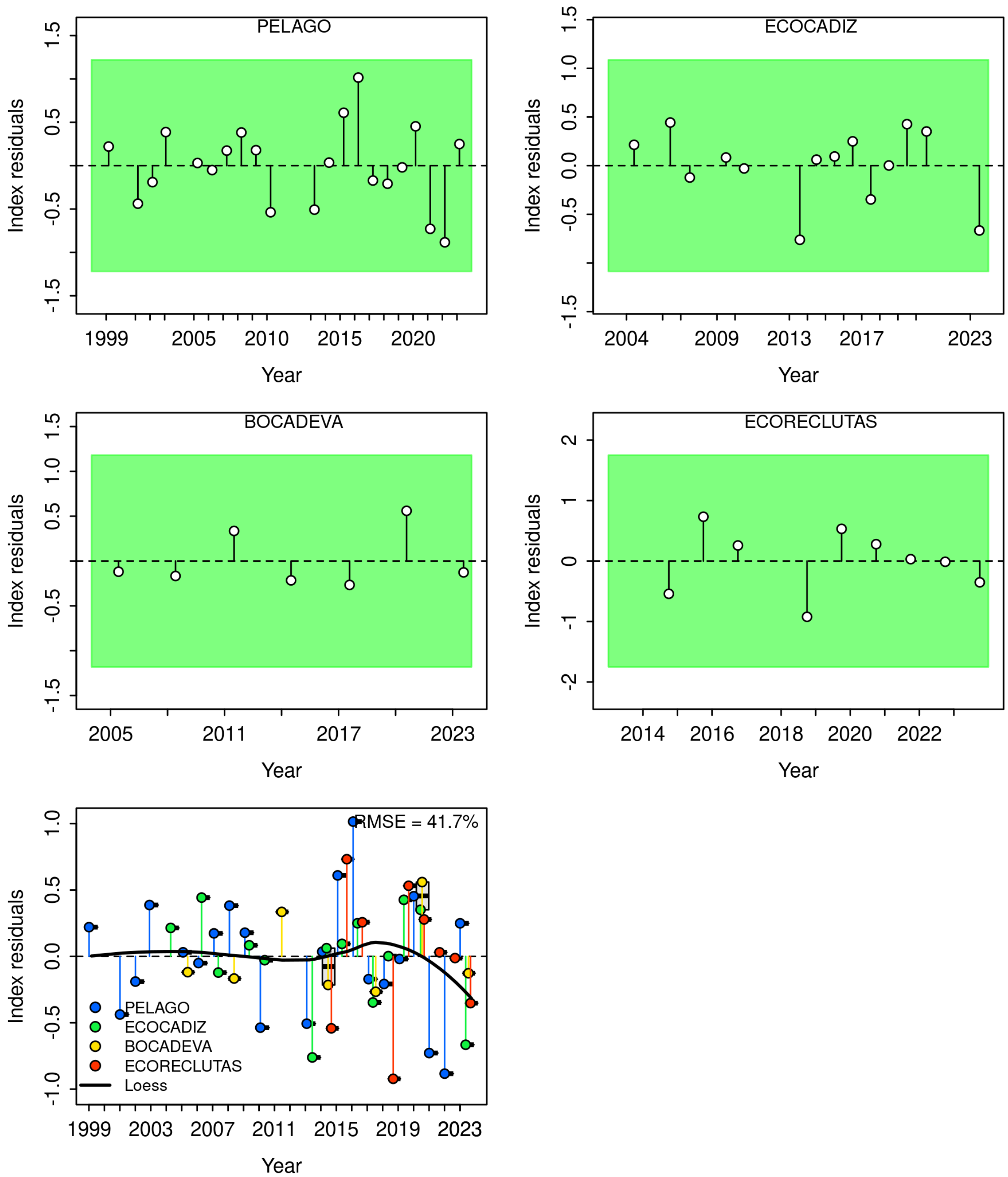

Figure 11: ane.27.9a Southern stock. a) Run test plots for the fit of acoustic and DEPM survey indices. Green shading indicates no evidence (p>=0.05) and red shading indicates evidence (p<0.05) for rejecting the hypothesis of a randomly distributed residual time series, respectively. The shaded area (green/red) spans three standard residual deviations on either side of zero, and red points outside the shading violate the three-sigma limit for that series. b) Joint residual plots for the fit of acoustic and DEPM survey indices (bottom left panel). Vertical lines with points show the residuals, and the solid black line show loess smoother through all residuals. Boxplots indicate the median and quantiles in cases where residuals from multiple indices are available for a given year, with the solid black line showing a loess smoother. The root mean square error (RMSE) is included in the top right corner of the panel.

Estimated mean age for the *SEINE* fleet (one by quarter) with a 95% confidence intervals based on current sample sizes, is presented in Figure 12.

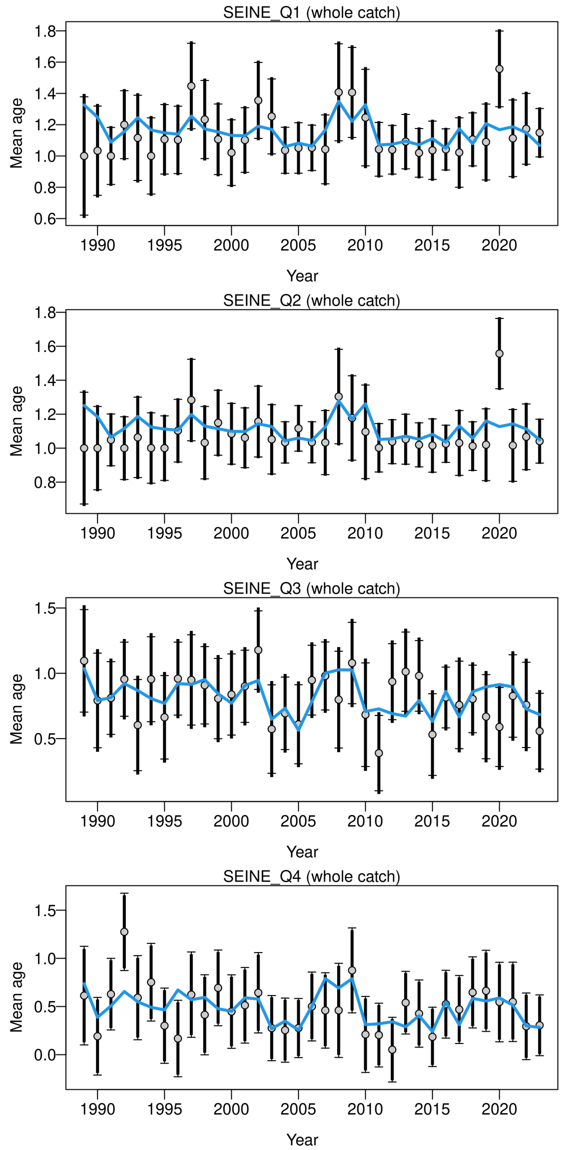

Figure 12: Mean age for commercial fleet by quarters with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.

While mean age for the *PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS* surveys is presented in Figure 13.

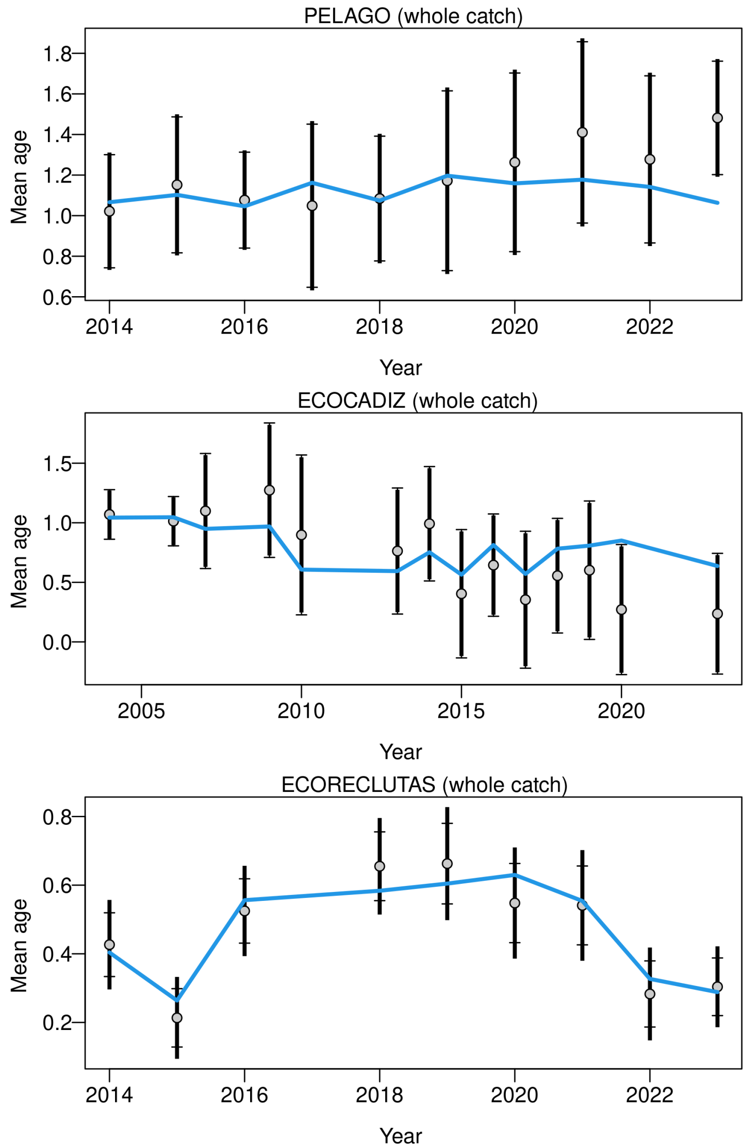

Figure 13: Mean age for *PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS* with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.

The Figure 14 shows the estimated age compositions aggregated over time for the different age data sources: *SEINE*, *ECOCADIZ*, *PELAGO* and *ECOCADIZ-RECLUTAS*. Overall, a high proportion of young individuals (ages 0 and 1) is observed in both the commercial fleet catches and acoustic surveys, with a significant decline in the proportions of older age classes. The green lines represent the model fits, demonstrating an adequate fit, with the aggregated age compositions well reconstructed.

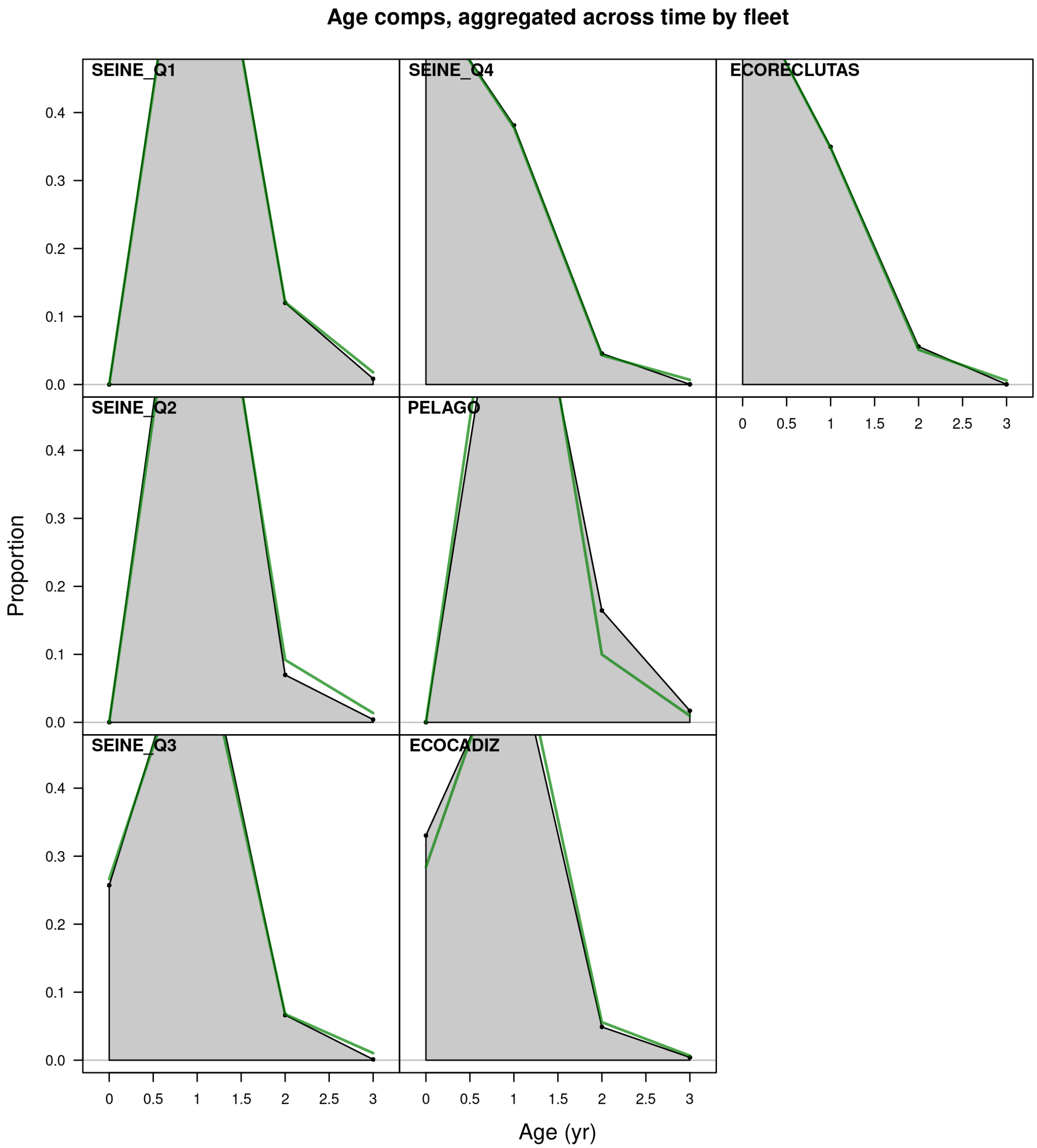

Figure 14: ane.27.9a Southern stock. Model fit to the aggregated age composition data from the *SEINE* fishery, and the acoustic surveys *PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS*. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 15 shows the estimated age composition for the commercial fleet in the first quarter.

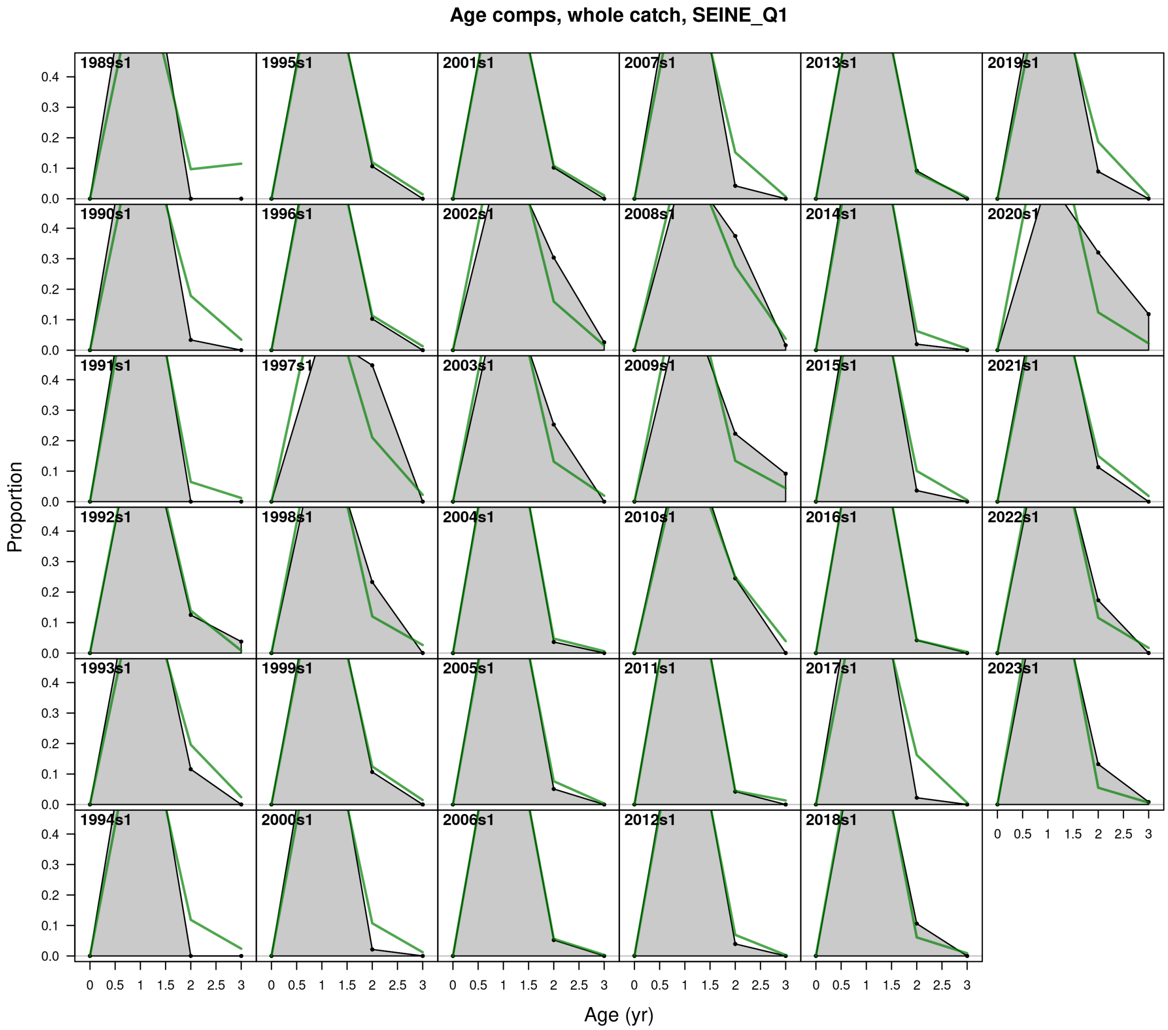

Figure 15: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ1* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 16 shows the estimated age composition for the commercial fleet in the second quarter.

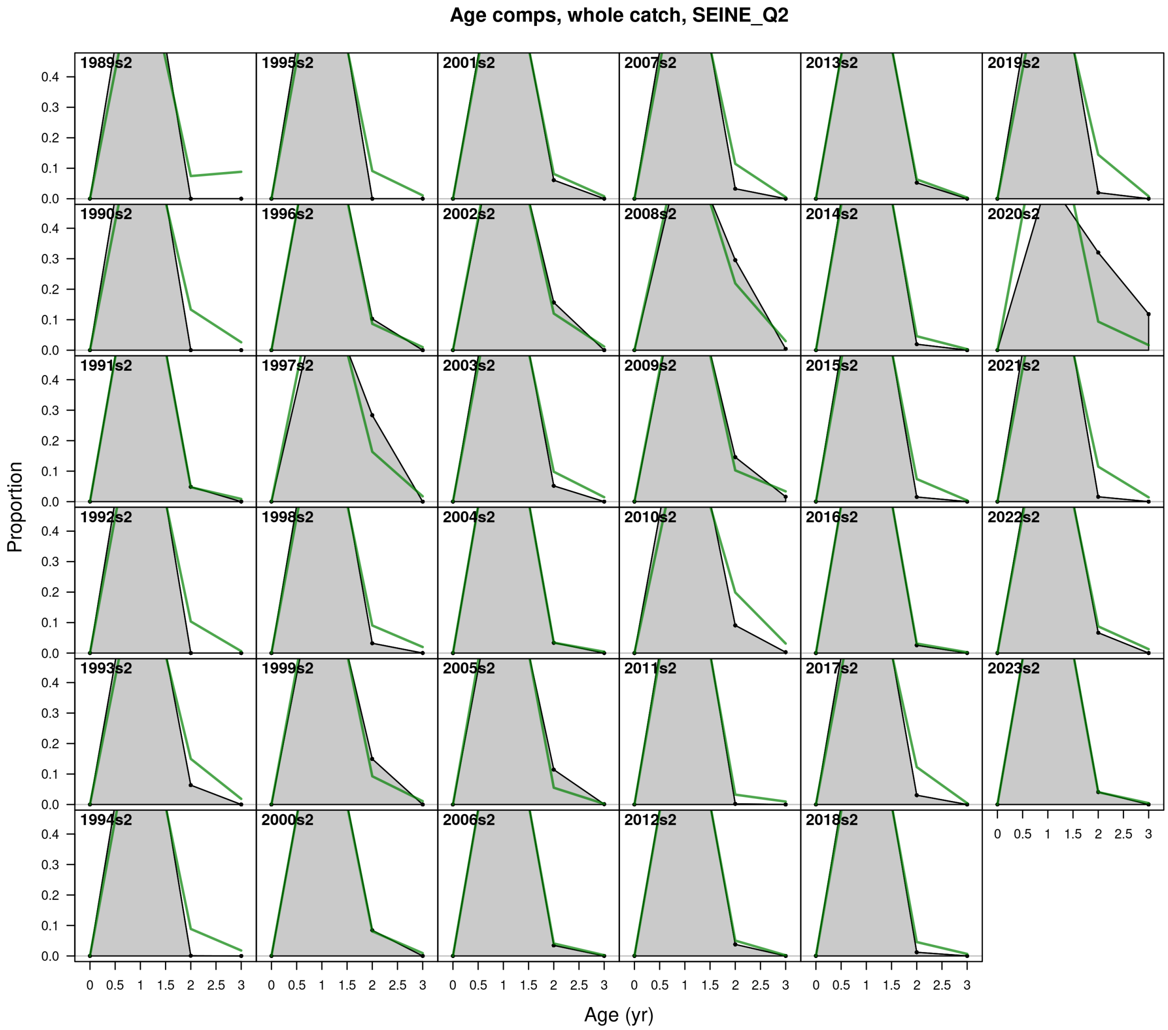

Figure 16: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ2* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 17 shows the estimated age composition for the commercial fleet in the third quarter.

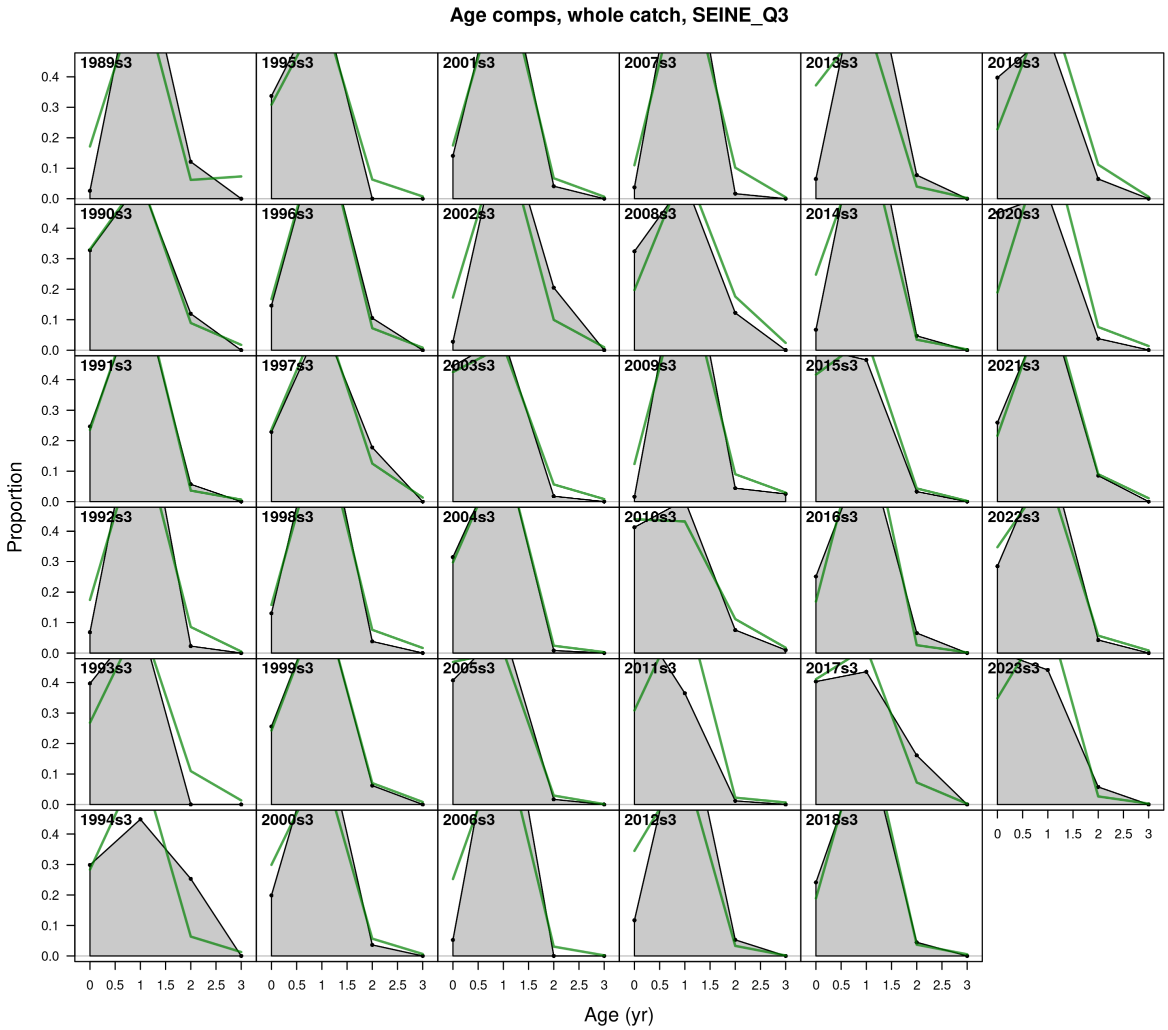

Figure 17: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ3* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 18 shows the estimated age composition for the commercial fleet in the fourth quarter.

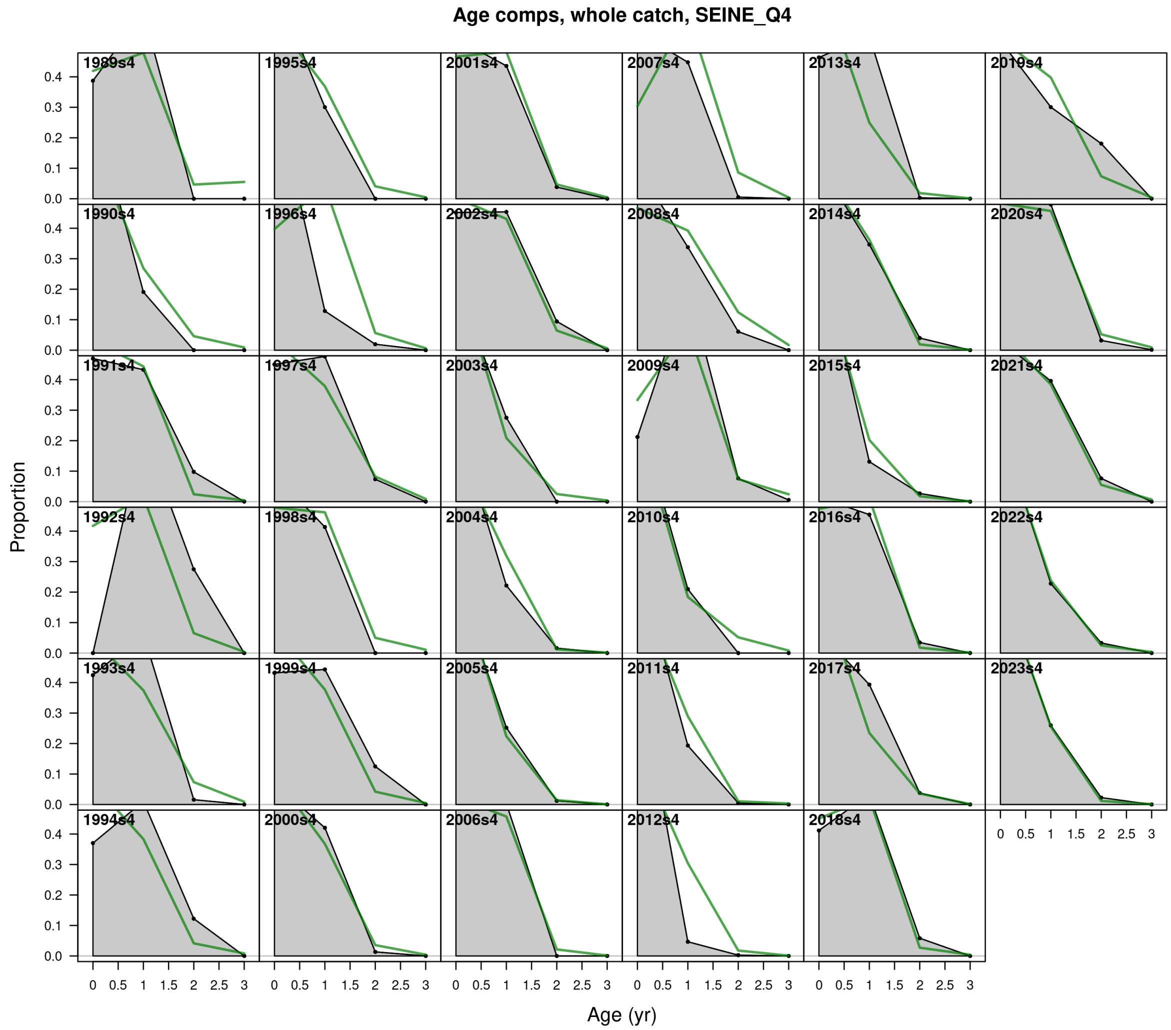

Figure 18: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ4* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Although the aggregated fits show an overall adequate result, some years exhibit variability in the age composition of the commercial fleet (*SEINE*) catches. This pattern is also evident in the annual data fits for the *PELAGO* survey, especially in the later years of the series (2020-2023), where there is a tendency to overestimate age 1 and underestimate age 2 (Figure 19).

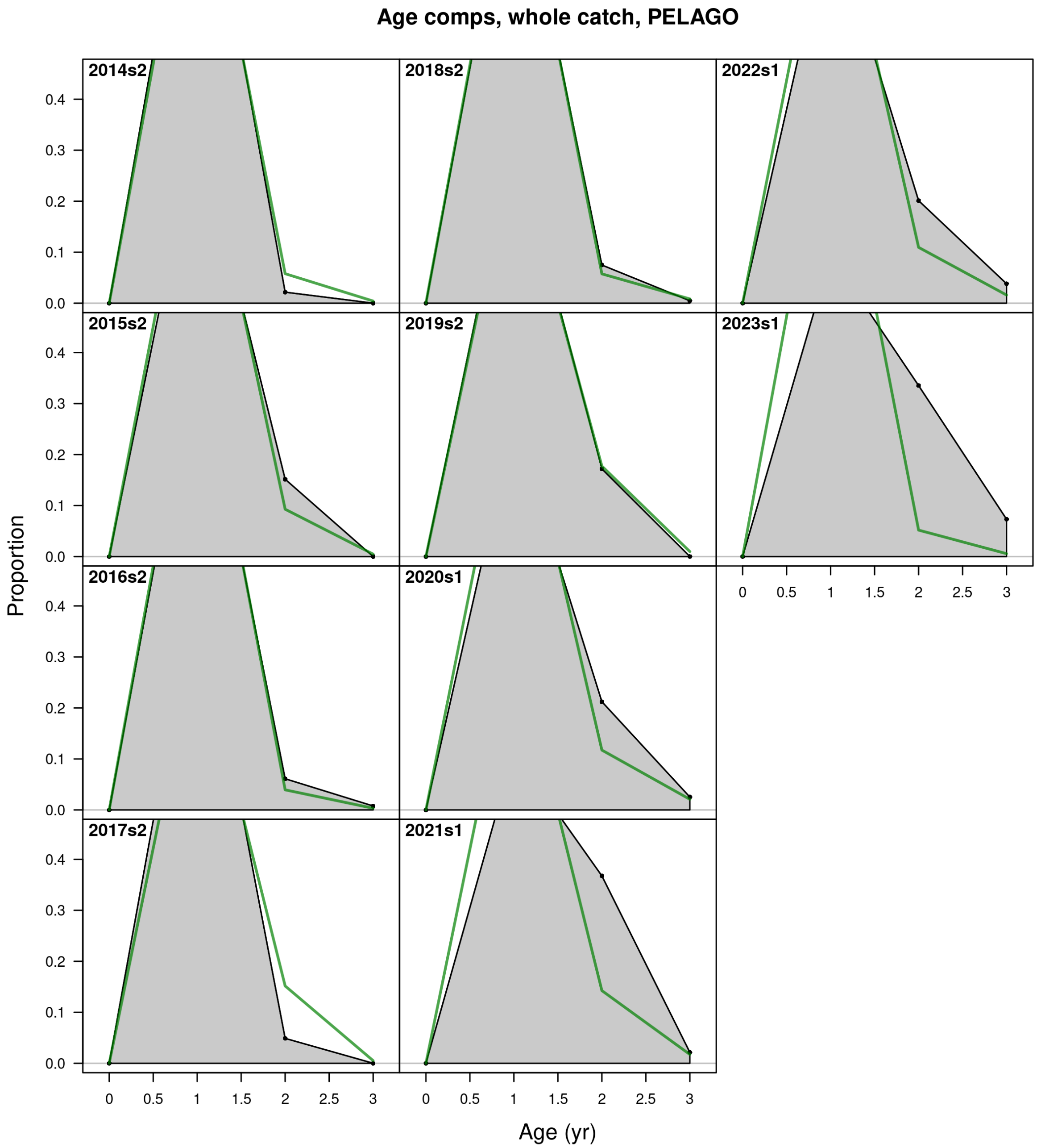

Figure 19: ane.27.9a Southern stock. Model fit to the age composition data from the *PELAGO* spring survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

In the *ECOCADIZ* survey, there are difficulties in estimating ages 0 and 1, with a tendency to underestimate age 0 and overestimate age 1 from 2016 to 2023 (Figure 20).

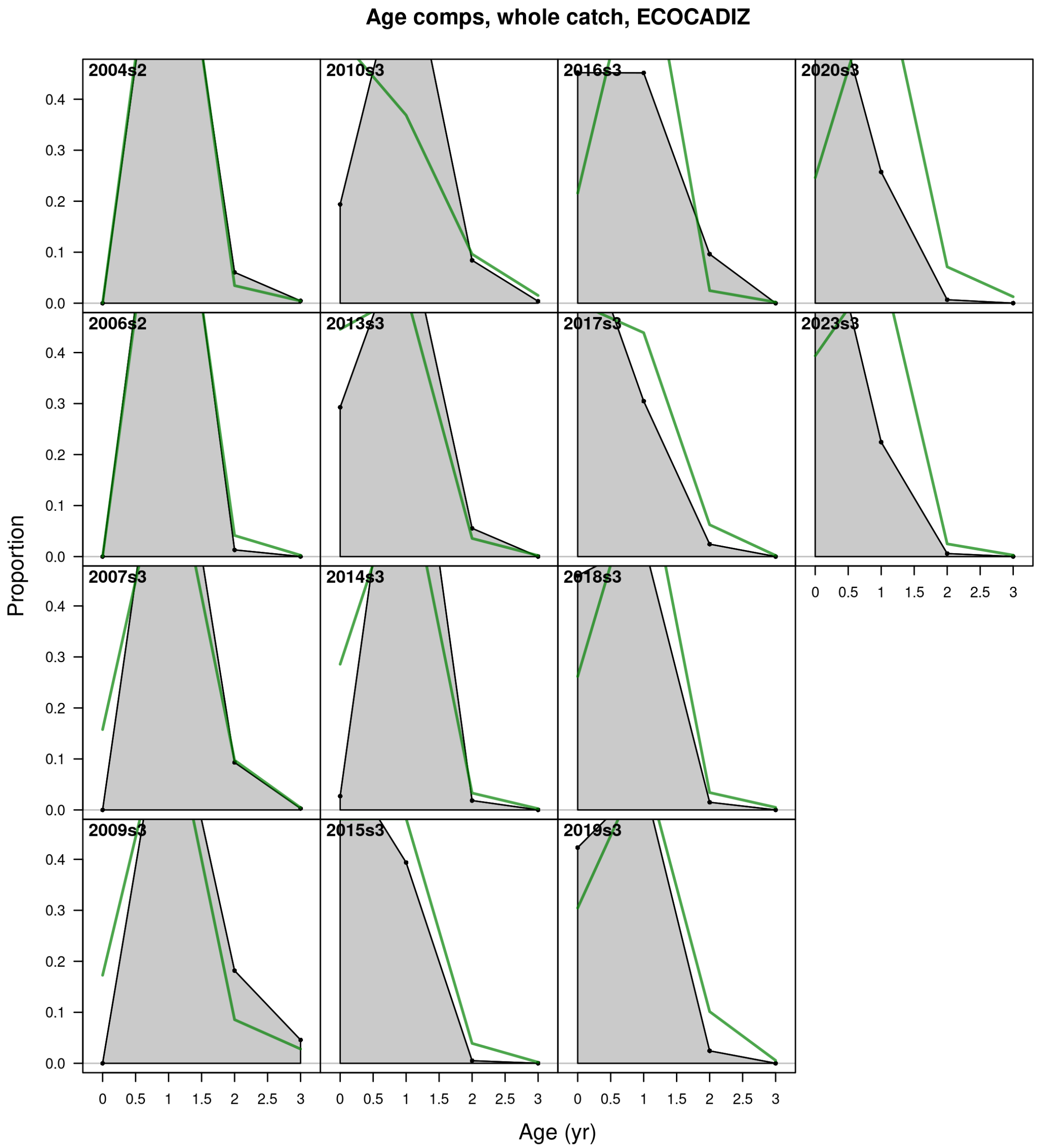

Figure 20: ane.27.9a Southern stock. Model fit to the age composition data from the *ECOCADIZ* summer survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

In *ECOCADIZ-RECLUTAS*, a generally good fit is observed without a clear pattern of overestimation or underestimation (Figure 21).

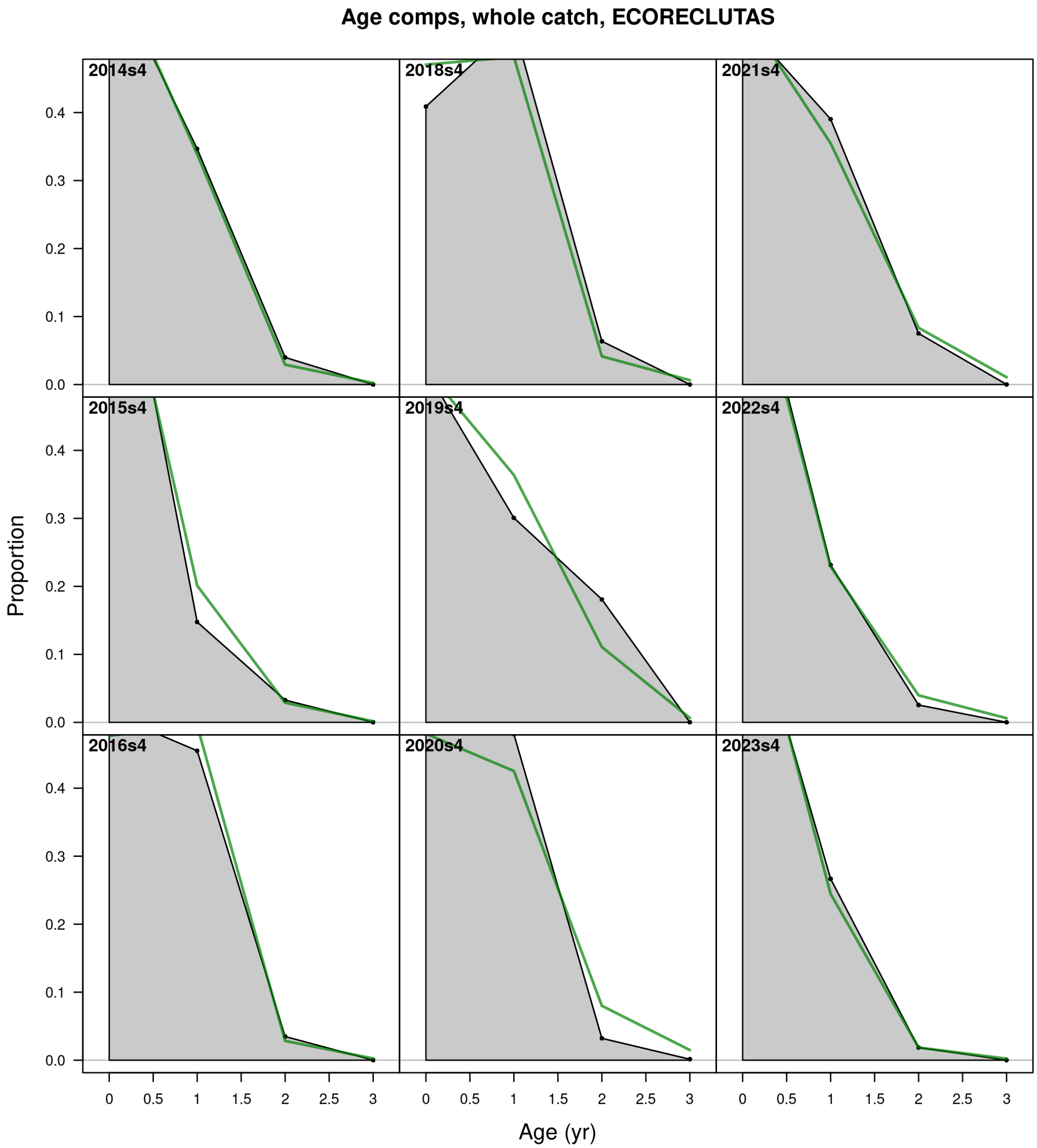

Figure 21: ane.27.9a Southern stock. Model fit to the age composition data from the *ECOCADIZ-RECLUTAS* fall survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

Bubble plots of the residuals corresponding to the fit of the *SEINE* data are presented in Figure 22.

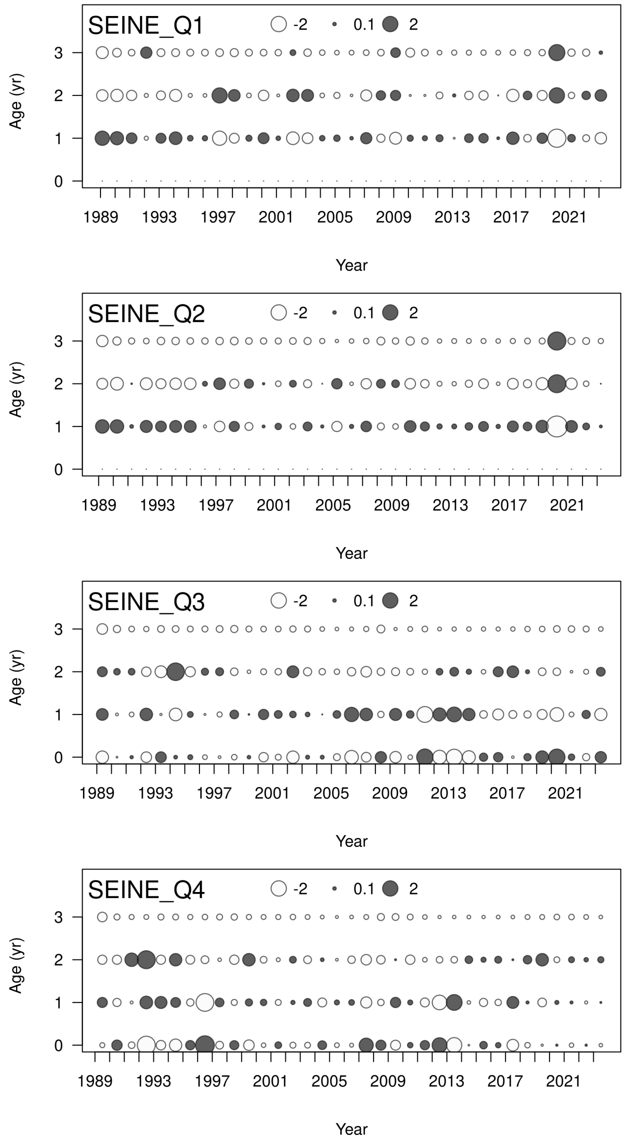

Figure 22: ane.27.9a Southern stock. Pearson residuals, comparing across fleets. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

Bubble plots of the residuals corresponding to the fit of the surveys age-data are presented in Figure 23.

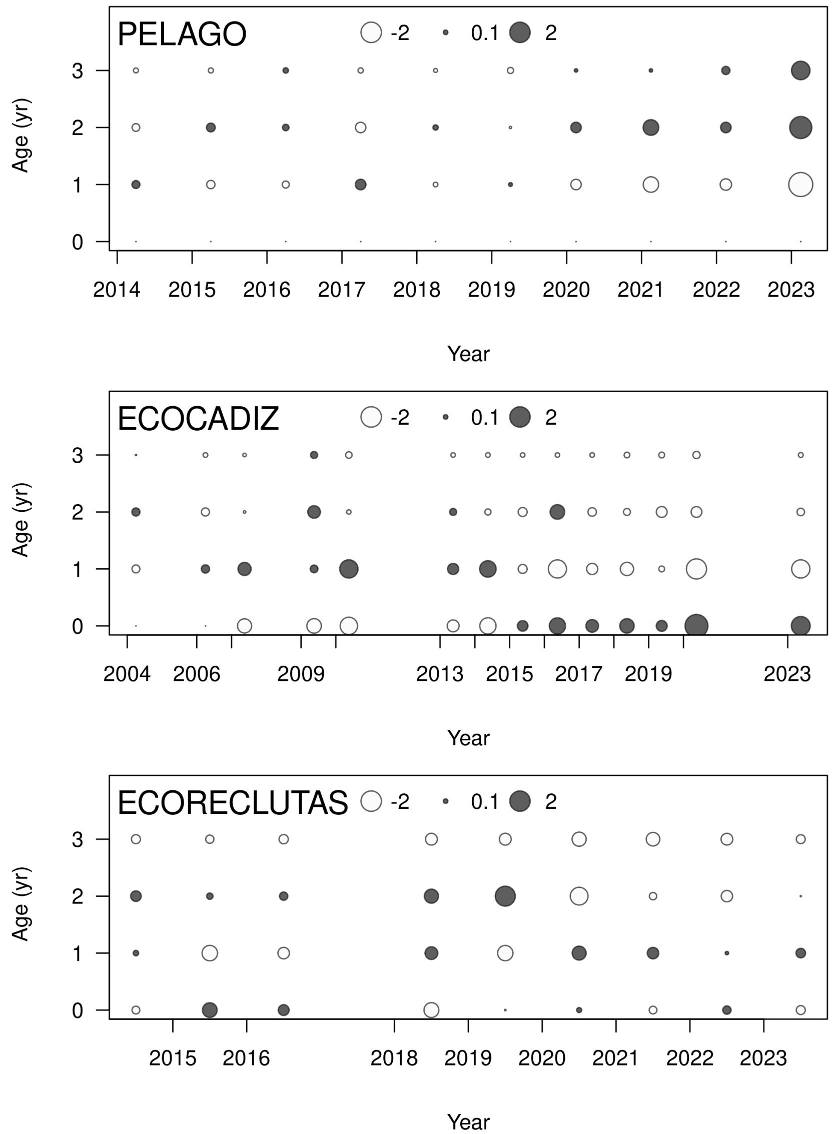

Figure 23: ane.27.9a Southern stock. Pearson residuals, comparing across surveys. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

The Figure 24 shows that the residuals from the fit of the age proportions are randomly distributed, with p-values greater than 0.05 in the case of the commercial fleet (*SEINE_Q1*: 0.202, *SEINE_Q2*: 0.669, *SEINE_Q3*: 0.912, *SEINE_Q4*: 0.698) and the acoustic surveys *PELAGO* 0.744 and *ECOCADIZ-RECLUTAS* 0.374, and with p-values less than 0.05 in the case of *ECOCADIZ* (0.014). The estimated root mean square error (RMSE) for the joint residual analysis is 29%.

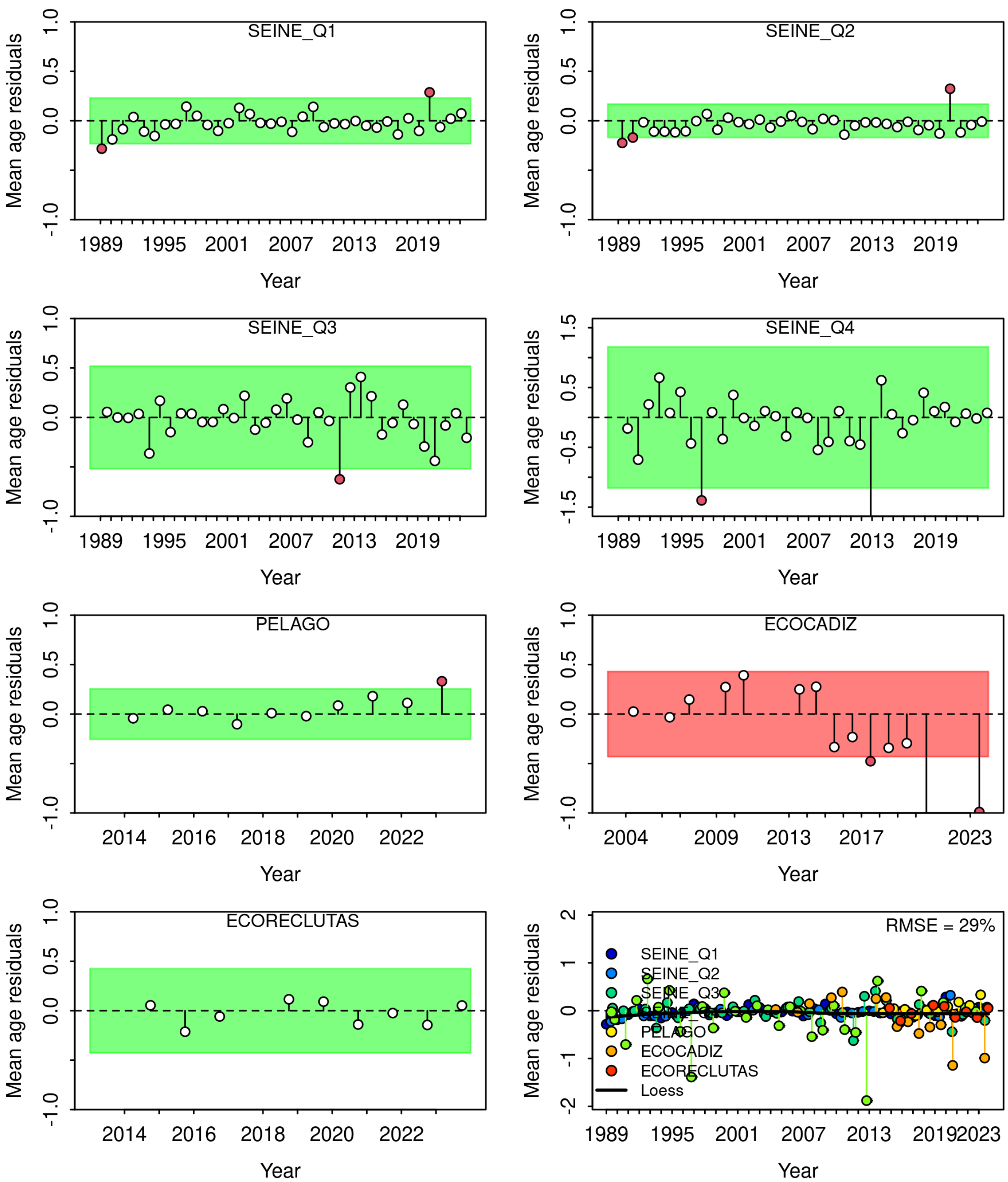

Figure 24: ane.27.9a Southern stock. a) Runs test results for fits to annual mean age estimates for the surveys (*PELAGO*, *ECOCADIZ* and *ECOCADIZ-RECLUTAS*), and the fishery (*SEINE*). Green shaded (green/red) area spans three residual standard deviations to either side from zero, and the red points outside of the shading violate the 'three-sigma limit' for that series. b) Joint residual plots for annual mean length estimates for surveys and fishery (bottom left panel). Vertical lines with points show the residuals, and the solid black line show loess smoother through all residuals. Root-mean squared error (RMSE) is included in the upper right-hand corner of the panel.

Retrospective analysis

Figure 25 shows a retrospective pattern in both spawning biomass and fishing mortality in the base model. The retrospective analysis of the assessment model reveals that, in terms of Mohn's rho (mean of retrospective anomalies), the reduction in data leads to a pattern of underestimation in fishing mortality (rho = -0.0703674) and overestimation in spawning biomass (rho = 0.0463587). These Mohn´s rho values were inside the bounds of recommended values, according to the rule proposed by Hurtado-Ferro *et al.* (2014), which states that Mohn's rho index values should be less than 0.30 and greater than -0.22 for short-lived species.

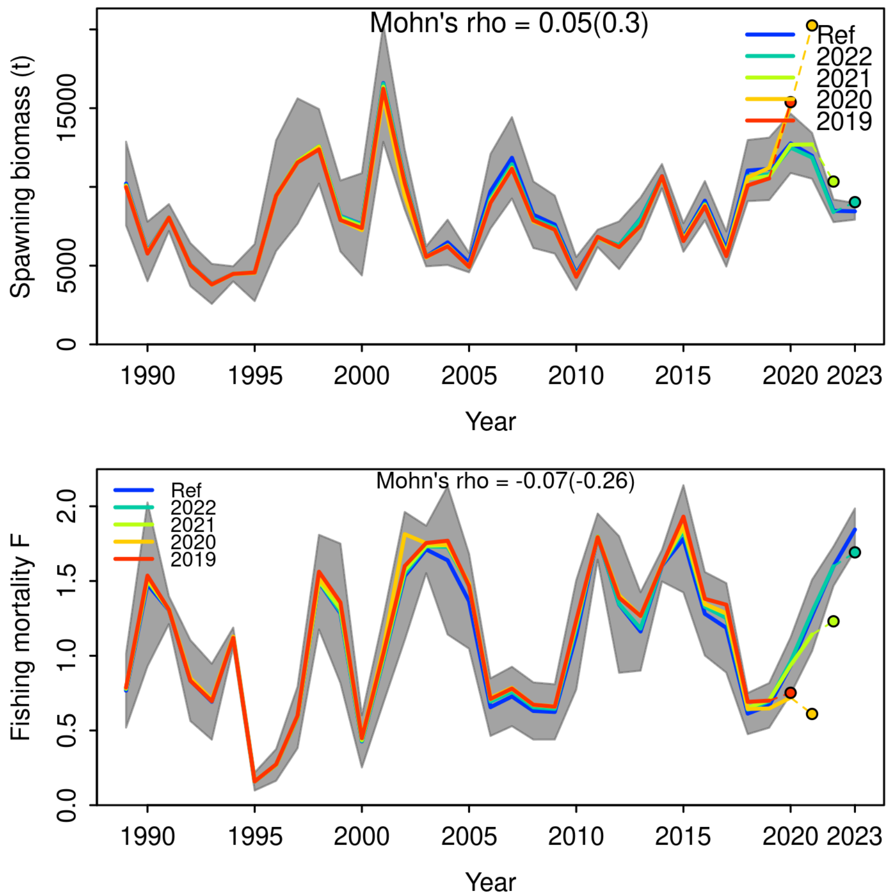

Figure 25: ane.27.9a Southern stock. Retrospective analysis of spawning stock biomass (SSB) and fishing mortality (F). Models conducted by re-fitting the reference model (Ref) after removing five years of observations, one year at a time sequentially. The retrospective results are shown the entire time series. Mohn's rho statistic and the corresponding 'hindcast rho' values (in brackets) are printed at the top of the panels. One-year-ahead projections denoted by color-coded dashed lines with terminal points are shown for each model. Grey shaded areas are the 95% confidence intervals from the reference model.

Results

Stock-recruitment relationship

Recruitment was modeled using a Beverton-Holt stock-recruitment relationship (Figure 26). The assumed level of underlying recruitment deviation error was fixed (σ_R=0.6), equilibrium recruitment was estimated ($log(R_0)$)=15.54) and steepness (h) was fixed at 0.8.

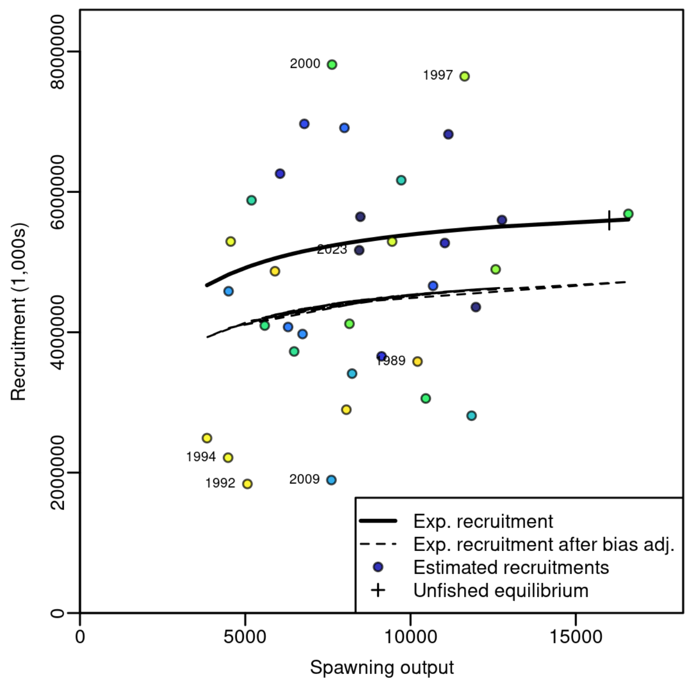

Figure 26: ane.27.9a Southern stock. Stock-recruit curve with labels on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

Recruitment deviations for the early from 1985 and main for 1991 - 2023 periods in the model are presented in (Figure 27).

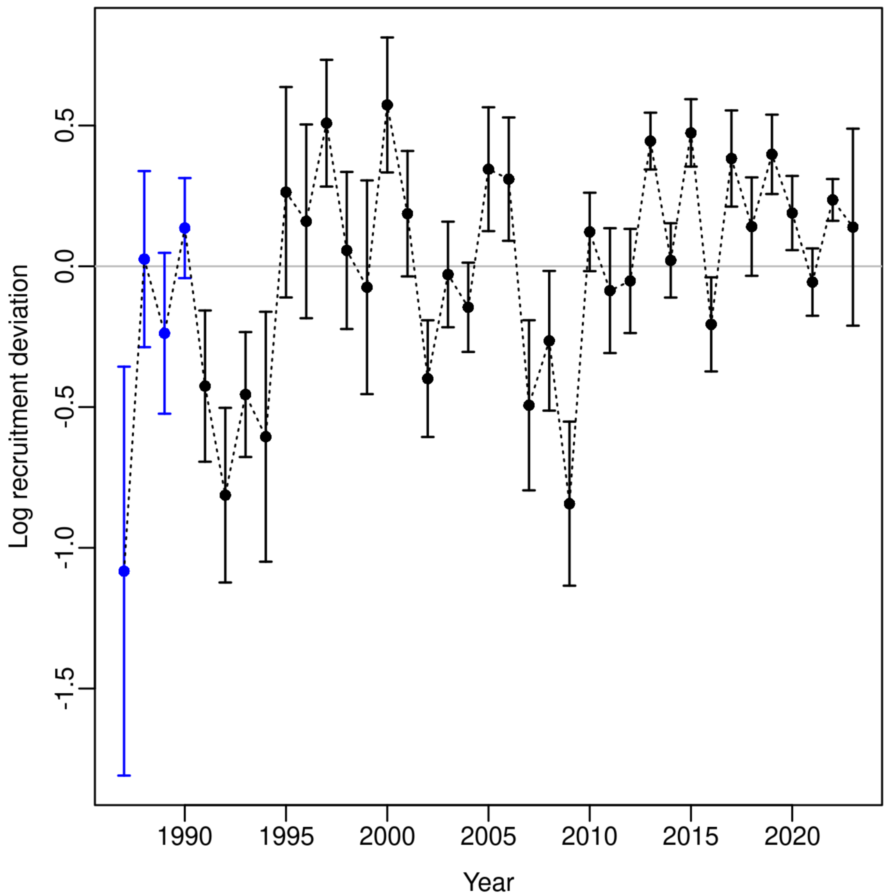

Figure 27: ane.27.9a Southern stock. Recruitment deviations with 95% intervals for the base model (sigmaR = 0.3).

Asymptotic standard errors for recruitment deviations are shown in Figure 28.

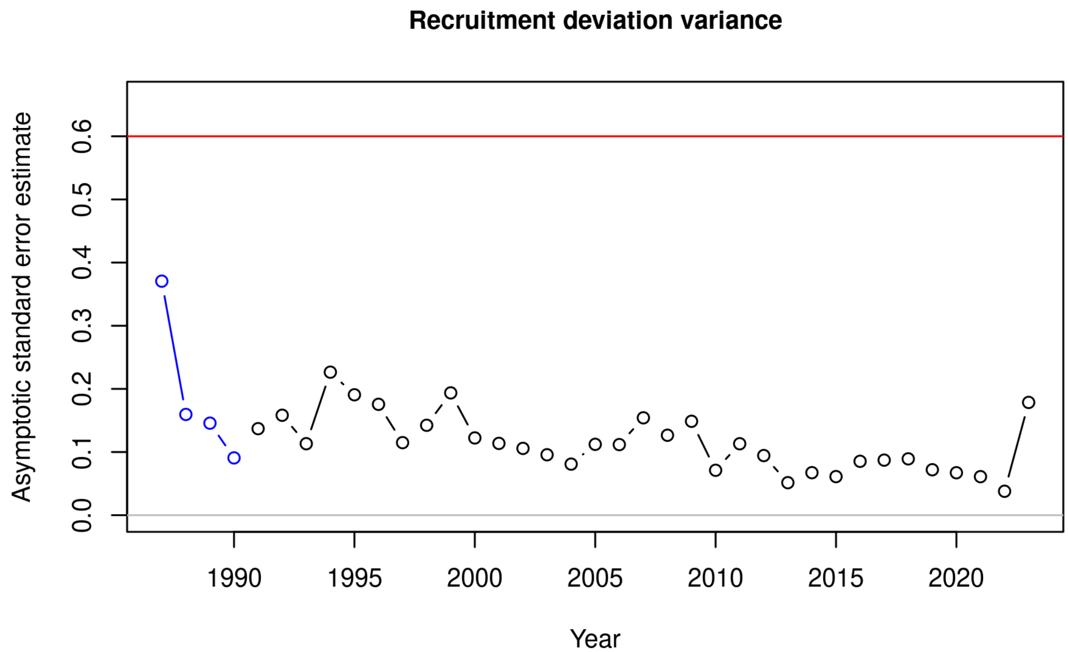

Figure 28: ane.27.9a Southern stock. Asymptotic standard errors for the estimated recruitment deviations.

Recruitment bias adjustment for the different periods is shown in Figure 29.

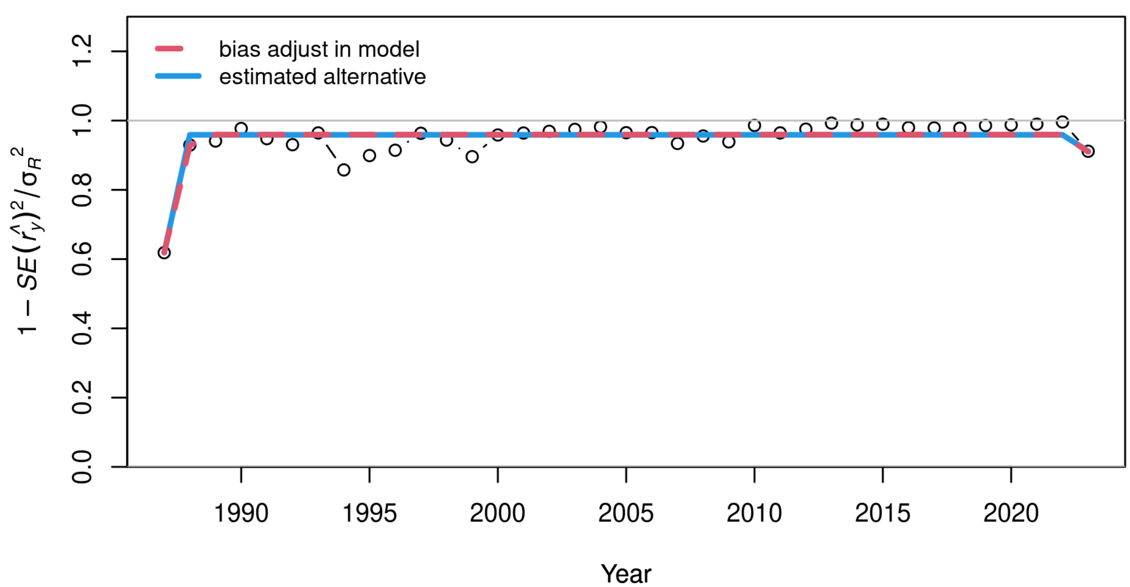

Figure 29: ane.27.9a Southern stock. Recruitment bias adjustment plot for early and main.

Selectivity

Figure 30 shows the estimated selectivity for the age composition of the commercial fleet.

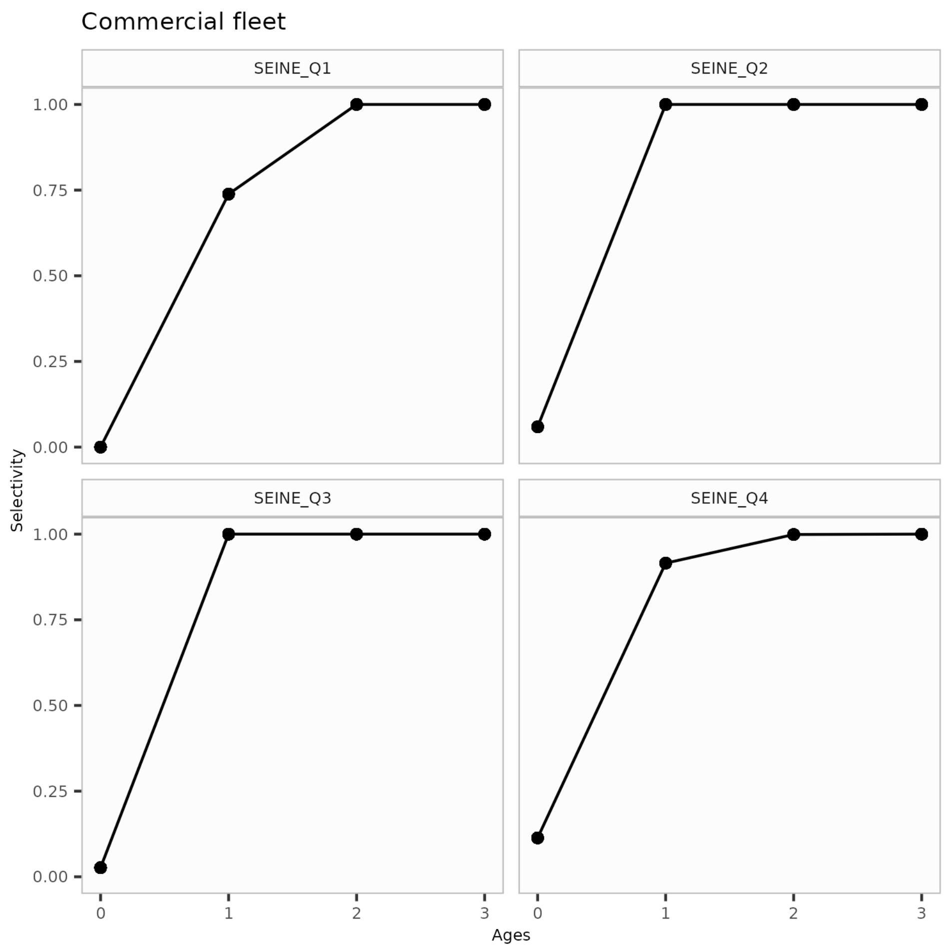

Figure 30: ane.27.9a Southern stock.Estimated selectivity for catch-at-age of commercial fleet (logistic shaped fixed selectivity across all years).

Figure 31 shows the estimated selectivity for the age composition of the acoustic surveys

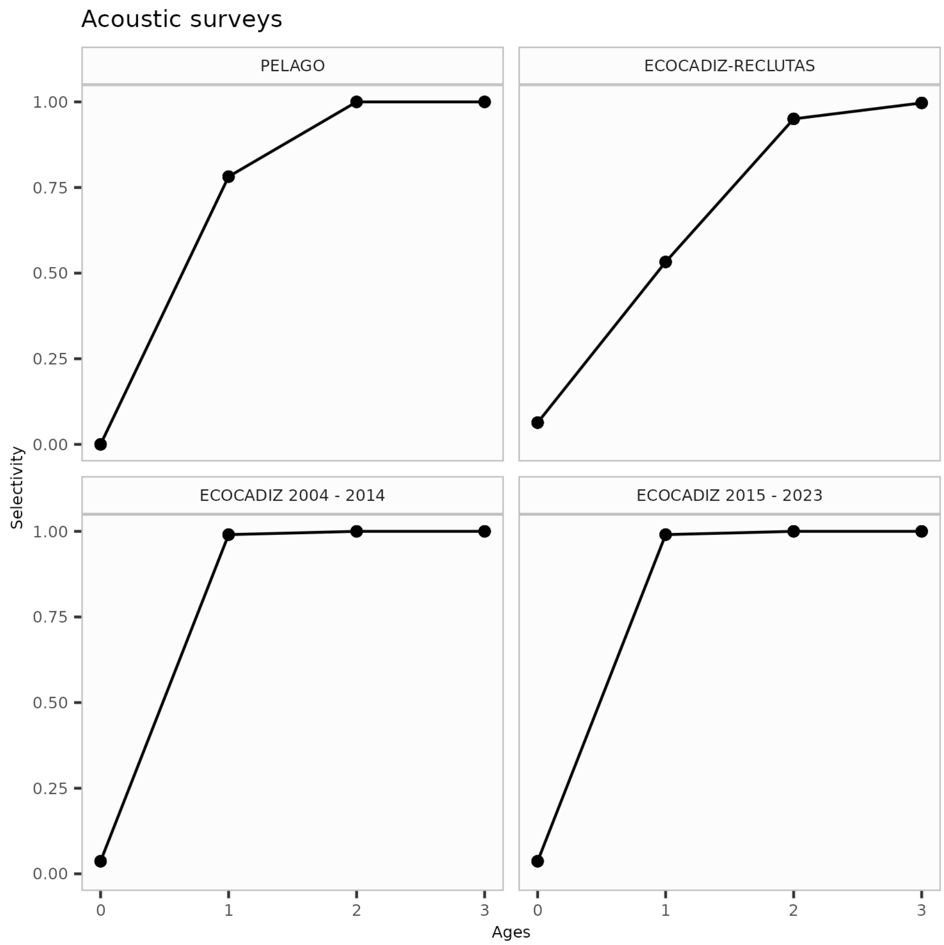

Figure 31: ane.27.9a Southern stock. Estimated selectivity for catch-at-age of surveys (logistic shaped fixed selectivity across all years)

But, it is important to remark that the selectivity assumption for *ECOCADIZ* survey was different from the others, and it was separated into two different periods: 2004 to 2014 and 2015 to 2023, this difference can be appreciated in Figure 32

Catchability

The catchability (q) is adjusted to maintain a consistent relationship between the observed biomass and the vulnerable biomass in acoustic surveys (Figure 32).

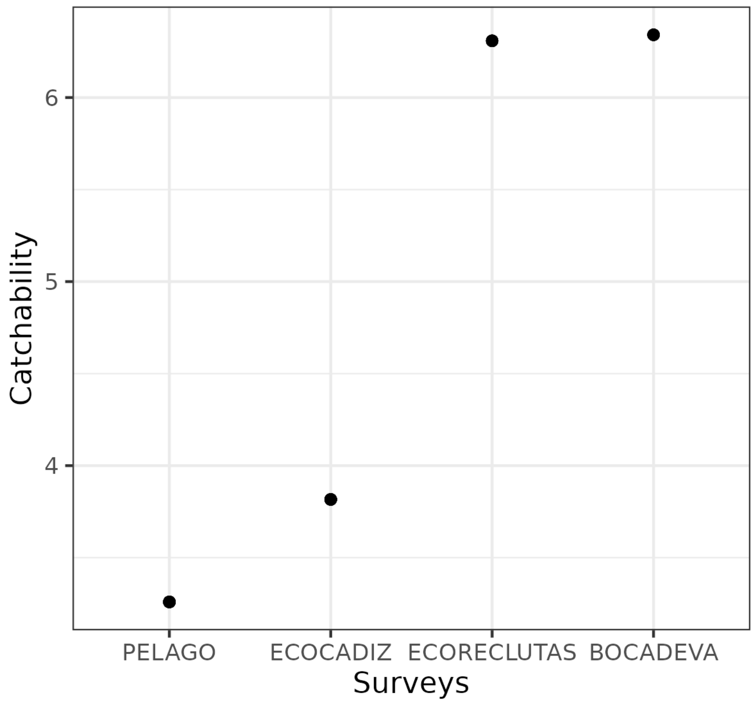

Figure 32: ane.27.9a Southern stock. Estimated catchability parameters for the different surveys indices.

Estimated time series

The Figure 33 shows that total biomass fluctuates around a historical mean of 10.54 thousand tonnes, with a minimum in 1995 of 5.29 thousand tonnes and a maximum recorded in 2001 of 18.76 thousand tonnes. In 2023, the biomass is estimated to be -1% below the historical mean. The catch shows variability around the historical mean of 5.22 thousand tonnes, with a maximum value recorded in 1998 of 9.6 thousand tonnes and a minimum in 1995 of 0.57 thousand tonnes. In 2023, the catch is estimated to be 42% above the historical mean.

The fishing mortality (F_t) fluctuates around a historical mean of 1.1, with a maximum value recorded in 2023 of 1.84 and a minimum in 1995 of 0.16. Confidence intervals range from 0.21 to 0.03, with an average of 0.13. The F_{2023} is estimated to be 68% above the historical mean.

The recruitment (R_t) fluctuates around a historical mean of 4.68 millions recruits, with a maximum value recorded in 2000 of 7.81 millions recruits and a minimum in 1992 of 1.84 millions recruits. Confidence intervals range from 0.23 to 0.03, with an average of 0.11. The R_{2023} is estimated to be -11% below the historical mean.

Finally, the spawning biomass (SSB_t) varies around a historical mean of 8.44 thousand tonnes, with a maximum value recorded in 2001 of 16.59 thousand tonnes and a minimum in 1993 of 3.84 thousand tonnes. Confidence intervals range from 0.22 to 0.03, with an average of 0.11.The SSB_{2023} is estimated to be 0% below the historical mean.

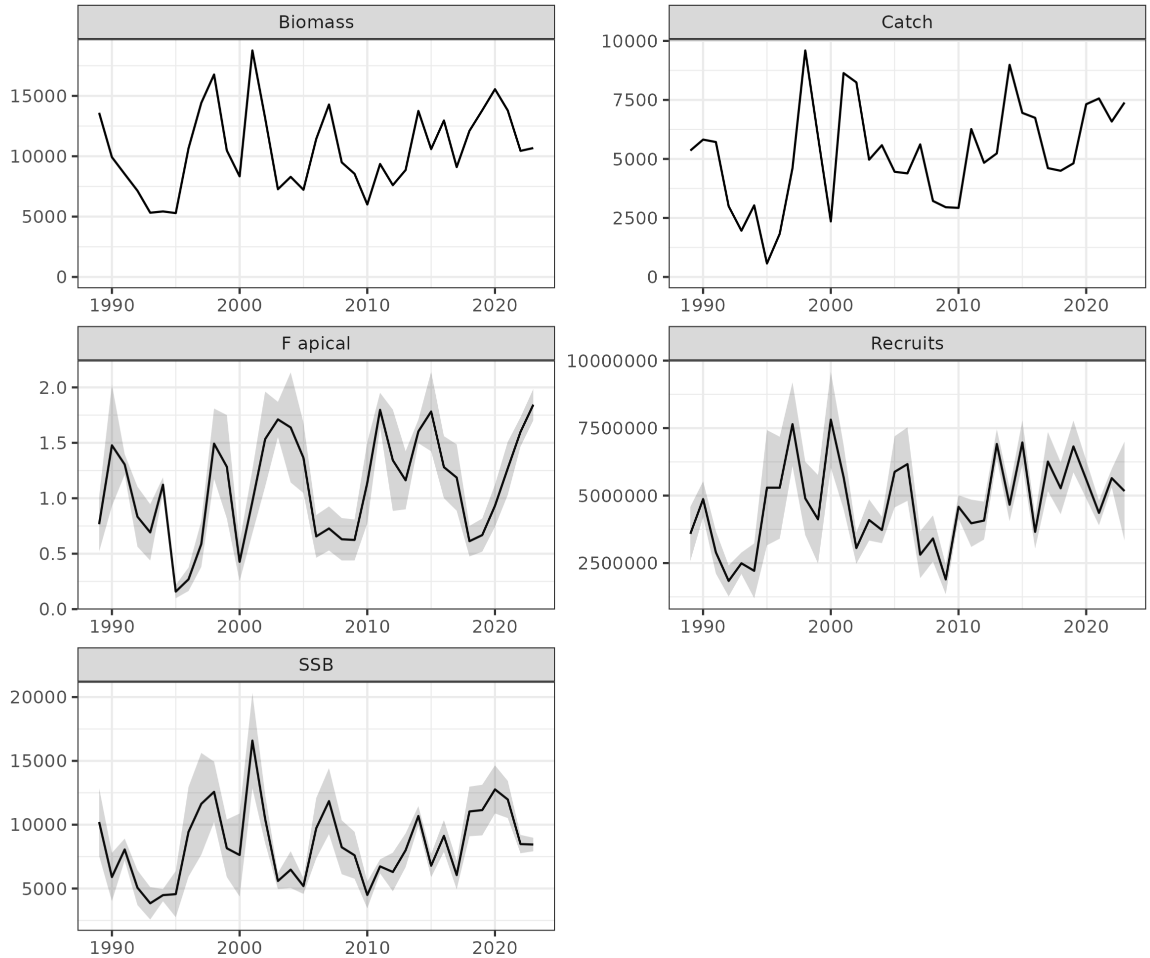

Figure 33: ane.27.9a Southern stock. Time series estimated by the model for annual catches (in tons), recruitment (millions of fish), total biomass and spawning biomass (in tons), and fishing mortality (year-1).

The summarised data resulting from model outputs is shown in Figure 34.

Year	SSB ton	CV SSB	Recruits number	CV Recruits	F apical year-1	CV F apical	Total Biomass ton	Catch ton
1989	10211.80	0.13	3582960	0.14	0.77	0.16	13600.60	5354.25
1990	5899.18	0.16	4869320	0.07	1.48	0.19	9923.34	5819.06
1991	8058.54	0.05	2896830	0.14	1.30	0.04	8526.07	5716.59
1992	5065.71	0.14	1839190	0.16	0.83	0.17	7145.64	2996.70
1993	3842.34	0.17	2491640	0.08	0.69	0.19	5320.99	1959.95
1994	4480.87	0.05	2213260	0.23	1.12	0.03	5428.81	3033.07
1995	4559.73	0.20	5292860	0.21	0.16	0.19	5289.70	570.61
1996	9443.32	0.19	5292120	0.18	0.27	0.20	10658.30	1831.41
1997	11636.20	0.17	7645870	0.10	0.59	0.18	14420.90	4613.21
1998	12575.30	0.10	4895920	0.14	1.49	0.11	16770.60	9595.06
1999	8152.42	0.14	4120750	0.20	1.28	0.19	10476.60	5940.55
2000	7624.81	0.22	7812990	0.12	0.43	0.21	8335.88	2353.44
2001	16589.80	0.11	5686770	0.11	0.97	0.15	18762.70	8636.66
2002	10460.60	0.09	3057050	0.10	1.53	0.14	13160.00	8244.26
2003	5589.69	0.06	4095540	0.09	1.71	0.05	7269.35	4969.11
2004	6479.28	0.11	3726440	0.07	1.64	0.15	8292.85	5581.19
2005	5190.29	0.06	5879900	0.11	1.36	0.12	7223.30	4455.43
2006	9719.44	0.12	6165750	0.11	0.66	0.15	11430.90	4389.09
2007	11847.80	0.11	2811110	0.16	0.73	0.14	14285.20	5616.24
2008	8231.44	0.13	3410900	0.13	0.63	0.15	9491.18	3219.63
2009	7606.14	0.12	1894580	0.15	0.62	0.15	8547.92	2954.92
2010	4495.79	0.12	4584240	0.05	1.14	0.16	6006.05	2927.42
2011	6733.35	0.04	3974710	0.11	1.80	0.04	9359.67	6264.97
2012	6295.65	0.12	4074870	0.09	1.34	0.17	7605.90	4838.20
2013	7999.69	0.08	6911620	0.04	1.16	0.12	8860.52	5235.86
2014	10681.60	0.04	4661330	0.07	1.60	0.03	13754.70	8986.11
2015	6787.52	0.07	6968740	0.06	1.78	0.10	10594.40	6950.09
2016	9124.41	0.07	3656740	0.09	1.28	0.11	12960.00	6741.82
2017	6053.20	0.09	6259490	0.09	1.19	0.13	9101.95	4610.86
2018	11037.80	0.09	5271280	0.09	0.61	0.11	12106.10	4498.81
2019	11145.60	0.09	6820340	0.07	0.67	0.11	13804.70	4813.58
2020	12765.60	0.08	5598630	0.06	0.93	0.10	15555.00	7317.35
2021	11976.20	0.06	4358380	0.05	1.27	0.10	13789.60	7561.60
2022	8482.40	0.04	5645520	0.03	1.60	0.04	10447.90	6585.17
2023	8448.08	0.03	5168160	0.18	1.84	0.04	10679.20	7390.68

Figure 34: ane.27.9a Southern stock. Time series estimated by the model for annual catches (in tons), recruitment (millions of fish), total biomass and spawning biomass (in tons), and fishing mortality (year-1).

Acknowledgements

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necessarily reflect those of the European Union or European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Additionally, this work would have not been possible without the collection of Spanish fisheries and surveys data, co-funded by the Spanish Institute of Oceanography (IEO) and the EU through the European Maritime and Fisheries Fund (EMFF) within the National Program of collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy (PNDB/EU-DCF-Programa Nacional de Datos Básicos/EU-Data Collection Framework).

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Scenario *S1.0_InitCond_sigmaR*: Assessment for WKBANSP 2024 using age-structured data in SS3: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)

María José Zúñiga*, Margarita María Rincón†, Fernando Ramos‡

Assessment model

The assessment of the anchovy in ICES division 9a, southern component was performed in Stock Synthesis software, version 3.30.22.1 (SS3, Methot *et al.*, 2024) under the Linux platform. SS3 is a generalized age and/or length-based model that is very flexible with regard to the types of data that may be included, the functional forms that are used for various biological processes, the level of complexity and number of parameters that may be estimated. The model is coded in C++ with parameter estimation enabled by automatic differentiation (www.admb-project.org) and available at the NOAA Fisheries integrated toolbox: https://noaa-fisheries-integrated-toolbox.github.io/SS3. A description and discussion of the model can be found in Methot and Wetzel (2013).

The model is defined quarterly between 1989 and 2023, for one area and it is age-based, where the population is comprised of 3+ age-classes (with age 3 representing a plus group) with sexes combined (male and females are modelled together).

Data

The input data includes total catch (in biomass) and age composition of the catch (in proportion) for the commercial *SEINE* fleet, as well as abundance (in biomass) and age composition from the *PELAGO* and *ECOCADIZ* surveys. Age composition data from *PELAGO* was included only for the period 2014–2023, when age-length keys were available, as specified by WKPELA 2018. The biomass index from the *ECOCADIZ-RECLUTAS* survey, based on the biomass of age-0 individuals, provides a direct measure of recruitment. Spawning stock biomass (SSB) estimates are derived from the triennial *BOCADEVA* survey using DEPM. To account for seasonal variability in catches, the *SEINE* fleet has been subdivided into four quarterly fleets.

The Figure 1 provides a visual representation of the input data used in the model, categorized into three main types: catches, abundance indices, and age compositions. These data are displayed over time (years) and are represented by circles, with the size of each circle reflecting the magnitude of the data.

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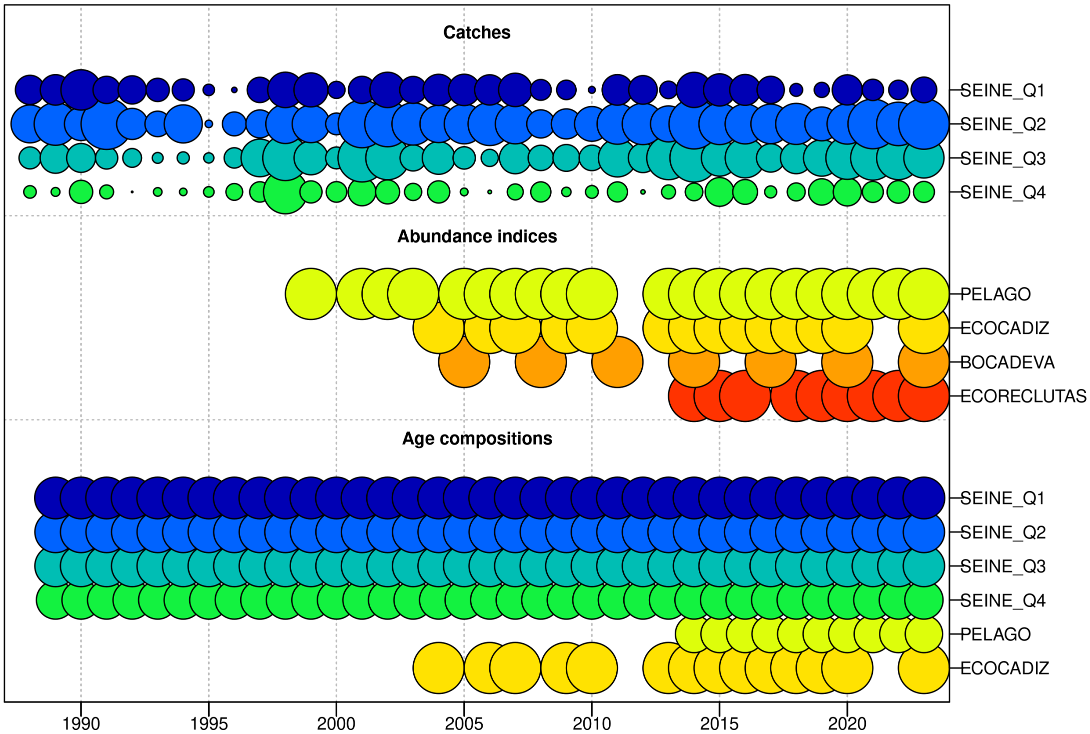


Figure 1: ane.27.9a Southern stock. Summary of model data input by year, where circle area is relative within a data type. Circles are proportional to total catch for catches, to precision for indices and to total sample size for age compositions.

Catches

Anchovy catches in the Gulf of Cádiz exhibit seasonality, with 40.61% concentrated in the second quarter (Q2), averaging 2120.26 tons historically, followed by the third quarter (Q3) with 29.60% (1545.23 tons), the first quarter (Q1) with 19.39% (1012.42 tons), and the fourth quarter (Q4) with 10.39% (542.61 tons). In 2023, first-quarter catches were 7.84% lower than the historical average, while second, third, and fourth-quarter catches increased by 71.03%, 48.06%, and 14.70%, respectively (Figures 2 and 3).

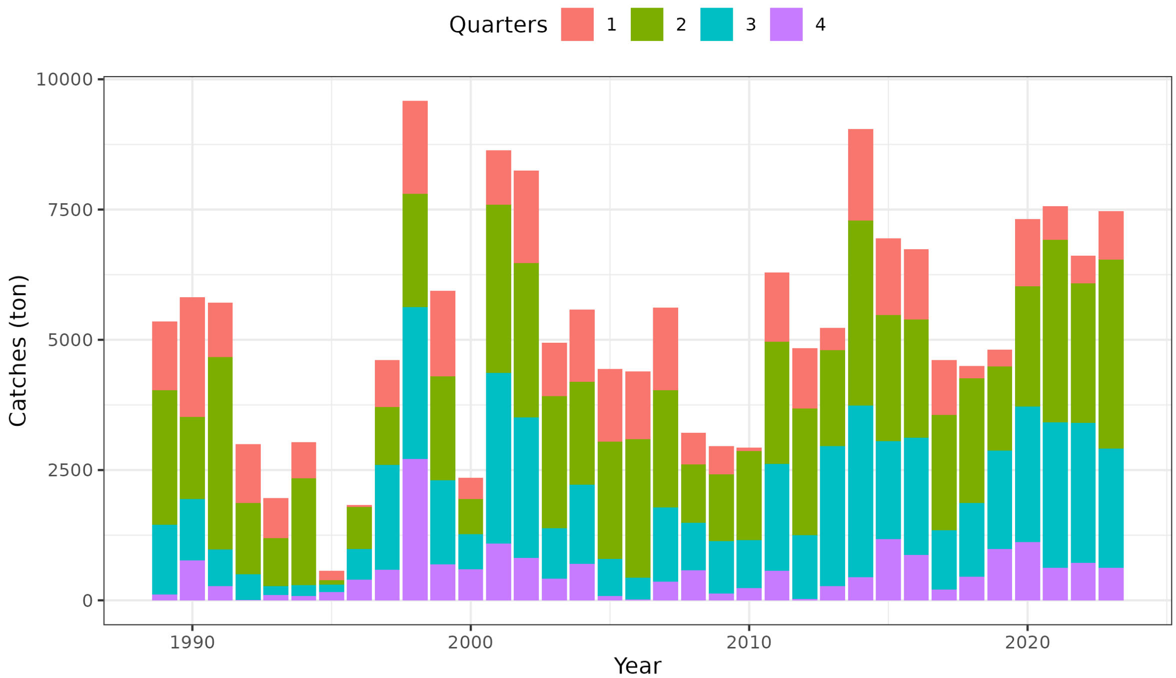


Figure 2: ane.27.9a Southern stock. Time series of quarterly catches.

	Catches (ton)				
Year	Q1	Q2	Q3	Q4	Total
1989	1318	2589	1336	111	5354
1990	2300	1571	1182	765	5818
1991	1049	3693	702	274	5718
1992	1125	1368	500	4	2997
1993	767	921	167	105	1960
1994	690	2055	210	80	3035
1995	185	80	148	157	570
1996	41	807	586	398	1832
1997	908	1110	2007	588	4613
1998	1781	2176	2909	2716	9582
1999	1638	1995	1616	691	5940
2000	412	668	673	600	2353
2001	1046	3227	3275	1089	8637
2002	1772	2957	2699	816	8244
2003	1027	2539	965	416	4947
2004	1384	1976	1522	699	5581
2005	1398	2252	706	85	4441
2006	1297	2657	416	19	4389
2007	1581	2251	1423	361	5616
2008	613	1121	910	576	3220
2009	533	1280	1016	126	2955
2010	67	1709	920	232	2928
2011	1326	2343	2051	571	6291
2012	1159	2433	1220	26	4838
2013	434	1837	2683	277	5231
2014	1754	3553	3300	439	9046
2015	1471	2425	1880	1174	6950
2016	1352	2267	2254	869	6742
2017	1051	2213	1140	206	4610
2018	236	2391	1414	458	4499
2019	322	1621	1889	982	4814
2020	1286	2315	2603	1113	7317
2021	644	3500	2794	623	7561
2022	532	2682	2679	722	6615
2023	933	3626	2288	622	7469

Figure 3: ane.27.9a Southern stock. Time series data of quarterly catches

Abundance indices

The abundance indices *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS* exhibit inter-annual variability over time (Figure 4). *PELAGO*, with data from 1999 to 2023, shows fluctuations with a peak in 2016 at 65,345 tons, followed by a decline, but with a slight recovery in 2023 to 26,786 tons. *ECOCADIZ*, covering the period from 2004 to 2023, reaches its maximum in 2019 at 57,700 tons, followed by a significant decrease to 9,714 tons in 2023. *BOCADEVA*, with data from 2005 to 2023, shows a steady increase to its peak in 2020 at 81,466 tons, followed by a reduction to 15,138 tons in 2023. *ECOCADIZ-RECLUTAS*, recorded from 2014 to 2023, shows a sustained increase until 2019 at 48,398 tons, followed by a decrease to 8,300 tons in 2023.

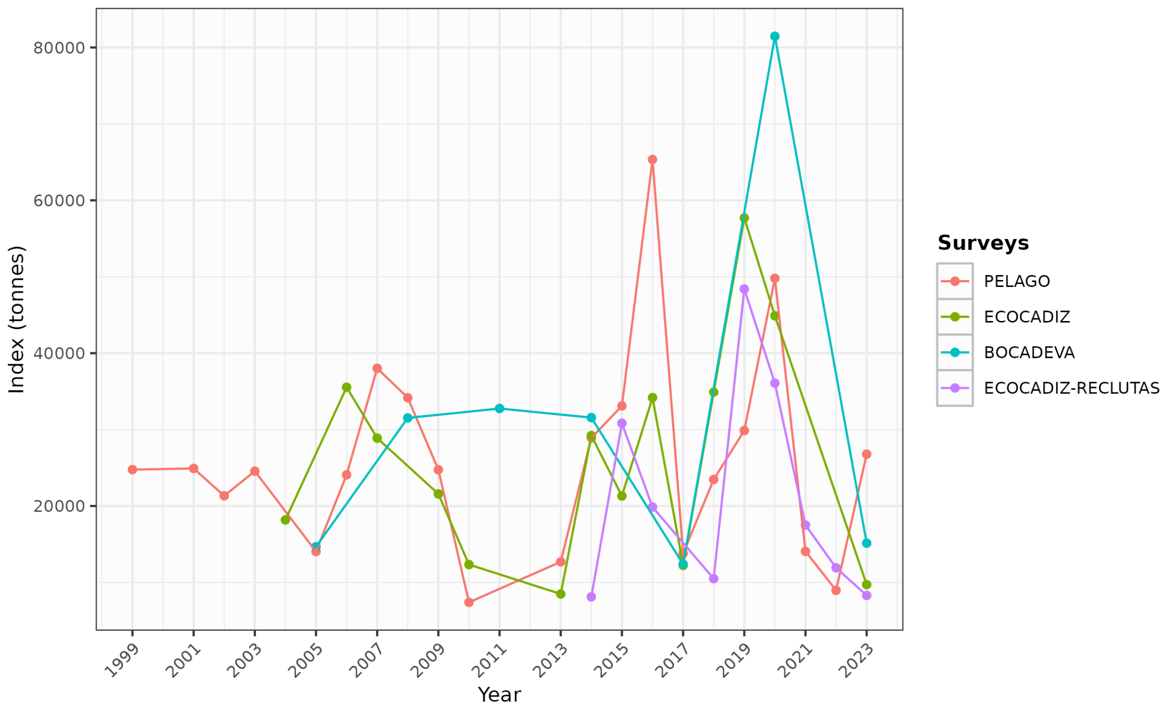


Figure 4: ane.27.9a Southern stock. Biomass estimates from *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS surveys*.

As it can be observed also in the raw data (Figure 5), these patterns reflect a high variability in abundance over time with periods of increase followed by declines in the later years of each series.

Acoustic Biomass (ton) by surveys				
year	PELAGO	ECOCADIZ	BOCADEVA	ECOCADIZ-RECLUTAS
1999	24763			
2001	24913			
2002	21335			
2003	24565			
2004		18177		
2005	14041		14673	
2006	24082	35539		
2007	38020	28882		
2008	34162		31527	
2009	24745	21580		
2010	7395	12339		
2011			32757	
2013	12700	8487		
2014	28917	29219	31569	8113
2015	33100	21305		30827
2016	65345	34184		19861
2017	13797	12229	12392	
2018	23473	34908		10493
2019	29876	57700		48398
2020	49787	44887	81466	36070
2021	14065			17512
2022	8972			11912
2023	26786	9714	15138	8300

Figure 5: ane.27.9a Southern stock. Acoustic biomass (ton) by surveys *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS*.

Age composition

In the model, the age proportion of the commercial fleet (*SEINE*) by quarter from 1989 to 2023, is used (Figure 6). It can be observed that age-0 proportion compared to other ages has been increasing in the last years while age-1 predominates in Q1 and Q2, with a constant proportion over time. Age-0 is not recorded in Q1 and Q2 by convention. In Q3 and Q4, the proportion of age-1 individuals decreases as the proportion of age-0 increases. Additionally, ages 2 and 3 exhibit lower and variable proportions across all quarters over the years, without a defined pattern of change.

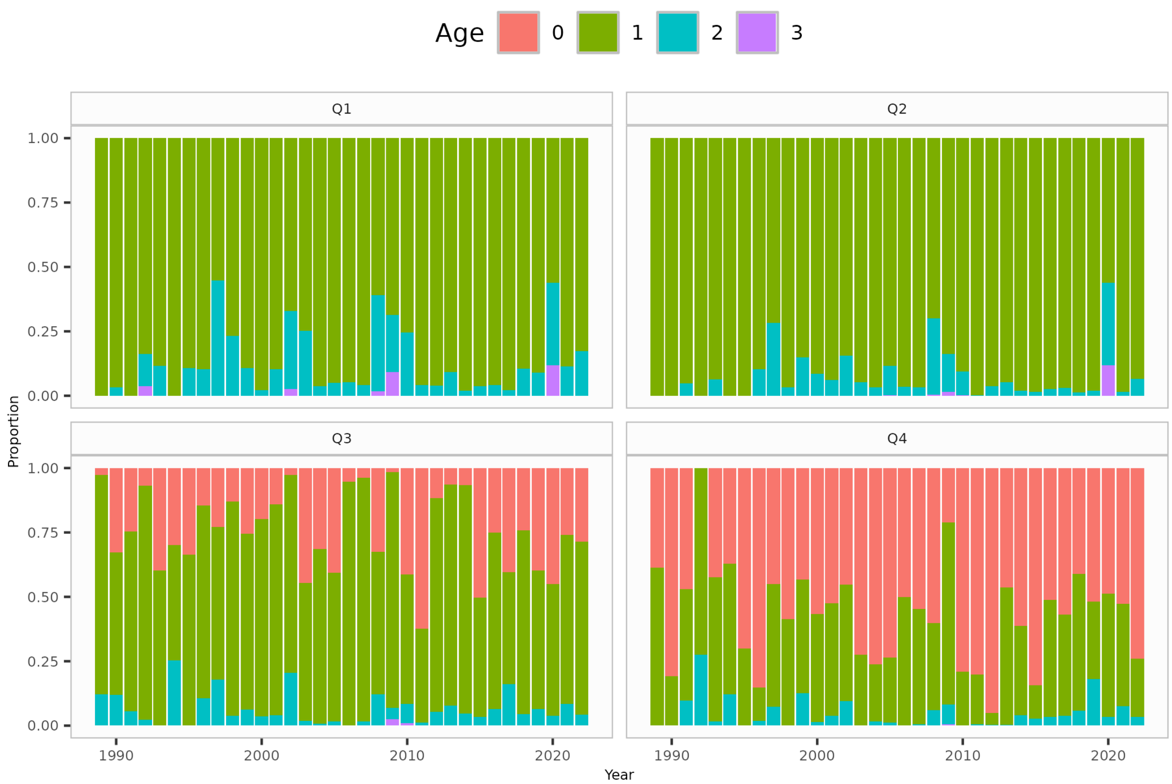


Figure 6: ane.27.9a Southern stock. Age proportion in the commercial fleet catches (*SEINE*) by quarter (1989 to 2023).

Figure 7 shows the yearly age proportions from surveys *PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS* that were used as input for the model. It can be observed that in the *PELAGO* survey, conducted in the second quarter (Q2), age 1 represents the highest proportion over time, with a presence of ages 2 and 3, and no records of age 0 individuals. The *ECOCADIZ* survey, primarily conducted in the third quarter (Q3), shows a predominance of age 1, with an increase in the proportion of age 0 from 2010 onwards; in 2004 and 2006, when the survey was conducted in the second quarter (Q2), no age 0 individuals were recorded by convention. The *ECOCADIZ-RECLUTAS* survey, conducted since 2014 in October (fourth quarter, Q4), shows a higher proportion of age 0, followed by age 1, with lower representation of ages 2 and 3.

In the *SS3* model, age-based data from the *PELAGO* survey were included only for the period 2014-2023, when age-length keys from the surveys were available, as per WKPELA 2018. The *ECOCADIZ-RECLUTAS* index relies exclusively on the biomass of age-0 individuals, allowing it to serve as a direct measure of recruitment.

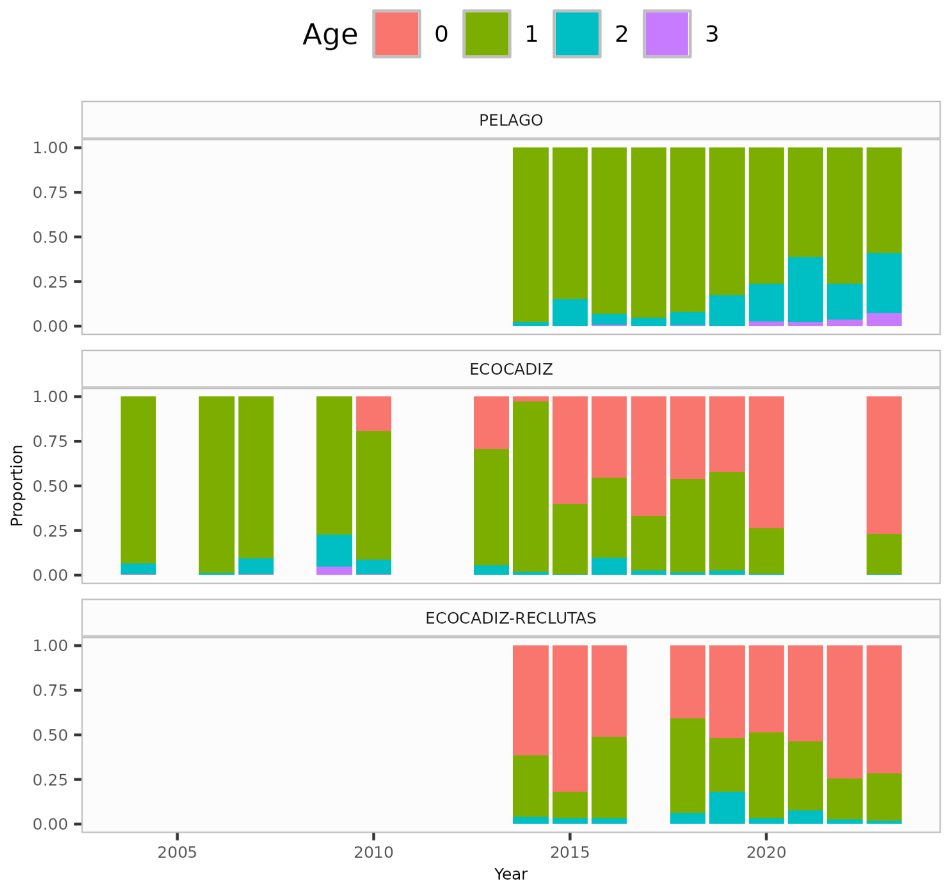


Figure 7: ane.27.9a Southern stock. Age proportion in acoustic surveys estimates (*PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS*).

Weigth-at-age

Figure 8 presents the age-specific weight-at-age values at the start of each season, estimated from external data sources. The figure illustrates that mean weight differences between age groups remain consistent over time, with some variability observed across quarters. Individuals aged 3 show greater variability in mean weight compared to younger age groups. For further details, refer to the working document by *Zuñiga et al.(2024) WD: Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).*

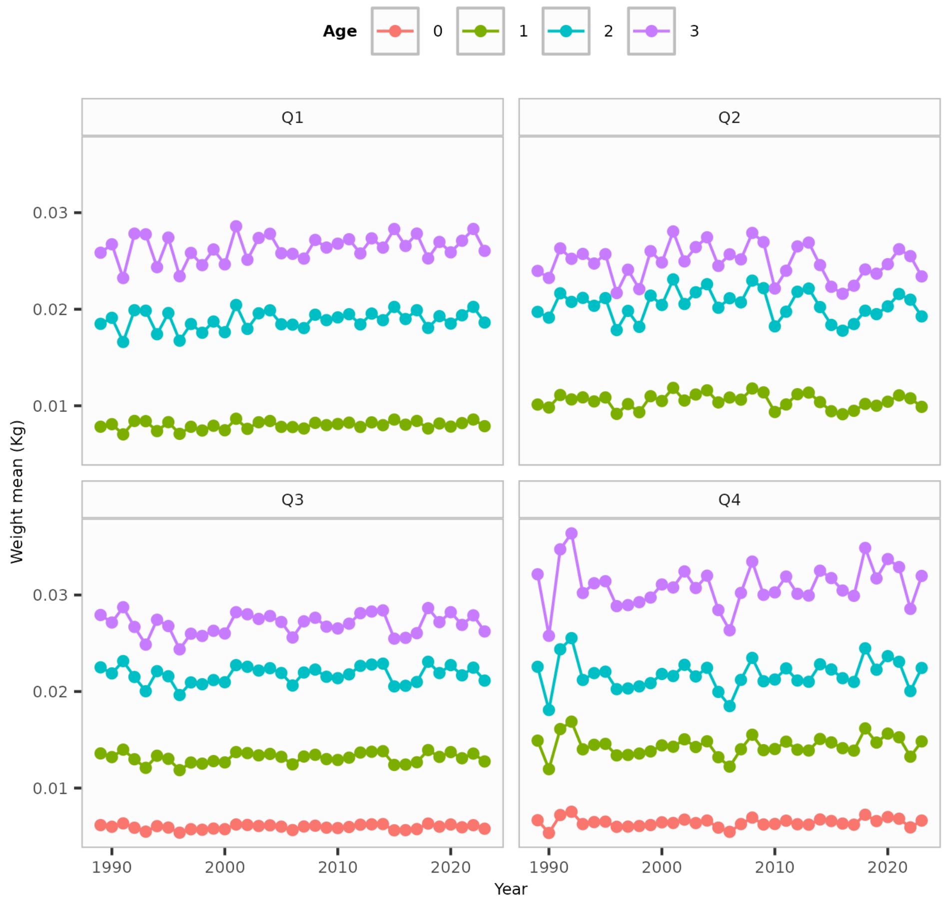


Figure 8: ane.27.9a Southern stock. Weight at age by quarters.

Model settings

Natural mortality

Age-specific natural mortality input values at the beginning of the year were derived from external data sources. For further details, refer to the working document by *Rincón et al. 2024 WD: Growth and natural Mortality parameters estimation for anchovy 9a South.*

Parameter	Age_0	Age_1	Age_2	Age_3
natM1	2.97	1.6	2.48	2.48

Maturity

Due to some inconsistencies in the maturity ogives not noticed during WKPELA 2018, we assume that all individuals with age 1 or higher (B_{1+}), are mature i.e. these abundance estimates result equivalent to spawning stock biomass (SSB) estimates.

Parameter	Age_0	Age_1	Age_2	Age_3
Maturity	0	1	1	1

Growth

It is not modelled explicitly.

Recruitment

Equilibrium recruitment (R_0) was estimated in the base model, and steepness (h) fixed at 0.8, supported by studies from Hsu *et al.* (2024) and Thorson (2020), which are consistent with pelagic species. This value is biologically reasonable for small pelagic species due to their fast growth, early maturity, and short lifespan, allowing them to maintain high reproductive potential at low biomass levels. The recruitment standard deviation (sigmaR) was adjusted after 5 iterations, starting from an initial value of 0.6 and converging to the recommended value of sigmaR = 0.33, as specified by the sigma_R_info object in SS3.

The early recruitment deviations for the initial population were estimated from 1961.7. A recruitment bias adjustment ramp (Methot and Taylor, 2011) was applied to this early period, and bias-adjusted recruitment was estimated for the main period. Recruitment deviations for the main period were estimated for 1991 - 2023.

Fishing mortality

Calculation of fishing mortality is performed by using the hybrid F method that does a Pope's approximation to provide initial values for iterative adjustment of the Baranov continuous F values to closely approximate the observed catch. Total catch biomass by year is assumed to be accurate and precise and the F values are tuned to match this catch.

Catchability

All the surveys are assumed to be relative indices of abundance. The catchability is modelled with a simple q linear model.

Selectivity

The fishery and the surveys selectivity were defined as logistic functions fixed over time, except for *BOCADEVA*, where selectivity was fixed at 1 from age 1 onwards, assuming it is a indicator of spawning biomass. Nevertheless, considering the difference in age patterns over the years in the *ECOCADIZ* survey it was decided to split it into two periods: 2004-2014 and 2015-2023.

Data weighting

Constant standard errors of 0.05 and 0.3 were assumed for quarterly catches and surveys, respectively.

The age compositions were adjusted assuming a multinomial error structure with variance described by the sample size, set at 100 for both, the commercial fleet and acoustic surveys. After that, these data was weighted using the Francis method TA1.8 (Francis, 2011), which was adjusted after 5 iterations.

Initial population

It is calculated by estimating an initial equilibrium population modified by age composition data in the first year of the assessment (Methot and Wetzel, 2013). The model starts in 1988 and the equilibrium population age structure was assumed to be in an exploited state with an initial catch of catch Q1 = 1208, catch Q2 = 2033, catch Q3 = 683, catch Q4 = 223 tonnes, assuming the average catch between 1989-1994 for each season.

Variance estimates for all estimated parameters are calculated from the Hessian matrix. Minimisation of the likelihood is implemented in phases using standard ADMB process. The phases in which estimation will begin for each parameter are shown in the control file available in the TAF repository for this stock (https://github.com/ices-taf/2024_ane.27.9a_south_benchmark). The R packages r4ss version 1.50.0 (Taylor *et al.*, 2021) and ss3diags version 1.10.3 (Carvalho *et al.*, 2021) were used to process and view model outputs. All analyses were conduction in R version 4.4.1 (2024-06-14).

Diagnostics

The model successfully converged, as evidenced by the Hessian matrix being positive definite and the final gradient being relatively small, with a gradient value of 0.0000258. The "Status" column in Figure 9 shows that the initial model configuration has allowed for adequate optimization of the parameters. Additionally, the gradient for all parameters is relatively small. It is important to note that the bounds imposed on the initial parameters have not restricted the search for optimized values, as reflected in the "Afterbound" column.

Parameter	Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Afterbound
SR_LN(R0)	15.866400	1	1.0	25.0	20.0	OK	0.0817914	0.000025771500000	OK
InitF_seas_1_flt_1SEINE_Q1	0.416433	1	0.0	3.0	0.3	OK	0.0792145	-0.000002067720000	OK
InitF_seas_2_flt_2SEINE_Q2	0.824384	1	0.0	3.0	0.3	OK	0.1037190	0.000000051804400	OK
InitF_seas_3_flt_3SEINE_Q3	0.443340	1	0.0	3.0	0.3	OK	0.1161430	-0.000000146502000	OK
InitF_seas_4_flt_4SEINE_Q4	0.286632	1	0.0	3.0	0.3	OK	0.1184200	0.000001006850000	OK
LnQ_base_PELAGO(5)	1.149240	1	-7.0	5.0	0.0	OK	0.2582830	0.000010967400000	OK
LnQ_base_ECOCADIZ(6)	0.855584	2	-7.0	5.0	0.0	OK	0.1582320	-0.000001783390000	OK
LnQ_base_BOCADEVA(7)	1.482650	2	-7.0	5.0	0.0	OK	0.1907530	-0.000000241541000	OK
LnQ_base_ECORECLUTAS(8)	-0.292167	1	-7.0	5.0	0.0	OK	0.1285470	-0.000000036404900	OK
Age_inflection_SEINE_Q1(1)	0.923326	2	0.0	4.0	0.0	OK	0.8640190	-0.000007860690000	OK
Age_95%width_SEINE_Q1(1)	0.198597	2	0.1	0.3	0.2	OK	2.2350500	0.000000179365000	OK
Age_inflection_SEINE_Q2(2)	0.194189	2	0.1	0.3	0.2	OK	2.2130400	-0.000000003534300	OK
Age_95%width_SEINE_Q2(2)	0.216707	2	0.0	4.0	0.5	OK	2.3077700	-0.000000004601900	OK
Age_inflection_SEINE_Q3(3)	0.800988	2	0.0	4.0	0.0	OK	0.1411190	-0.000000895401000	OK
Age_95%width_SEINE_Q3(3)	0.610032	2	0.0	4.0	0.5	OK	0.0739844	0.000001454390000	OK
Age_inflection_SEINE_Q4(4)	1.179070	2	0.0	4.0	0.0	OK	0.2860840	-0.000000505532000	OK
Age_95%width_SEINE_Q4(4)	1.233920	2	0.0	4.0	0.5	OK	0.1418720	-0.000001356490000	OK
Age_inflection_PELAGO(5)	1.005460	2	0.0	3.5	0.9	OK	0.0925685	-0.000021391100000	OK
Age_95%width_PELAGO(5)	0.255726	2	0.1	0.4	0.3	OK	3.7549100	0.000000044397200	OK
Age_inflection_ECOCADIZ(6)	1.750000	2	0.0	3.5	0.2	OK	39.1278000	-0.000000000774443	OK
Age_95%width_ECOCADIZ(6)	0.204918	2	0.0	3.5	0.5	OK	1.0583500	-0.000008708260000	OK
Age_inflection_ECOCADIZ(6)_BLK1repl_2004	0.327971	4	0.0	3.5	0.5	OK	1.6941800	0.000000485457000	OK
Age_inflection_ECOCADIZ(6)_BLK1repl_2015	0.161121	4	0.0	3.5	0.0	OK	0.8323810	0.000009213230000	OK

Figure 9: ane.27.9a Southern stock. Parameters estimated by the initial base model.

Model fit and residuals

The Figure 10 shows that the abundance indices from the acoustic surveys exhibit a high level of variability, as reflected by the width of the assumed confidence intervals, with a maximum coefficient of variation of

30%. The model follows the overall trend of the indices, though it encounters some difficulties in accurately fitting the extreme biomass values, both the highest and lowest. However, it adequately reproduces the general trend of variability in biomass levels presented by the survey estimates.

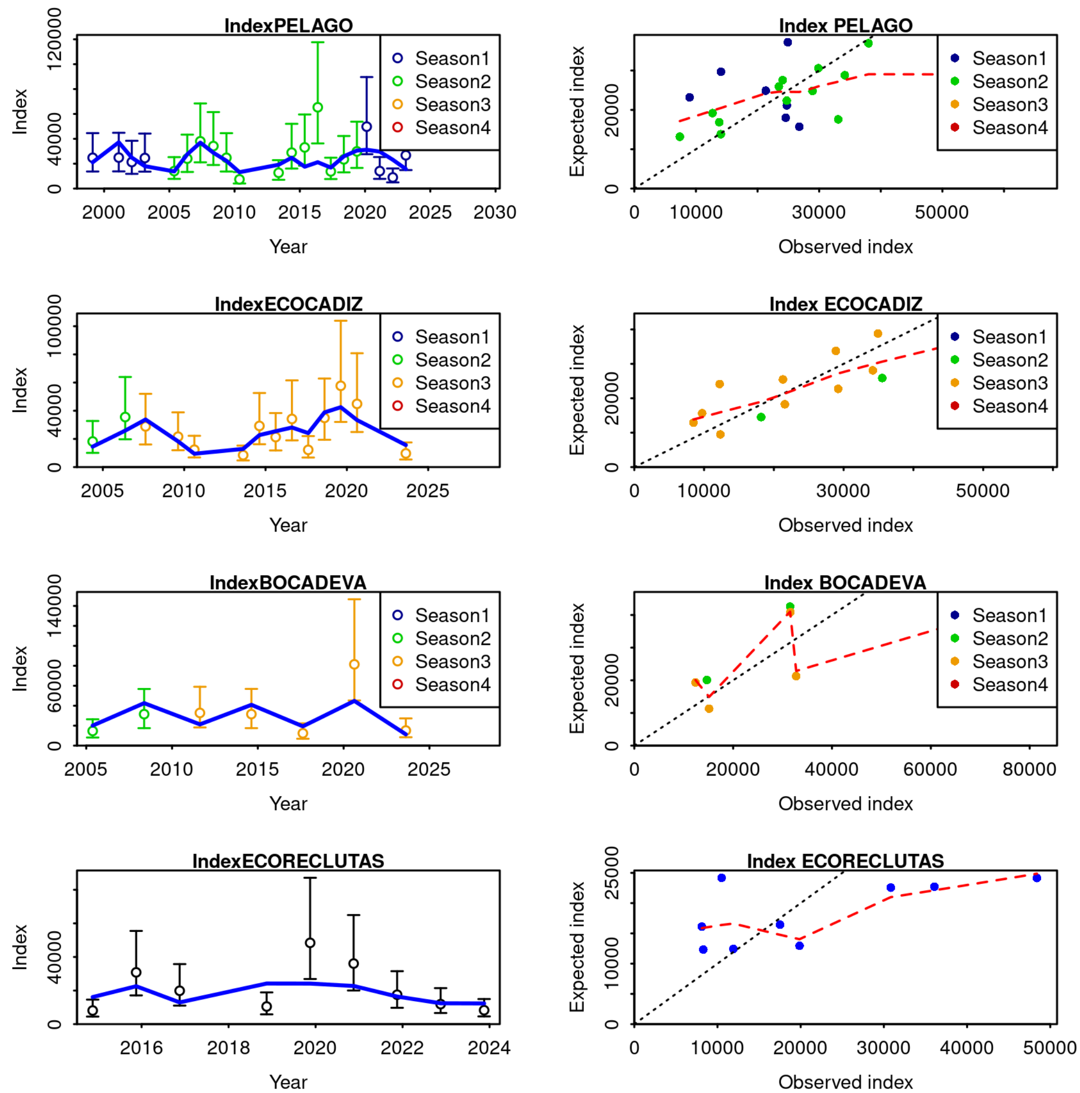


Figure 10: ane.27.9a Southern stock. Model fit to the data (left panel) and observed versus expected values (right panel) of the indices from the surveys *PELAGO*, *ECOCADIZ*, *BOCADEVA* and *ECOCADIZ-RECLUTAS*. The lines indicate a 95% uncertainty interval around the index values based on the lognormal error model assumption.

Figure 11 shows that the residuals from the fit of the biomass indices are randomly distributed, with p-values greater than 0.05 (*PELAGO* = 0.415, *ECOCADIZ* = 0.889, *BOCADEVA* = 0.358, *ECOCADIZ-RECLUTAS* = 0.374). The estimated root mean square error (RMSE) for the joint residual analysis is 43%.

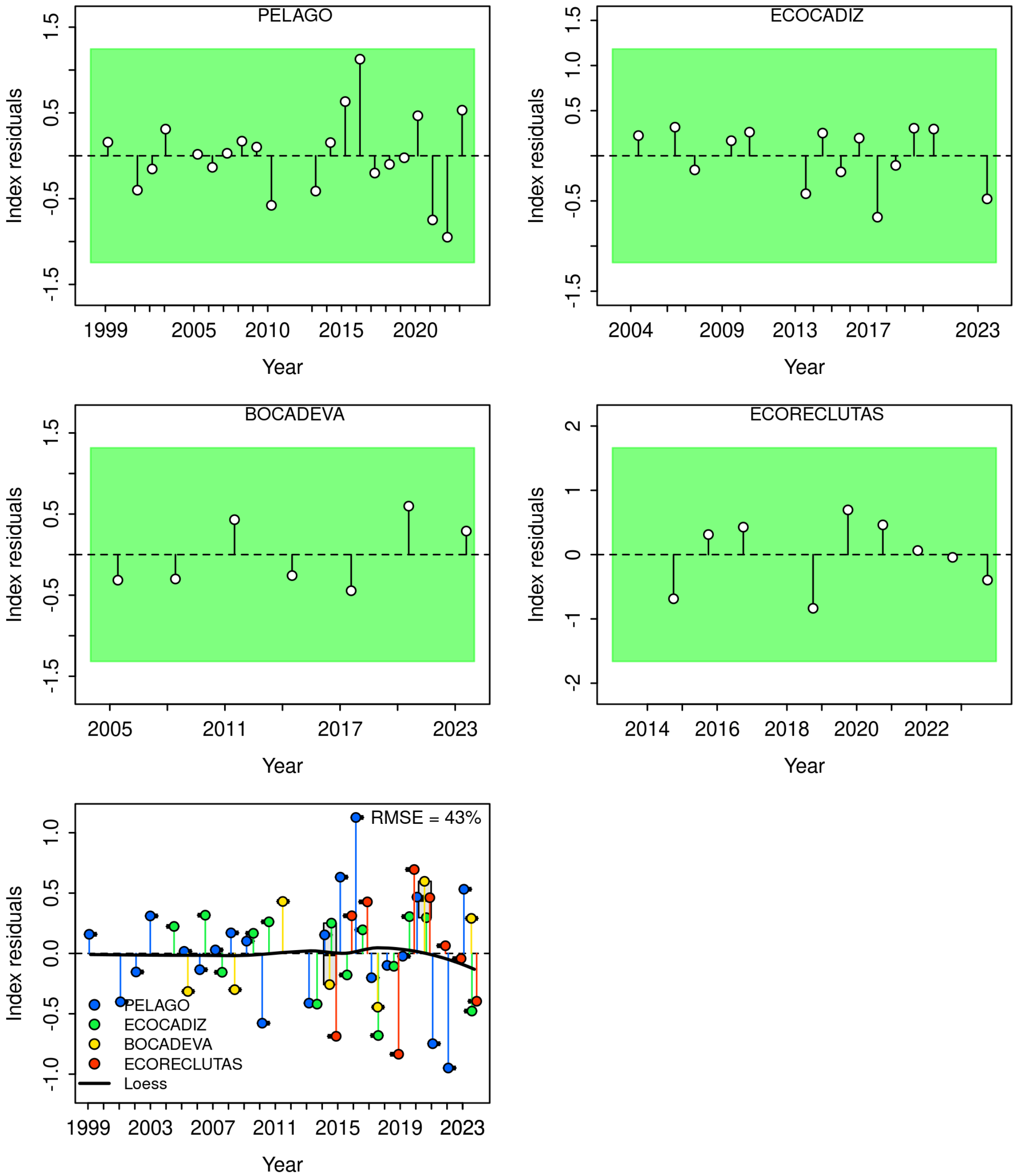


Figure 11: ane.27.9a Southern stock. a) Run test plots for the fit of acoustic and DEPM survey indices. Green shading indicates no evidence (p>=0.05) and red shading indicates evidence (p<0.05) for rejecting the hypothesis of a randomly distributed residual time series, respectively. The shaded area (green/red) spans three standard residual deviations on either side of zero, and red points outside the shading violate the three-sigma limit for that series. b) Joint residual plots for the fit of acoustic and DEPM survey indices (bottom left panel). Vertical lines with points show the residuals, and the solid black line show loess smoother through all residuals. Boxplots indicate the median and quantiles in cases where residuals from multiple indices are available for a given year, with the solid black line showing a loess smoother. The root mean square error (RMSE) is included in the top right corner of the panel.

Estimated mean age for the *SEINE* fleet (one by quarter) with a 95% confidence intervals based on current sample sizes, is presented in Figure 12.

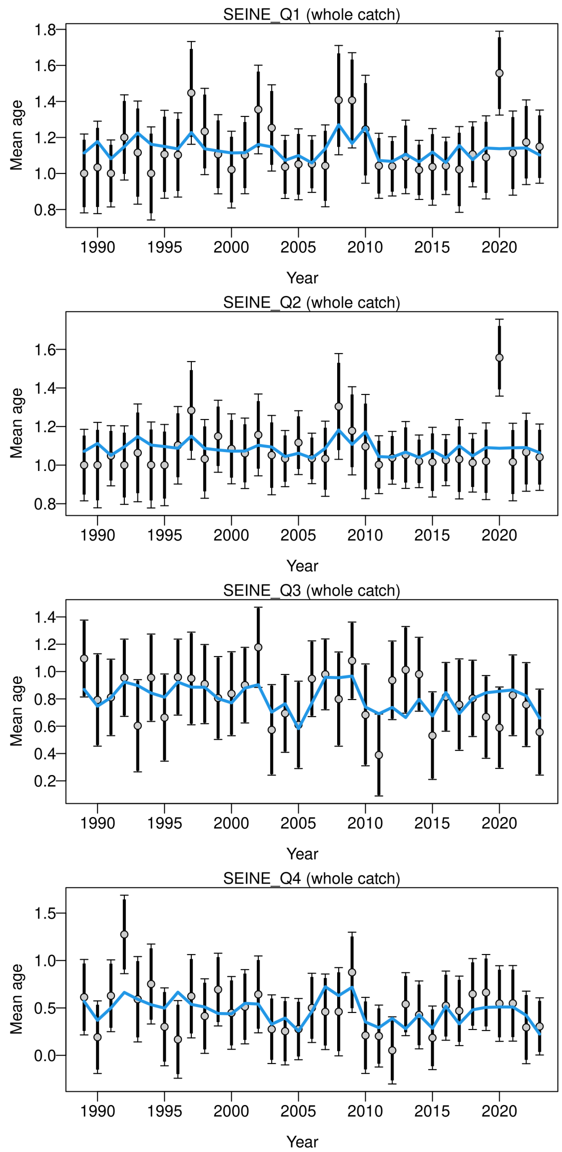


Figure 12: Mean age for commercial fleet by quarters with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.

While mean age for the *PELAGO* and *ECOCADIZ* surveys is presented in Figure 13.

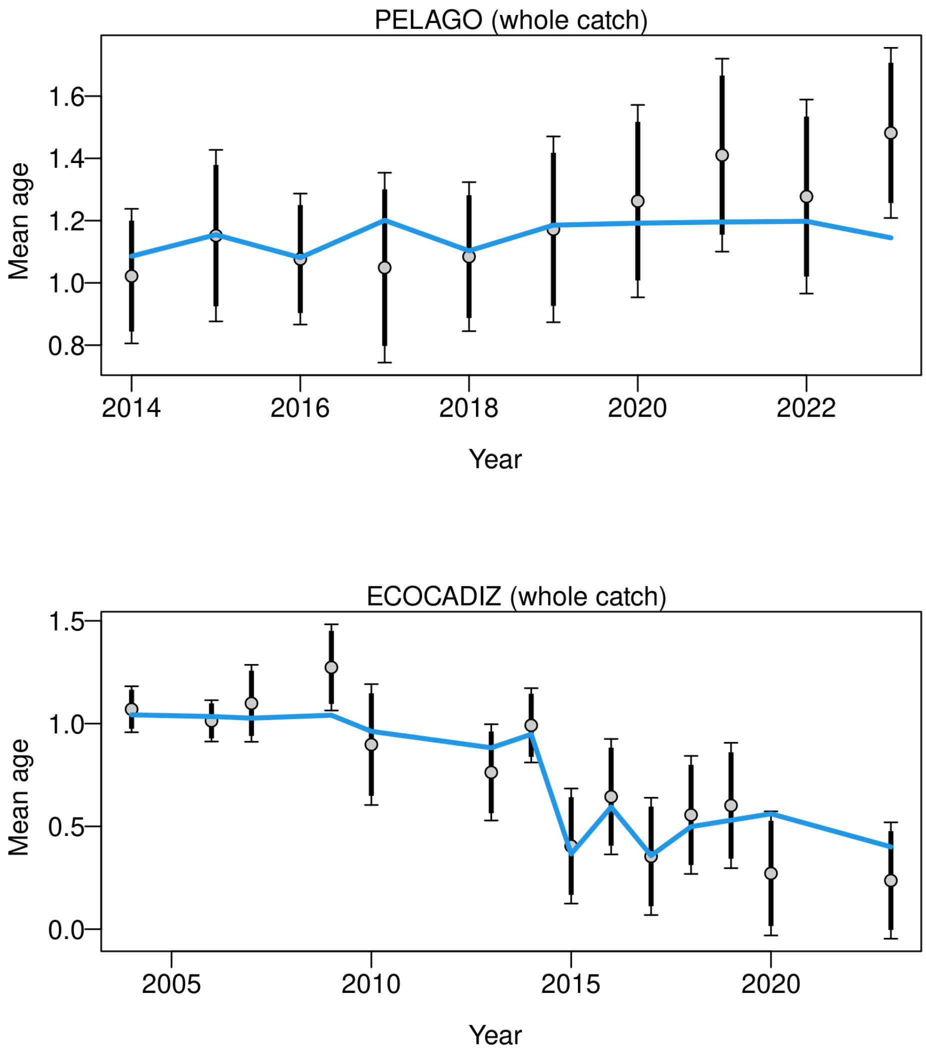


Figure 13: Mean age for *PELAGO* and *ECOCADIZ* with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.

The Figure 14 shows the estimated age compositions aggregated over time for the different age data sources: *SEINE*, *ECOCADIZ* and *PELAGO*. Overall, a high proportion of young individuals (ages 0 and 1) is observed in both the commercial fleet catches and acoustic surveys, with a significant decline in the proportions of older age classes. The green lines represent the model fits, demonstrating an adequate fit, with the aggregated age compositions well reconstructed.

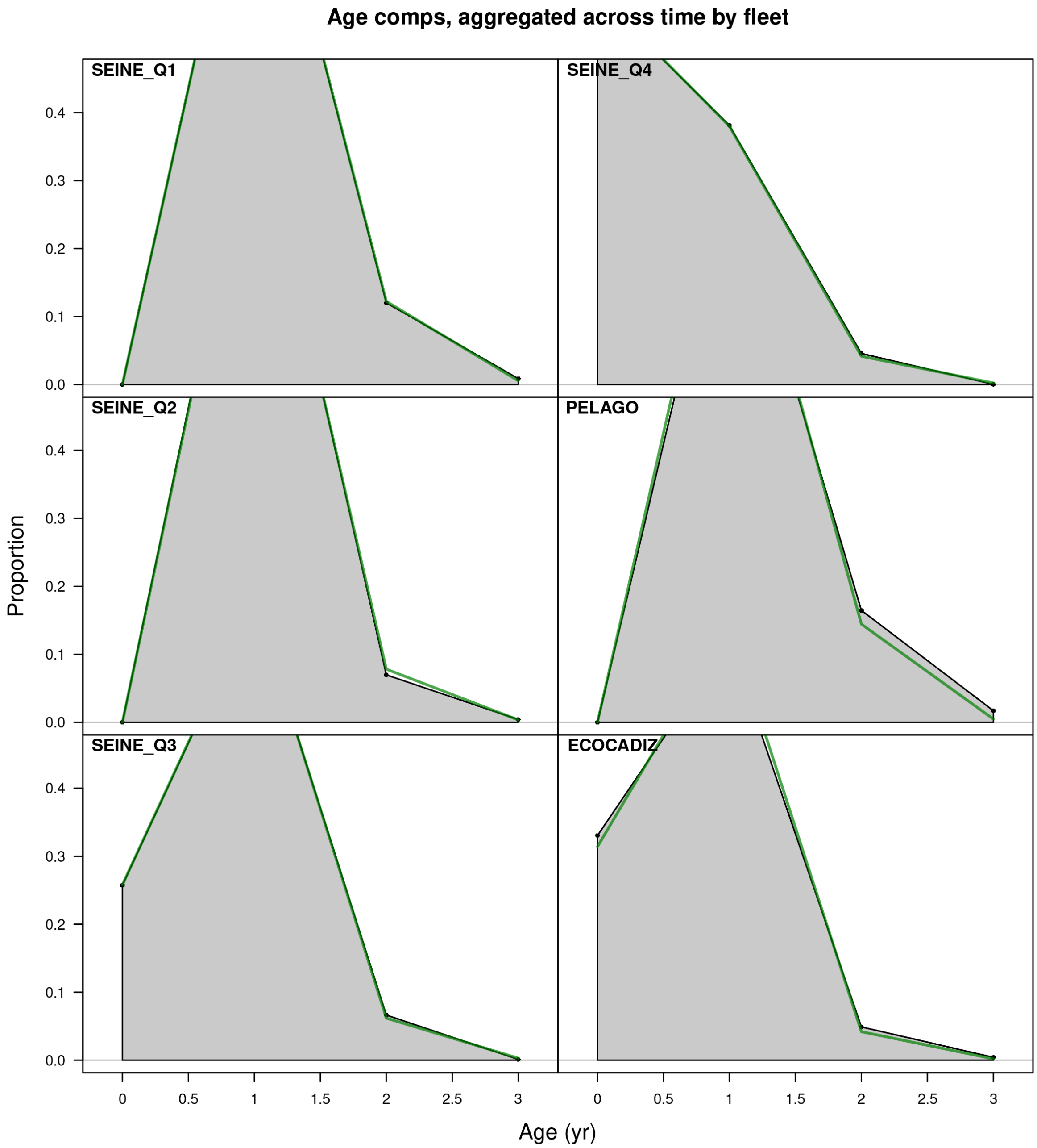


Figure 14: ane.27.9a Southern stock. Model fit to the aggregated age composition data from the *SEINE* fishery, and the acoustic surveys *PELAGO* and *ECOCADIZ*. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 15 shows the estimated age composition for the commercial fleet in the first quarter.

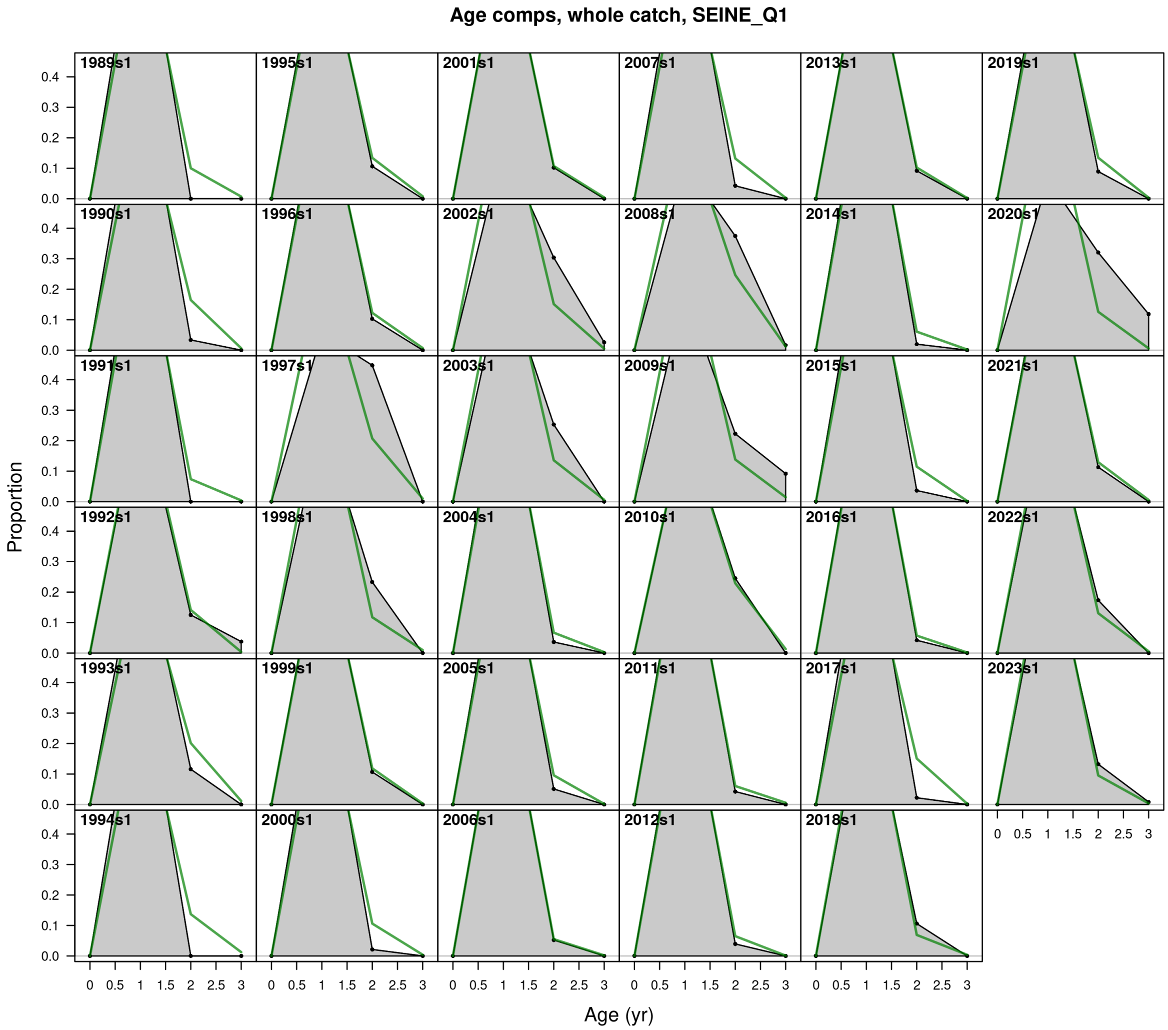


Figure 15: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ1* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 16 shows the estimated age composition for the commercial fleet in the second quarter.

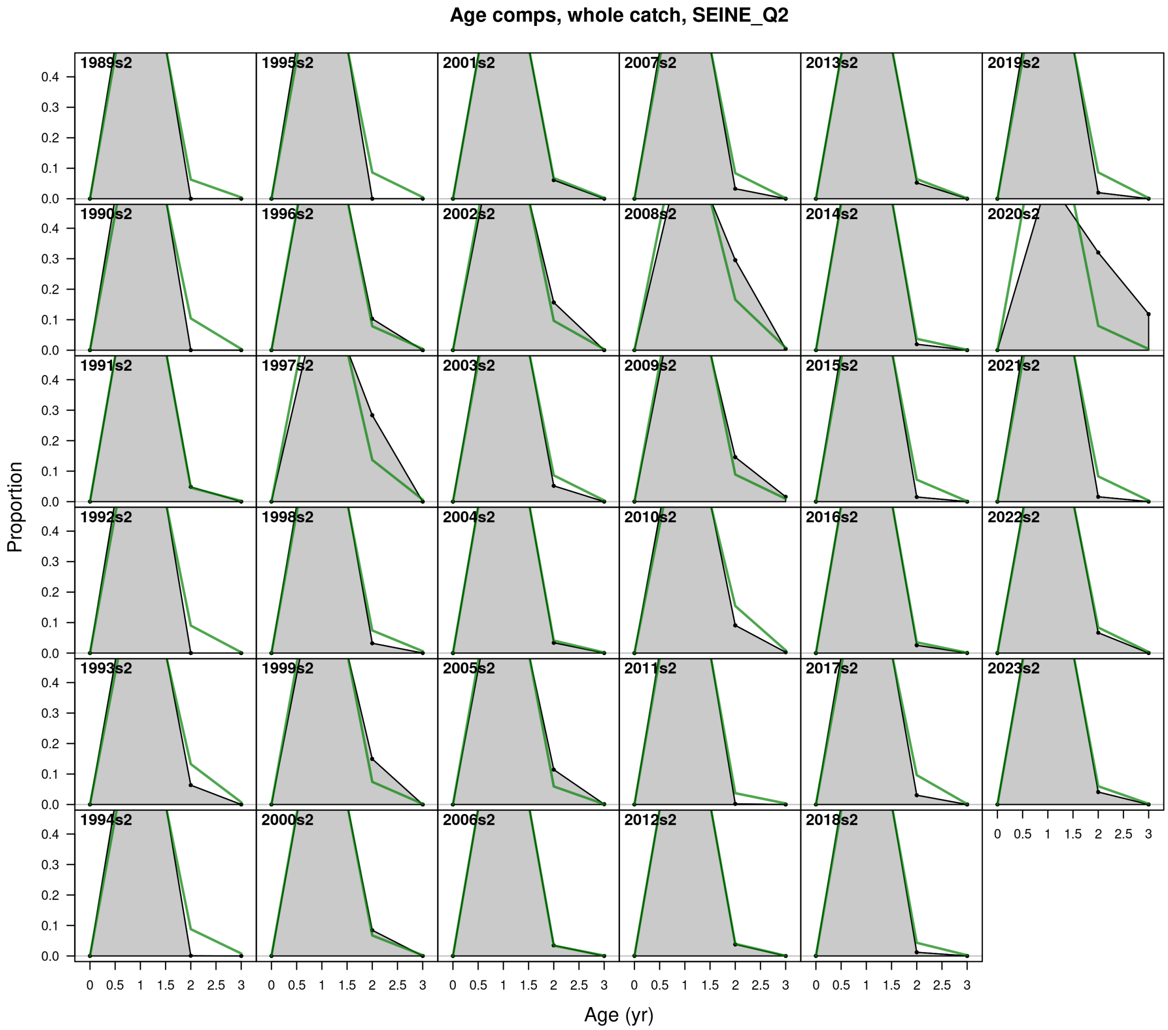


Figure 16: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ2* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 17 shows the estimated age composition for the commercial fleet in the third quarter.

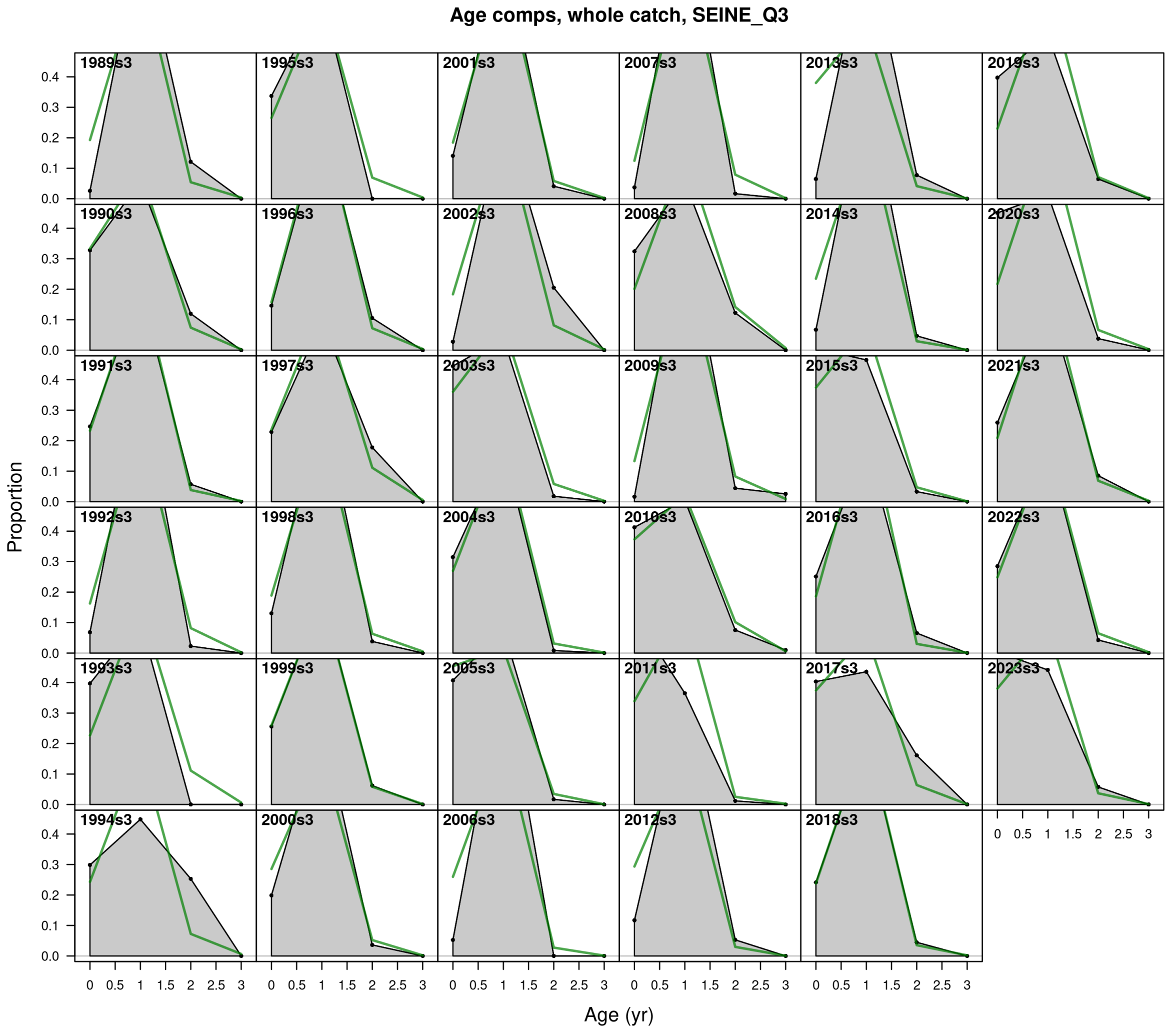


Figure 17: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ3* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 18 shows the estimated age composition for the commercial fleet in the fourth quarter.

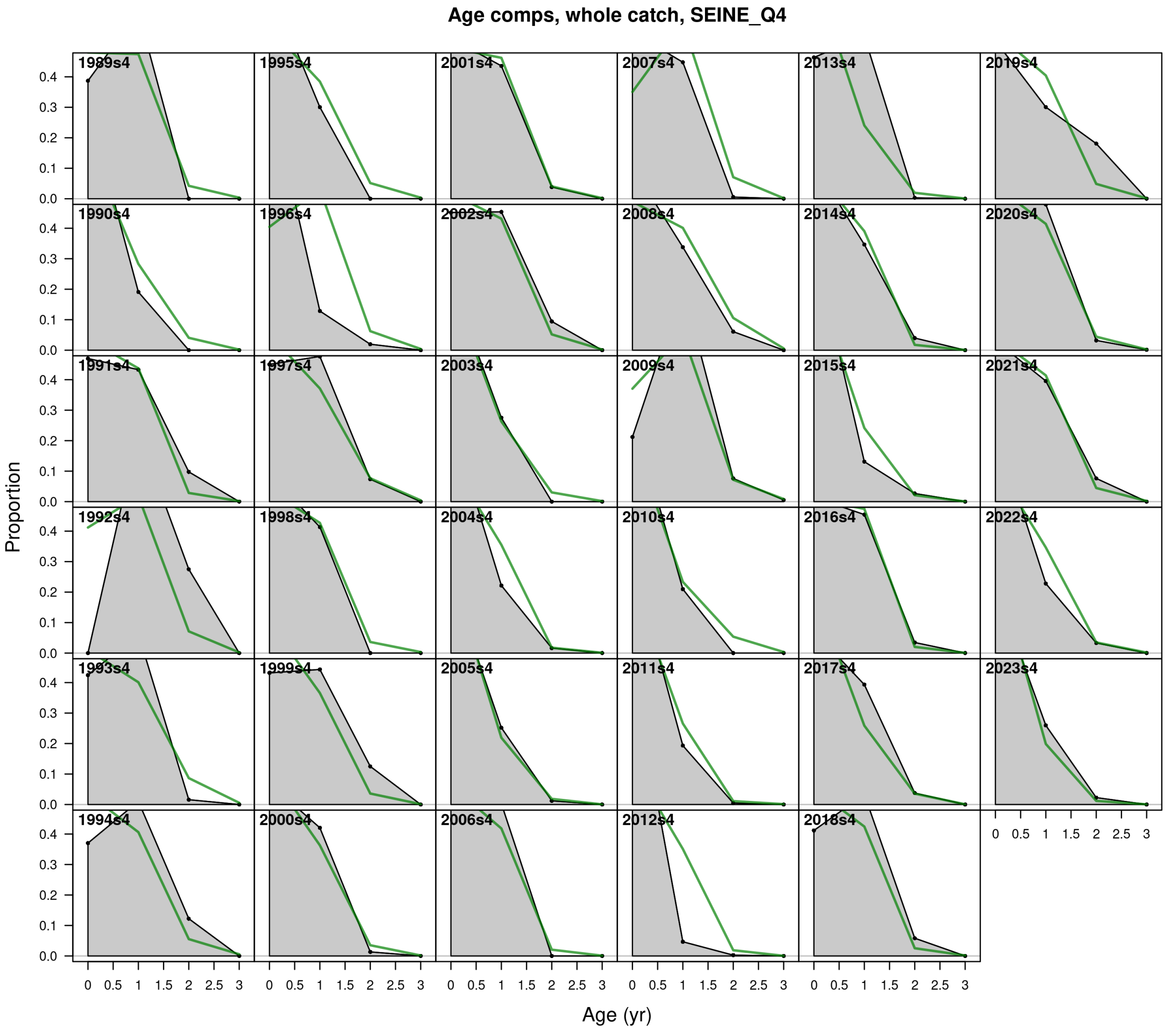


Figure 18: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ4* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Although the aggregated fits show an overall adequate result, some years exhibit variability in the age composition of the commercial fleet (*SEINE*) catches. This pattern is also evident in the annual data fits for the *PELAGO* survey, especially in the later years of the series (2020-2023), where there is a tendency to overestimate age 1 and underestimate age 2 (Figure 19).

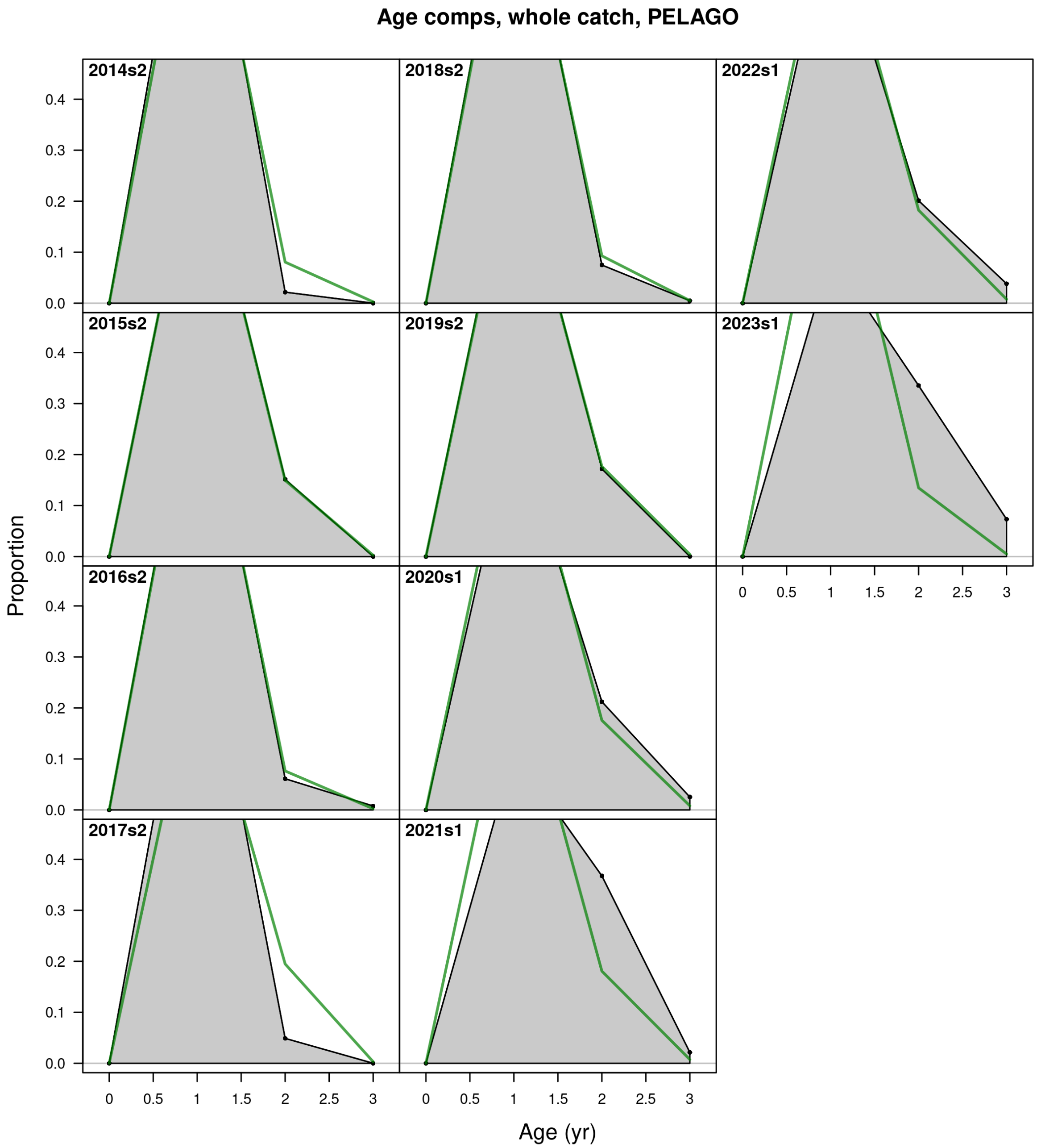


Figure 19: ane.27.9a Southern stock. Model fit to the age composition data from the *PELAGO* spring survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

In the *ECOCADIZ* survey, there are difficulties in estimating ages 0 and 1, with a tendency to underestimate age 0 and overestimate age 1 from 2016 to 2023 (Figure20).

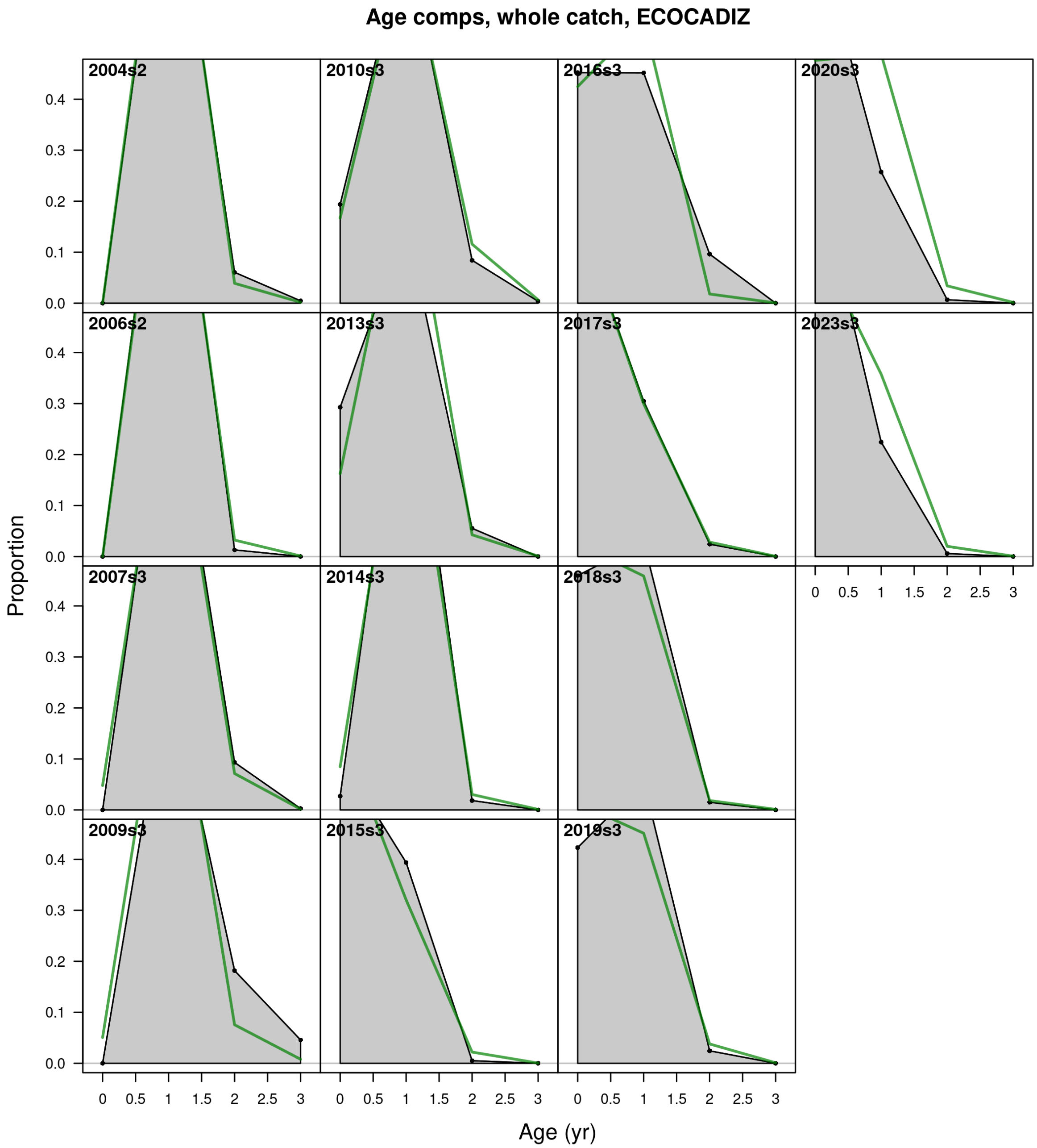


Figure 20: ane.27.9a Southern stock. Model fit to the age composition data from the *ECOCADIZ* summer survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

Bubble plots of the residuals corresponding to the fit of the *SEINE* data are presented in Figure 21.

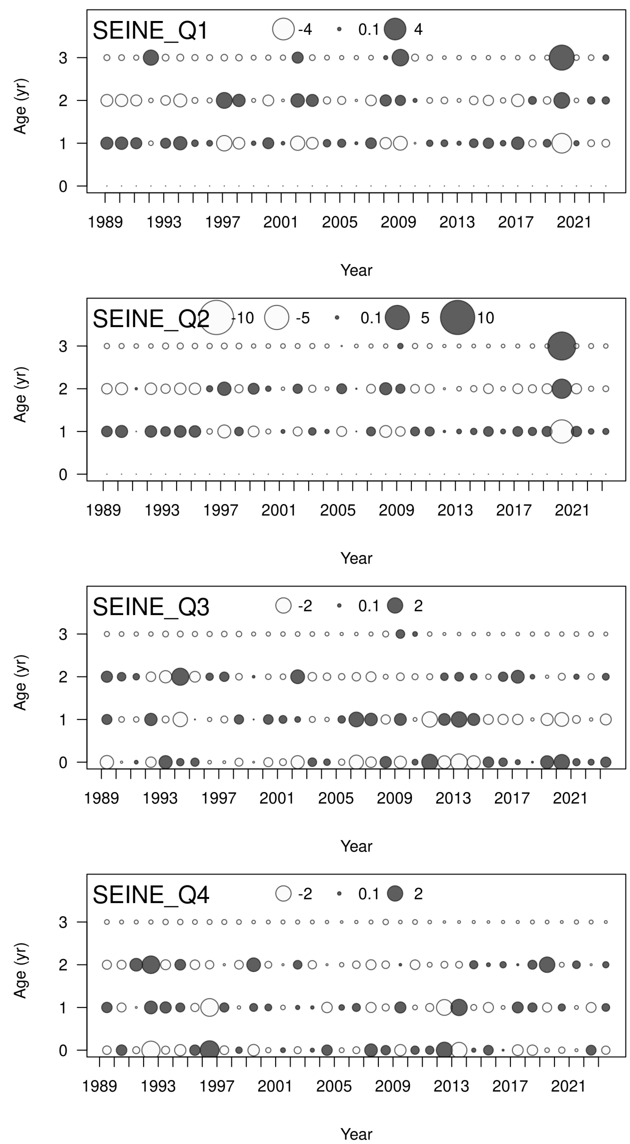
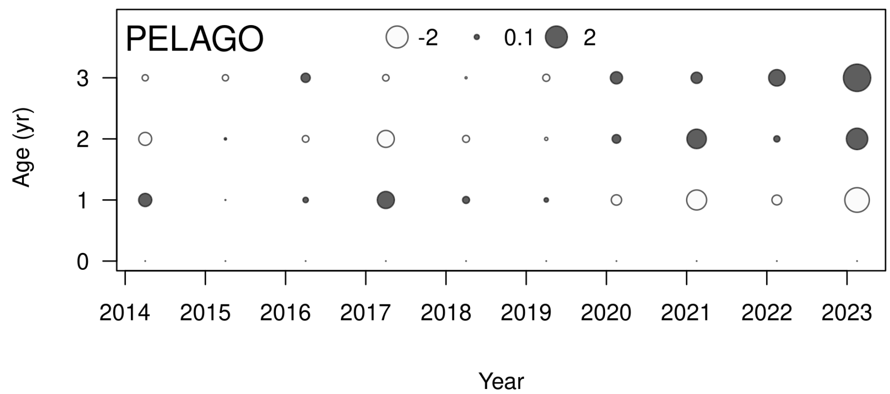


Figure 21: ane.27.9a Southern stock. Pearson residuals, comparing across fleets. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

Bubble plots of the residuals corresponding to the fit of the surveys age-data are presented in Figure 22.



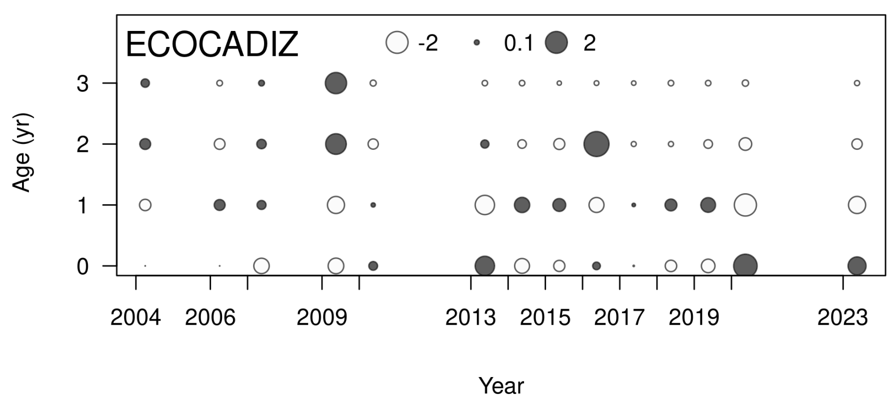


Figure 22: ane.27.9a Southern stock. Pearson residuals, comparing across surveys. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

The Figure 23 shows that the residuals from the fit of the age proportions are randomly distributed, with p-values greater than 0.05 in the case of the commercial fleet (*SEINE_Q1*: 0.202, *SEINE_Q2*: 0.267, *SEINE_Q3*: 0.087, *SEINE_Q4*: 0.618) and the acoustic surveys *ECOCADIZ*: 0.532, and with p-values less than 0.05 in the case of *PELAGO* (0.004). The estimated root mean square error (RMSE) for the joint residual analysis is 27.8%.

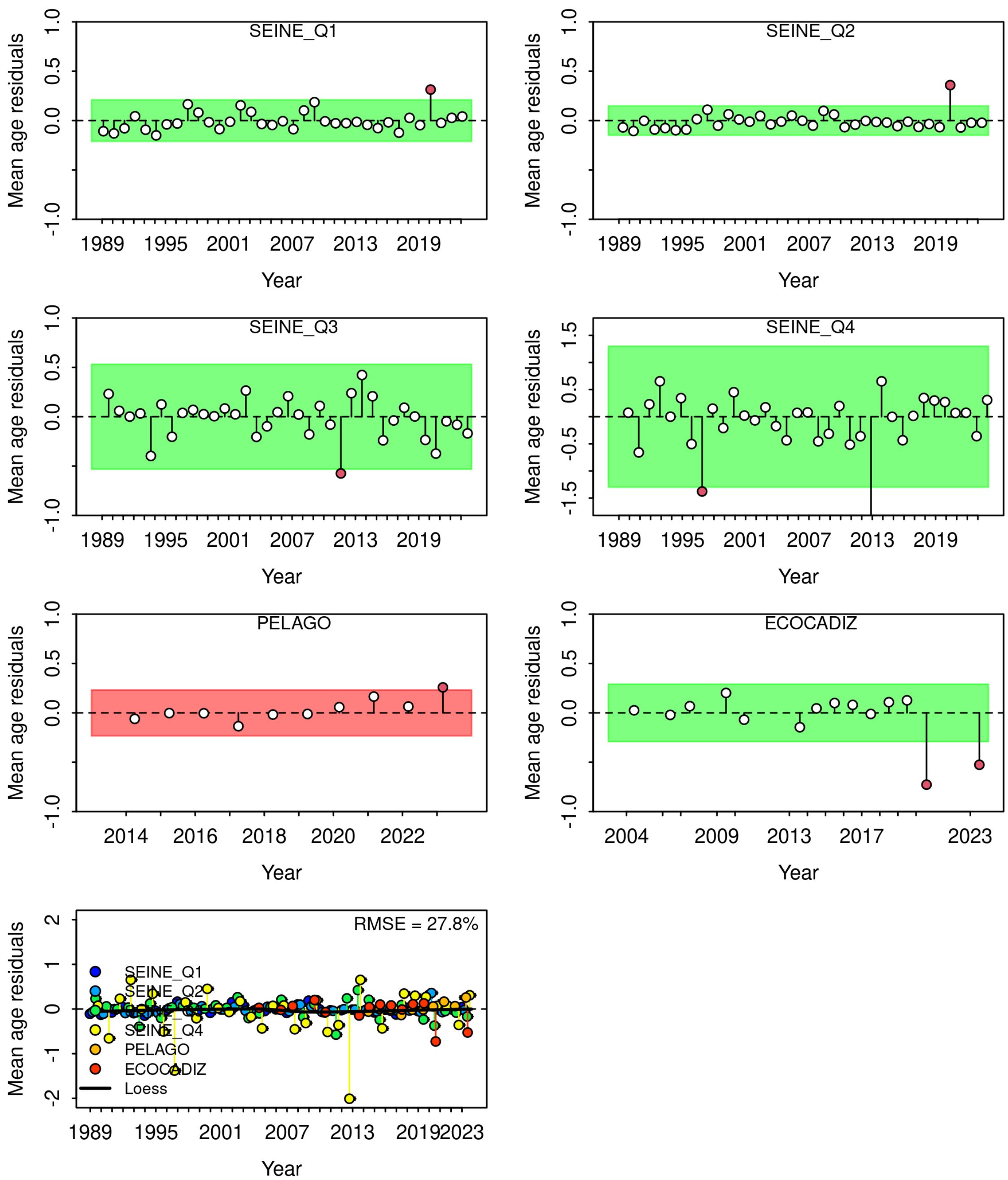


Figure 23: ane.27.9a Southern stock. a) Runs test results for fits to annual mean age estimates for the surveys (*PELAGO* and *ECOCADIZ*), and the fishery (*SEINE*). Green shaded (green/red) area spans three residual standard deviations to either side from zero, and the red points outside of the shading violate the 'three-sigma limit' for that series. b) Joint residual plots for annual mean length estimates for surveys and fishery (bottom left panel). Vertical lines with points show the residuals, and the solid black line show loess smoother through all residuals. Root-mean squared error (RMSE) is included in the upper right-hand corner of the panel.

Retrospective analysis

Figure 24 shows a retrospective pattern in both spawning biomass and fishing mortality in the base model. The retrospective analysis of the assessment model reveals that, in terms of Mohn's rho (mean of retrospective anomalies), the reduction in data leads to a pattern of underestimation in fishing mortality (rho = 0.2600665) and overestimation in spawning biomass (rho = -0.106914). These Mohn´s rho values were inside the bounds of recommended values, according to the rule proposed by Hurtado-Ferro *et al.* (2014), which states that Mohn's rho index values should be less than 0.30 and greater than -0.22 for short-lived species.

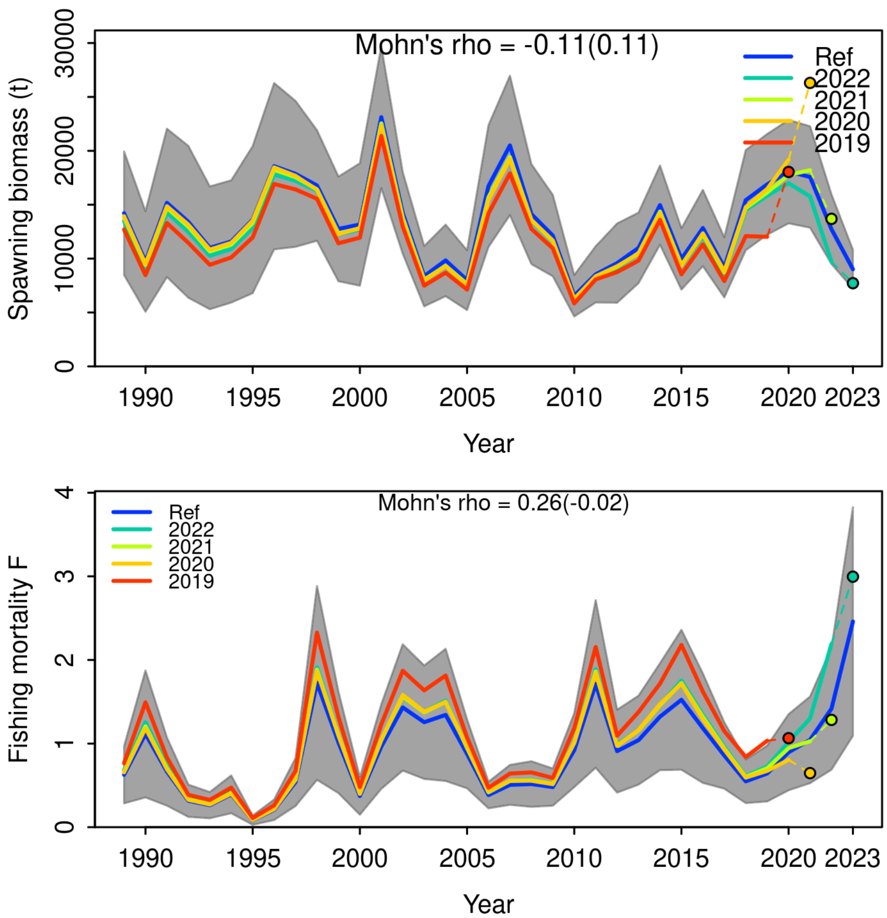


Figure 24: ane.27.9a Southern stock. Retrospective analysis of spawning stock biomass (SSB) and fishing mortality (F). Models conducted by re-fitting the reference model (Ref) after removing five years of observations, one year at a time sequentially. The retrospective results are shown the entire time series. Mohn's rho statistic and the corresponding 'hindcast rho' values (in brackets) are printed at the top of the panels. One-year-ahead projections denoted by color-coded dashed lines with terminal points are shown for each model. Grey shaded areas are the 95% confidence intervals from the reference model.

Results

Stock-recruitment relationship

Recruitment was modeled using a Beverton-Holt stock-recruitment relationship (Figure 25). The assumed level of underlying recruitment deviation error was fixed (σ_R=0.33), equilibrium recruitment was estimated ($log(R_0)$)=15.87) and steepness (h) was fixed at 0.8.

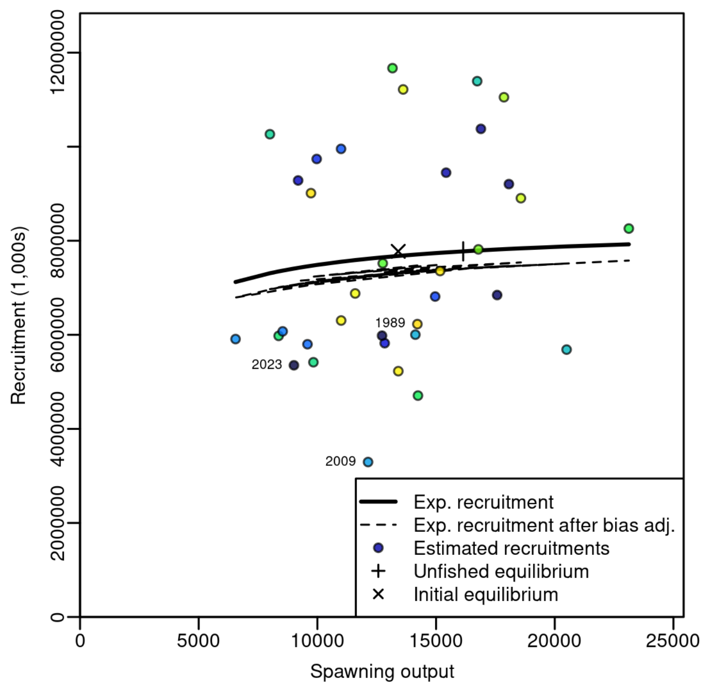


Figure 25: ane.27.9a Southern stock. Stock-recruit curve with labels on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

Recruitment deviations for the early from 1961.7 and main for 1991 - 2023 periods in the model are presented in (Figure 26).

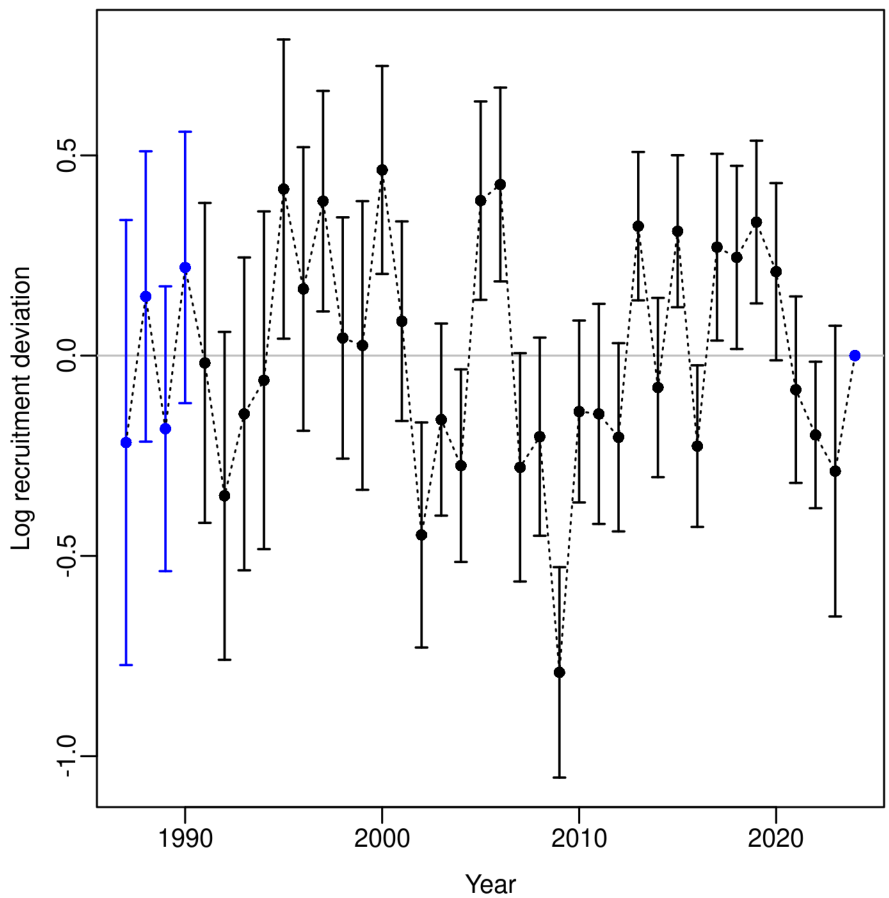


Figure 26: ane.27.9a Southern stock. Recruitment deviations with 95% intervals for the base model (sigmaR = 0.3).

Asymptotic standard errors for recruitment deviations are shown in Figure 27.

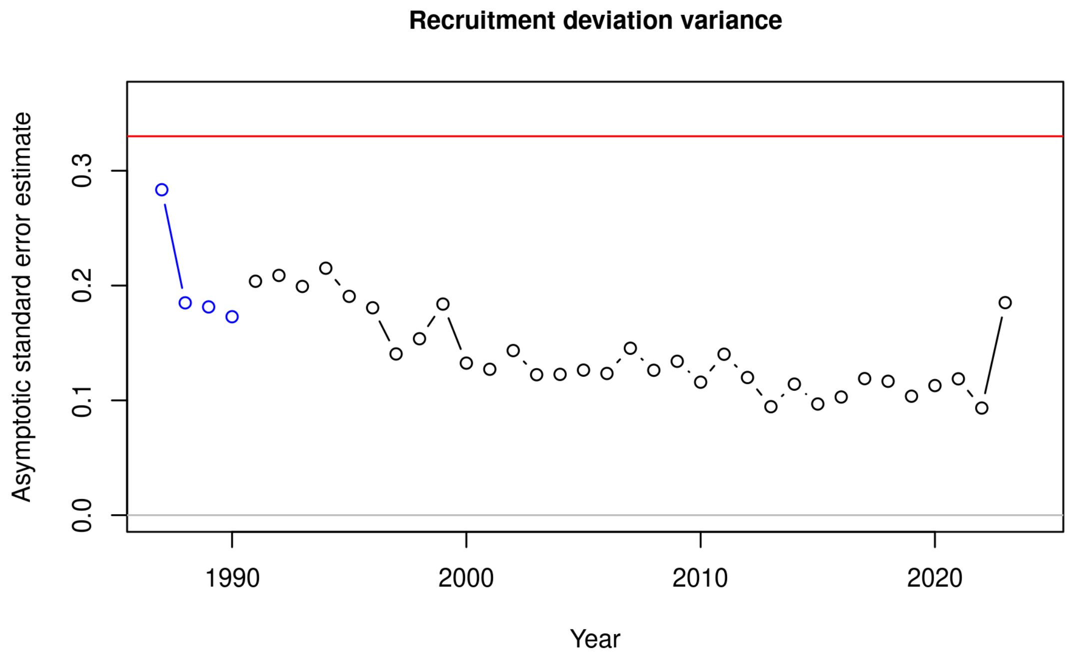


Figure 27: ane.27.9a Southern stock. Asymptotic standard errors for the estimated recruitment deviations.

Recruitment bias adjustment for the different periods is shown in Figure 28.

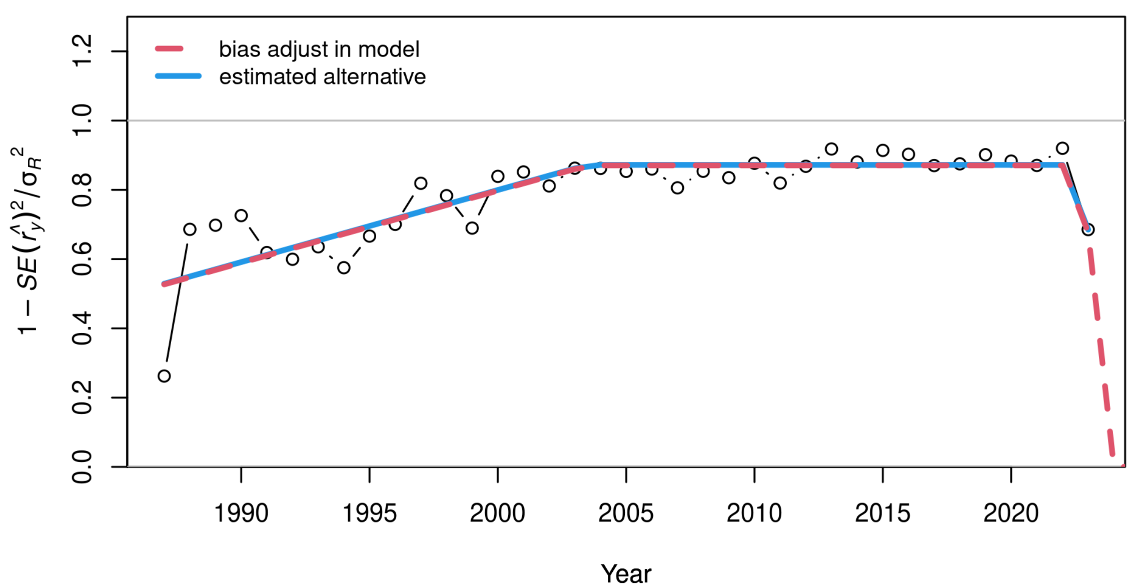


Figure 28: ane.27.9a Southern stock. Recruitment bias adjustment plot for early and main.

Selectivity

Figure 29 shows the estimated selectivity for the age composition of the commercial fleet.

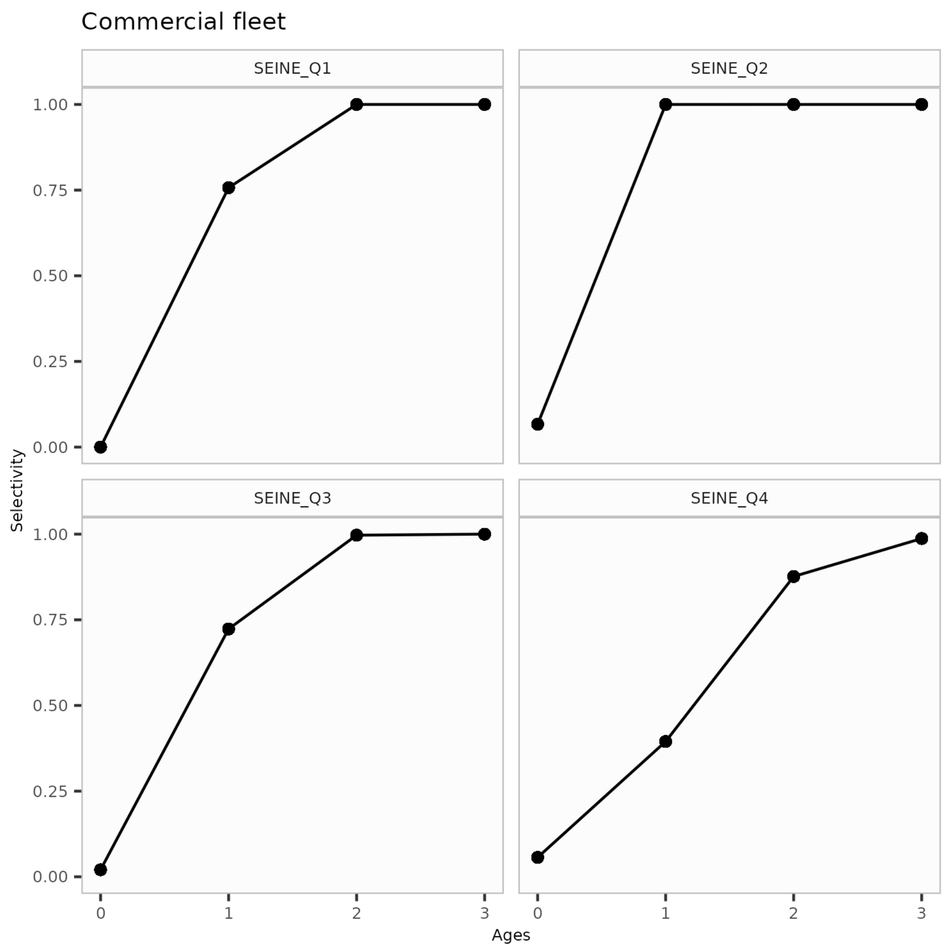


Figure 29: ane.27.9a Southern stock.Estimated selectivity for catch-at-age of commercial fleet (logistic shaped fixed selectivity across all years).

Figure 30 shows the estimated selectivity for the age composition of the acoustic surveys

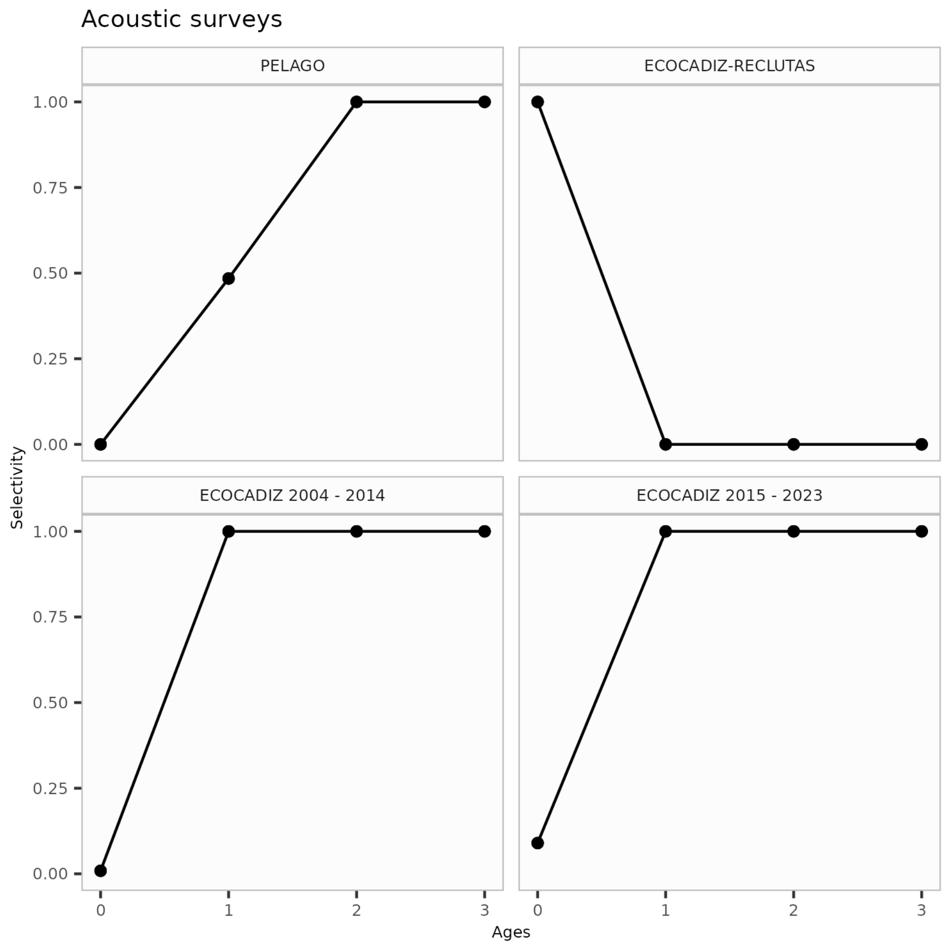


Figure 30: ane.27.9a Southern stock. Estimated selectivity for catch-at-age of surveys (logistic shaped fixed selectivity across all years)

But, it is important to remark that the selectivity assumption for *ECOCADIZ* survey was different from the others, and it was separated into two different periods: 2004 to 2014 and 2015 to 2023, this difference can be appreciated in Figure 31

Catchability

The catchability (q) is adjusted to maintain a consistent relationship between the observed biomass and the vulnerable biomass in acoustic surveys (Figure 31).

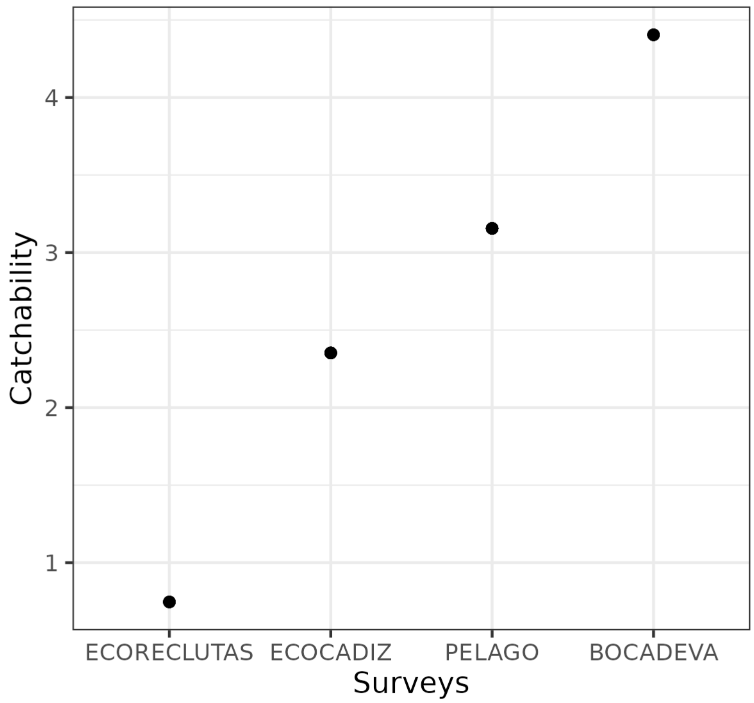


Figure 31: ane.27.9a Southern stock. Estimated catchability parameters for the different surveys indices.

Estimated time series

The Figure 32 shows that total biomass fluctuates around a historical mean of 17.63 thousand tonnes, with a minimum in 2010 of 9.88 thousand tonnes and a maximum recorded in 2001 of 28.34 thousand tonnes. In 2023, the biomass is estimated to be 29% below the historical mean. The catch shows variability around the historical mean of 5.22 thousand tonnes, with a maximum value recorded in 1998 of 9.58 thousand tonnes and a minimum in 1995 of 0.57 thousand tonnes. In 2023, the catch is estimated to be 43% above the historical mean.

The fishing mortality (F_t) fluctuates around a historical mean of 0.9, with a maximum value recorded in 2023 of 2.46 and a minimum in 1995 of 0.08. Confidence intervals range from 0.35 to 0.21, with an average of 0.28. The F_{2023} is estimated to be 173% above the historical mean.

The recruitment (R_t) fluctuates around a historical mean of 7.62 millions recruits, with a maximum value recorded in 2000 of 11.67 millions recruits and a minimum in 2009 of 3.29 millions recruits. Confidence intervals range from 0.26 to 0.09, with an average of 0.16. The R_{2023} is estimated to be 30% below the historical mean.

Finally, the spawning biomass (SSB_t) varies around a historical mean of 13.35 thousand tonnes, with a maximum value recorded in 2001 of 23.12 thousand tonnes and a minimum in 2010 of 6.55 thousand tonnes. Confidence intervals range from 0.27 to 0.1, with an average of 0.18.The SSB_{2023} is estimated to be 32% below the historical mean.

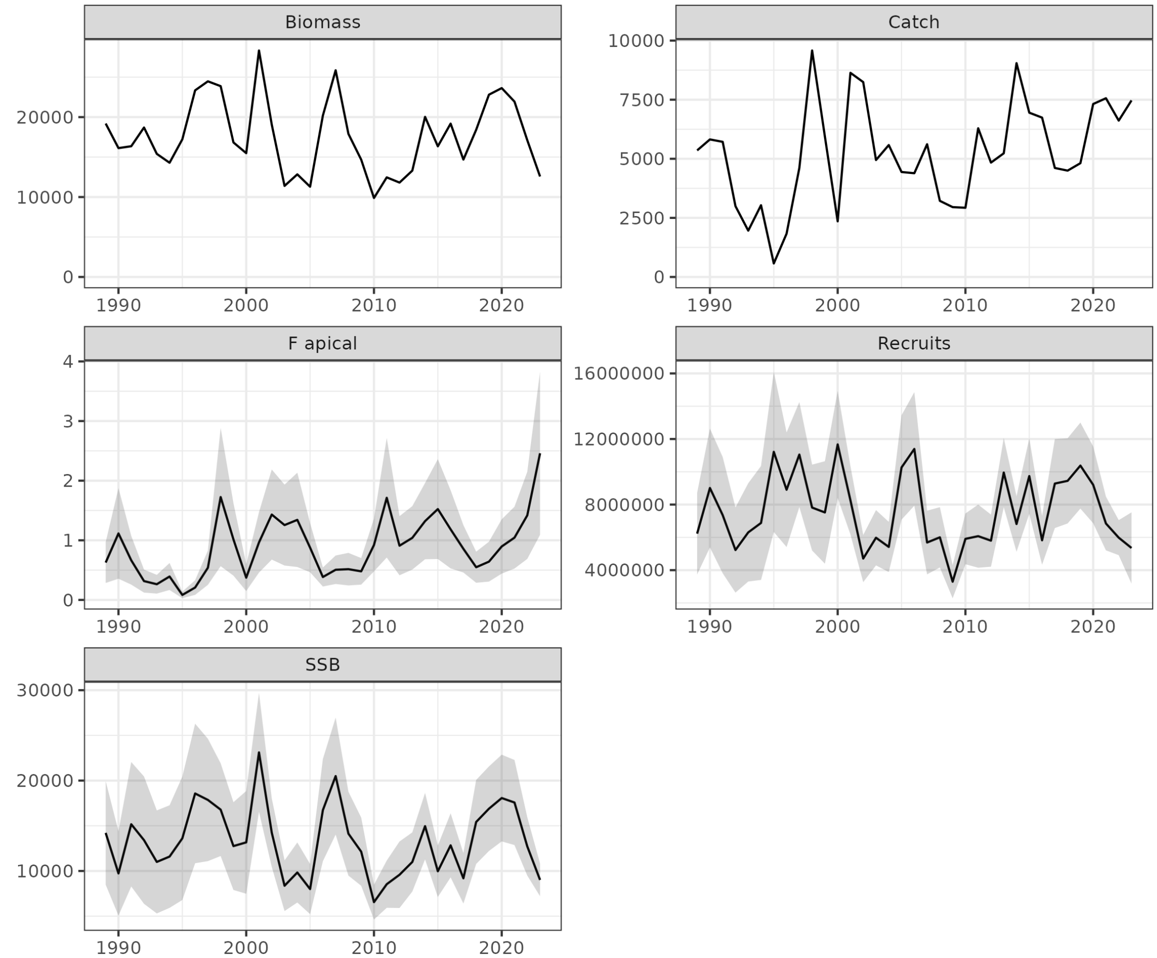


Figure 32: ane.27.9a Southern stock. Time series estimated by the model for annual catches (in tons), recruitment (millions of fish), total biomass and spawning biomass (in tons), and fishing mortality (year-1).

The summarised data resulting from model outputs is shown in Figure 33.

Year	SSB ton	CV SSB	Recruits number	CV Recruits	F apical year-1	CV F apical	Total Biomass ton	Catch ton
1989	14212.70	0.21	6227610	0.20	0.63	0.28	19194.00	5354.25
1990	9729.05	0.24	9011940	0.20	1.12	0.35	16122.50	5819.06
1991	15170.20	0.23	7356110	0.25	0.66	0.31	16357.10	5717.34
1992	13409.60	0.27	5226940	0.25	0.32	0.31	18699.50	2996.70
1993	11000.90	0.26	6303700	0.24	0.26	0.30	15401.60	1959.95
1994	11592.60	0.25	6879120	0.26	0.39	0.29	14289.30	3035.46
1995	13613.20	0.26	11217100	0.22	0.08	0.34	17223.80	570.61
1996	18574.00	0.21	8904840	0.20	0.21	0.30	23347.90	1831.41
1997	17860.20	0.19	11051000	0.15	0.54	0.27	24477.90	4613.21
1998	16783.00	0.16	7816410	0.17	1.73	0.34	23873.30	9582.31
1999	12753.90	0.19	7519210	0.21	1.02	0.31	16831.40	5940.55
2000	13164.20	0.22	11669700	0.14	0.37	0.31	15490.60	2353.44
2001	23121.10	0.14	8259640	0.13	0.96	0.27	28337.70	8636.66
2002	14237.20	0.14	4707280	0.16	1.43	0.27	19064.20	8244.27
2003	8366.95	0.17	5977090	0.14	1.26	0.28	11394.20	4947.81
2004	9832.47	0.17	5416590	0.14	1.34	0.30	12839.10	5581.19
2005	7999.14	0.18	10265200	0.16	0.88	0.24	11292.00	4440.82
2006	16733.10	0.17	11393000	0.15	0.38	0.21	20192.70	4389.09
2007	20500.00	0.16	5685580	0.17	0.51	0.24	25858.90	5616.24
2008	14128.90	0.17	6003020	0.16	0.52	0.27	17907.30	3219.63
2009	12134.70	0.16	3294540	0.16	0.48	0.24	14680.20	2954.92
2010	6552.06	0.15	5909260	0.13	0.92	0.24	9881.38	2927.43
2011	8537.14	0.16	6072950	0.16	1.71	0.30	12462.50	6291.32
2012	9582.81	0.20	5799260	0.14	0.91	0.28	11809.80	4838.21
2013	10996.90	0.15	9953150	0.11	1.04	0.26	13303.40	5231.46
2014	14961.80	0.13	6813700	0.13	1.32	0.25	20031.60	9046.24
2015	9970.18	0.15	9738730	0.12	1.52	0.28	16347.30	6950.09
2016	12835.40	0.14	5821760	0.13	1.18	0.28	19186.00	6741.82
2017	9188.40	0.15	9281840	0.15	0.86	0.24	14687.60	4610.87
2018	15423.10	0.15	9447650	0.14	0.55	0.24	18412.90	4498.81
2019	16888.90	0.14	10378700	0.13	0.64	0.27	22806.60	4813.58
2020	18068.40	0.14	9204590	0.13	0.90	0.26	23631.40	7317.35
2021	17573.50	0.14	6845210	0.12	1.04	0.25	21937.40	7561.60
2022	12723.20	0.13	5981990	0.09	1.42	0.26	17116.90	6615.12
2023	9011.44	0.10	5351940	0.21	2.46	0.28	12571.10	7469.66

Figure 33: ane.27.9a Southern stock. Time series estimated by the model for annual catches (in tons), recruitment (millions of fish), total biomass and spawning biomass (in tons), and fishing mortality (year-1).

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Scenario *S1.0_InitCond_sigmaR_AdjIndexRec*: Assessment for WKBANSP 2024 using age-structured data in SS3: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)

María José Zúñiga[*], Margarita María Rincón[†], Fernando Ramos[‡]

Assessment model

The assessment of the anchovy in ICES division 9a, southern component was performed in Stock Synthesis software, version 3.30.22.1 (SS3, Methot *et al.*, 2024) under the Linux platform. SS3 is a generalized age and/or length-based model that is very flexible with regard to the types of data that may be included, the functional forms that are used for various biological processes, the level of complexity and number of parameters that may be estimated. The model is coded in C++ with parameter estimation enabled by automatic differentiation (www.admb-project.org) and available at the NOAA Fisheries integrated toolbox: https://noaa-fisheries-integrated-toolbox.github.io/SS3. A description and discussion of the model can be found in Methot and Wetzel (2013).

The model is defined quarterly between 1989 and 2023, for one area and it is age-based, where the population is comprised of 3+ age-classes (with age 3 representing a plus group) with sexes combined (male and females are modelled together).

Data

The input data includes total catch (in biomass) and age composition of the catch (in proportion) for the commercial *SEINE* fleet, as well as abundance (in biomass) and age composition from the *PELAGO* and *ECOCADIZ* surveys. Age composition data from *PELAGO* was included only for the period 2014–2023, when age-length keys were available, as specified by WKPELA 2018. The biomass index from the *ECOCADIZ-RECLUTAS* survey, based on the biomass of age-0 individuals, provides a direct measure of recruitment. Spawning stock biomass (SSB) estimates are derived from the triennial *BOCADEVA* survey using DEPM. To account for seasonal variability in catches, the *SEINE* fleet has been subdivided into four quarterly fleets.

The Figure 1 provides a visual representation of the input data used in the model, categorized into three main types: catches, abundance indices, and age compositions. These data are displayed over time (years) and are represented by circles, with the size of each circle reflecting the magnitude of the data.

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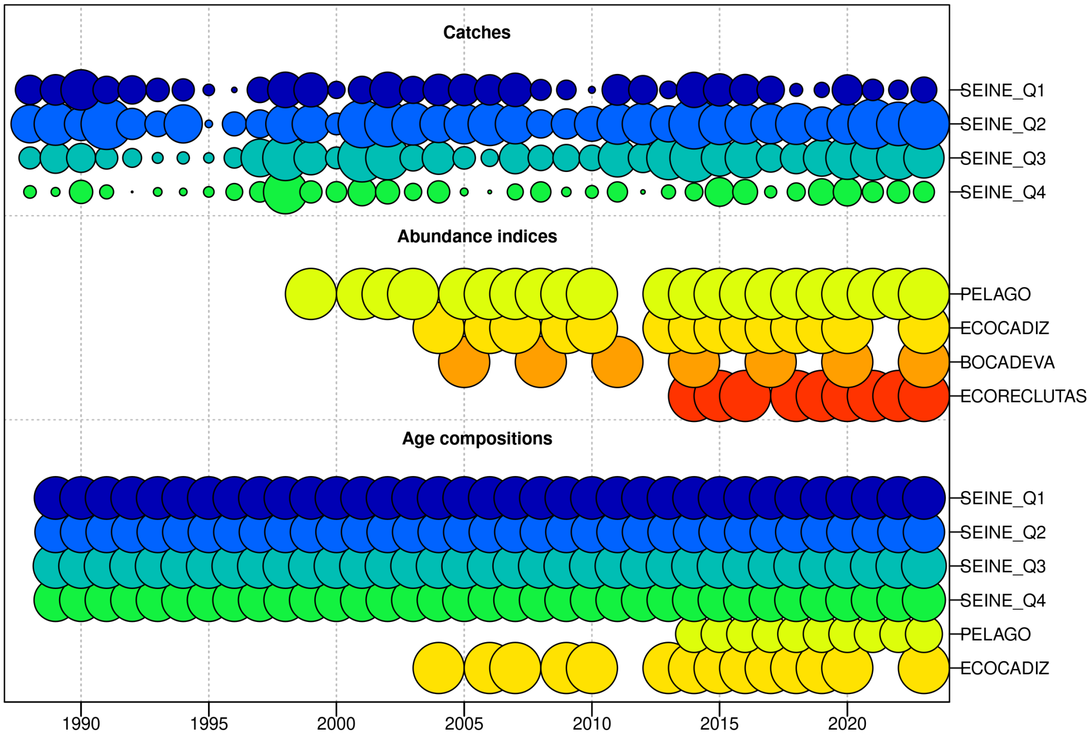


Figure 1: ane.27.9a Southern stock. Summary of model data input by year, where circle area is relative within a data type. Circles are proportional to total catch for catches, to precision for indices and to total sample size for age compositions.

Catches

Anchovy catches in the Gulf of Cádiz exhibit seasonality, with 40.61% concentrated in the second quarter (Q2), averaging 2120.26 tons historically, followed by the third quarter (Q3) with 29.60% (1545.23 tons), the first quarter (Q1) with 19.39% (1012.42 tons), and the fourth quarter (Q4) with 10.39% (542.61 tons). In 2023, first-quarter catches were 7.84% lower than the historical average, while second, third, and fourth-quarter catches increased by 71.03%, 48.06%, and 14.70%, respectively (Figures 2 and 3).

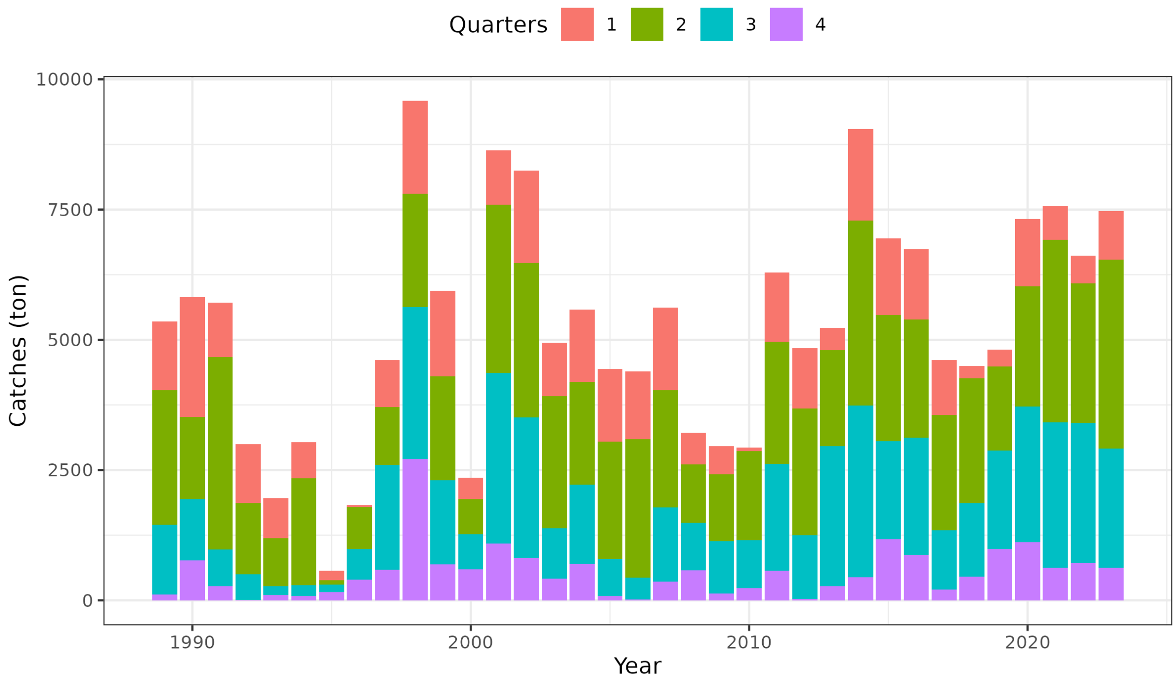


Figure 2: ane.27.9a Southern stock. Time series of quarterly catches.

Catches (ton)					
Year	Q1	Q2	Q3	Q4	Total
1989	1318	2589	1336	111	5354
1990	2300	1571	1182	765	5818
1991	1049	3693	702	274	5718
1992	1125	1368	500	4	2997
1993	767	921	167	105	1960
1994	690	2055	210	80	3035
1995	185	80	148	157	570
1996	41	807	586	398	1832
1997	908	1110	2007	588	4613
1998	1781	2176	2909	2716	9582
1999	1638	1995	1616	691	5940
2000	412	668	673	600	2353
2001	1046	3227	3275	1089	8637
2002	1772	2957	2699	816	8244
2003	1027	2539	965	416	4947
2004	1384	1976	1522	699	5581
2005	1398	2252	706	85	4441
2006	1297	2657	416	19	4389
2007	1581	2251	1423	361	5616
2008	613	1121	910	576	3220
2009	533	1280	1016	126	2955
2010	67	1709	920	232	2928
2011	1326	2343	2051	571	6291
2012	1159	2433	1220	26	4838
2013	434	1837	2683	277	5231
2014	1754	3553	3300	439	9046
2015	1471	2425	1880	1174	6950
2016	1352	2267	2254	869	6742
2017	1051	2213	1140	206	4610
2018	236	2391	1414	458	4499
2019	322	1621	1889	982	4814
2020	1286	2315	2603	1113	7317
2021	644	3500	2794	623	7561
2022	532	2682	2679	722	6615
2023	933	3626	2288	622	7469

Figure 3: ane.27.9a Southern stock. Time series data of quarterly catches

Abundance indices

The abundance indices *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS* exhibit interannual variability over time (Figure 4). *PELAGO*, with data from 1999 to 2023, shows fluctuations with a peak in 2016 at 65,345 tons, followed by a decline, but with a slight recovery in 2023 to 26,786 tons. *ECOCADIZ*, covering the period from 2004 to 2023, reaches its maximum in 2019 at 57,700 tons, followed by a significant decrease to 9,714 tons in 2023. *BOCADEVA*, with data from 2005 to 2023, shows a steady increase to its peak in 2020 at 81,466 tons, followed by a reduction to 15,138 tons in 2023. *ECOCADIZ-RECLUTAS*, recorded from 2014 to 2023, shows a sustained increase until 2019 at 36,405 tons, followed by a decrease to 4,723 tons in 2023.

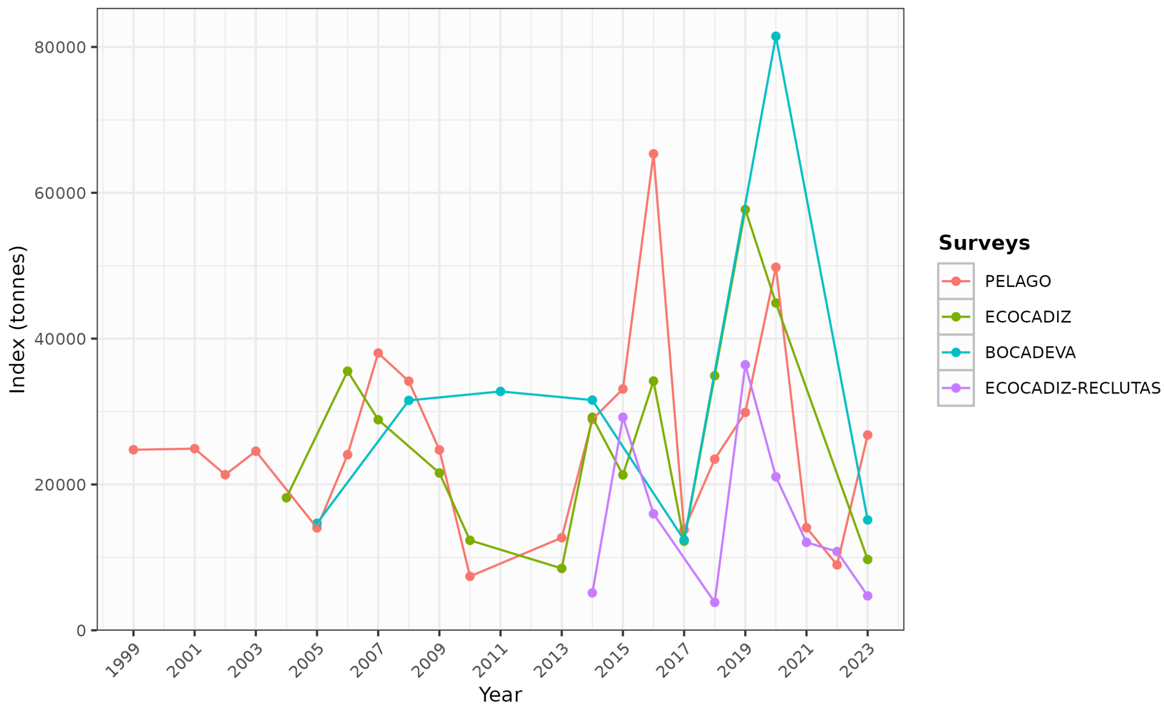


Figure 4: ane.27.9a Southern stock. Biomass estimates from *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS surveys.*

As it can be observed also in the raw data (Figure 5), these patterns reflect a high variability in abundance over time with periods of increase followed by declines in the later years of each series.

	Acoustic Biomass (ton) by surveys			
year	PELAGO	ECOCADIZ	BOCADEVA	ECOCADIZ-RECLUTAS
1999	24763			
2001	24913			
2002	21335			
2003	24565			
2004		18177		
2005	14041		14673	
2006	24082	35539		
2007	38020	28882		
2008	34162		31527	
2009	24745	21580		
2010	7395	12339		
2011			32757	
2013	12700	8487		
2014	28917	29219	31569	5131
2015	33100	21305		29219
2016	65345	34184		15969
2017	13797	12229	12392	
2018	23473	34908		3834
2019	29876	57700		36405
2020	49787	44887	81466	21060
2021	14065			12063
2022	8972			10797
2023	26786	9714	15138	4723

Figure 5: ane.27.9a Southern stock. Acoustic biomass (ton) by surveys *PELAGO*, *ECOCADIZ*, *BOCADEVA*, and *ECOCADIZ-RECLUTAS*.

Age composition

In the model, the age proportion of the commercial fleet (*SEINE*) by quarter from 1989 to 2023, is used (Figure 6). It can be observed that age-0 proportion compared to other ages has been increasing in the last years while age-1 predominates in Q1 and Q2, with a constant proportion over time. Age-0 is not recorded in Q1 and Q2 by convention. In Q3 and Q4, the proportion of age-1 individuals decreases as the proportion of age-0 increases. Additionally, ages 2 and 3 exhibit lower and variable proportions across all quarters over the years, without a defined pattern of change.

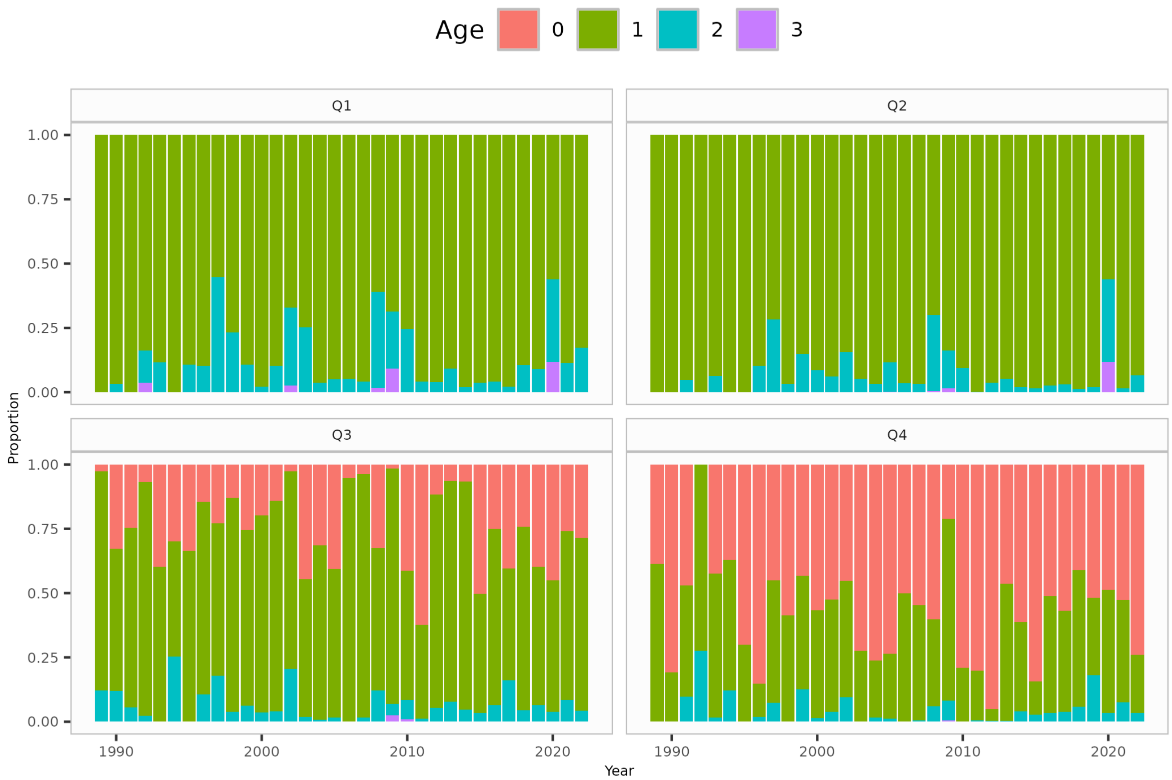


Figure 6: ane.27.9a Southern stock. Age proportion in the commercial fleet catches (*SEINE*) by quarter (1989 to 2023).

Figure 7 shows the yearly age proportions from surveys *PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS* that were used as input for the model. It can be observed that in the *PELAGO* survey, conducted in the second quarter (Q2), age 1 represents the highest proportion over time, with a presence of ages 2 and 3, and no records of age 0 individuals. The *ECOCADIZ* survey, primarily conducted in the third quarter (Q3), shows a predominance of age 1, with an increase in the proportion of age 0 from 2010 onwards; in 2004 and 2006, when the survey was conducted in the second quarter (Q2), no age 0 individuals were recorded by convention. The *ECOCADIZ-RECLUTAS* survey, conducted since 2014 in October (fourth quarter, Q4), shows a higher proportion of age 0, followed by age 1, with lower representation of ages 2 and 3.

In the *SS3* model, age-based data from the *PELAGO* survey were included only for the period 2014-2023, when age-length keys from the surveys were available, as per WKPELA 2018. The *ECOCADIZ-RECLUTAS* index relies exclusively on the biomass of age-0 individuals, allowing it to serve as a direct measure of recruitment.

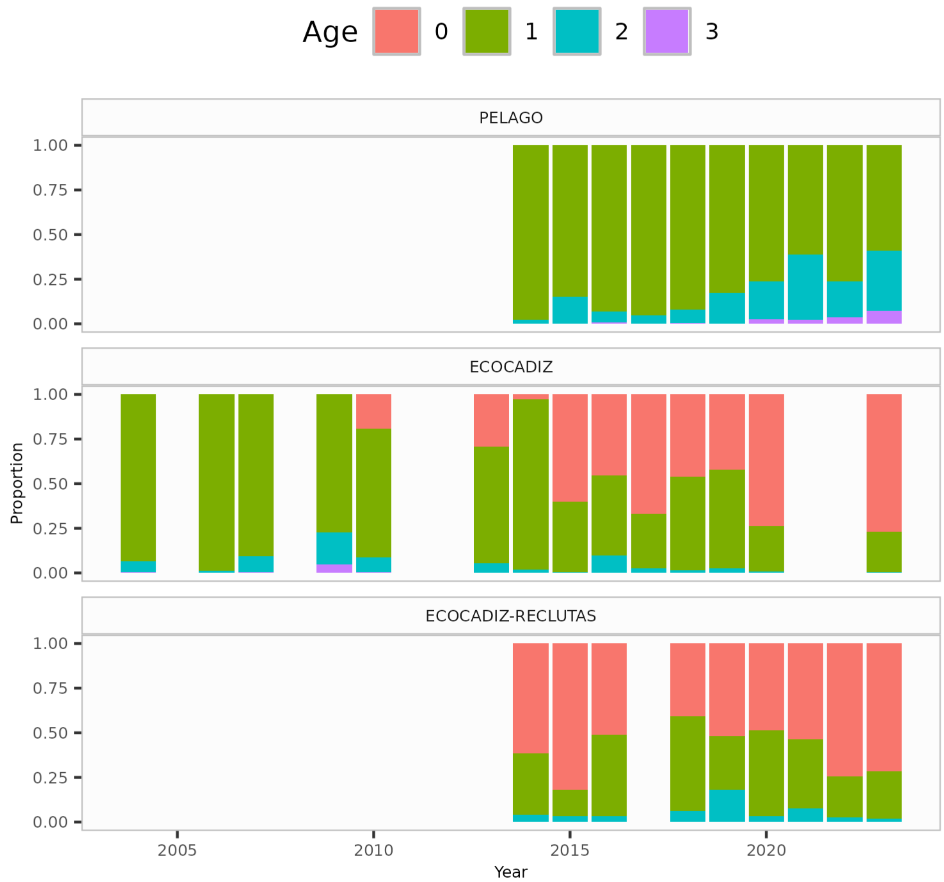


Figure 7: ane.27.9a Southern stock. Age proportion in acoustic surveys estimates (*PELAGO*, *ECOCADIZ*, and *ECOCADIZ-RECLUTAS*).

Weigth-at-age

Figure 8 presents the age-specific weight-at-age values at the start of each season, estimated from external data sources. The figure illustrates that mean weight differences between age groups remain consistent over time, with some variability observed across quarters. Individuals aged 3 show greater variability in mean weight compared to younger age groups. For further details, refer to the working document by *Zuñiga et al.(2024) WD: Analysis of mean weight by age from data available since 1989 to 2024 using linear mixed-effects models: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component).*

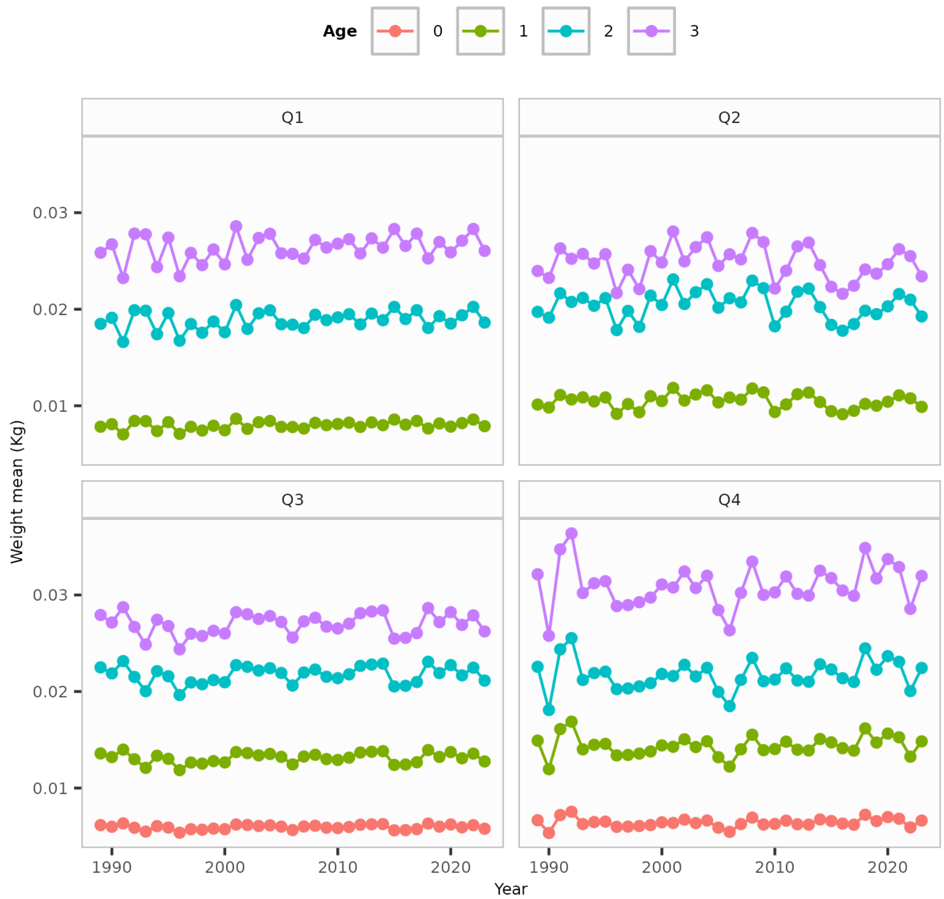


Figure 8: ane.27.9a Southern stock. Weight at age by quarters.

Model settings

Natural mortality

Age-specific natural mortality input values at the beginning of the year were derived from external data sources. For further details, refer to the working document by *Rincón et al. 2024 WD: Growth and natural Mortality parameters estimation for anchovy 9a South.*

Parameter	Age_0	Age_1	Age_2	Age_3
natM1	2.97	1.6	2.48	2.48

Maturity

Due to some inconsistencies in the maturity ogives not noticed during WKPELA 2018, we assume that all individuals with age 1 or higher (B_{1+}), are mature i.e. these abundance estimates result equivalent to spawning stock biomass (SSB) estimates.

Parameter	Age_0	Age_1	Age_2	Age_3
Maturity	0	1	1	1

Growth

It is not modelled explicitly.

Recruitment

Equilibrium recruitment (R_0) was estimated in the base model, and steepness (h) fixed at 0.8, supported by studies from Hsu *et al.* (2024) and Thorson (2020), which are consistent with pelagic species. This value is biologically reasonable for small pelagic species due to their fast growth, early maturity, and short lifespan, allowing them to maintain high reproductive potential at low biomass levels. Standard deviation of log number of recruits was set to 0.6.

The early recruitment deviations for the initial population were estimated from 1962.1. A recruitment bias adjustment ramp (Methot and Taylor, 2011) was applied to this early period, and bias-adjusted recruitment was estimated for the main period. Recruitment deviations for the main period were estimated for 1991 - 2023.

Fishing mortality

Calculation of fishing mortality is performed by using the hybrid F method that does a Pope's approximation to provide initial values for iterative adjustment of the Baranov continuous F values to closely approximate the observed catch. Total catch biomass by year is assumed to be accurate and precise and the F values are tuned to match this catch.

Catchability

All the surveys are assumed to be relative indices of abundance. The catchability is modelled with a simple q linear model.

Selectivity

The fishery and the surveys selectivity were defined as logistic functions fixed over time, except for *BOCADEVA*, where selectivity was fixed at 1 from age 1 onwards, assuming it is a indicator of spawning biomass. Nevertheless, considering the difference in age patterns over the years in the *ECOCADIZ* survey it was decided to split it into two periods: 2004-2014 and 2015-2023.

Data weighting

Constant standard errors of 0.05 and 0.3 were assumed for quarterly catches and surveys, respectively.

The age compositions were adjusted assuming a multinomial error structure with variance described by the sample size, set at 100 for both, the commercial fleet and acoustic surveys. After that, these data was weighted using the Francis method TA1.8 (Francis, 2011), which was adjusted after 5 iterations.

Initial population

It is calculated by estimating an initial equilibrium population modified by age composition data in the first year of the assessment (Methot and Wetzel, 2013). The model starts in 1988 and the equilibrium population age structure was assumed to be in an exploited state with an initial catch of catch Q1 = 1208, catch Q2 = 2033, catch Q3 = 683, catch Q4 = 223 tonnes, assuming the average catch between 1989-1994 for each season.

Variance estimates for all estimated parameters are calculated from the Hessian matrix. Minimisation of the likelihood is implemented in phases using standard ADMB process. The phases in which estimation will begin for each parameter are shown in the control file available in the TAF repository for this stock (https://github.com/ices-taf/2024_ane.27.9a_south_benchmark). The R packages r4ss version 1.50.0 (Taylor *et al.*, 2021) and ss3diags version 1.10.3 (Carvalho *et al.*, 2021) were used to process and view model outputs. All analyses were conduction in R version 4.4.1 (2024-06-14).

Diagnostics

The model successfully converged, as evidenced by the Hessian matrix being positive definite and the final gradient being relatively small, with a gradient value of 0.000042. The "Status" column in Figure 9 shows that the initial model configuration has allowed for adequate optimization of the parameters. Additionally, the gradient for all parameters is relatively small. It is important to note that the bounds imposed on the initial parameters have not restricted the search for optimized values, as reflected in the "Afterbound" column.

Parameter	Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Afterbound
SR_LN(R0)	15.855100	1	1.0	25.0	20.0	OK	0.0833350	0.00004195980000	OK
InitF_seas_1_flt_1SEINE_Q1	0.422549	1	0.0	3.0	0.3	OK	0.0828993	0.00000096885800	OK
InitF_seas_2_flt_2SEINE_Q2	0.836572	1	0.0	3.0	0.3	OK	0.1070740	0.00000168668000	OK
InitF_seas_3_flt_3SEINE_Q3	0.452368	1	0.0	3.0	0.3	OK	0.1200510	0.00000072663300	OK
InitF_seas_4_flt_4SEINE_Q4	0.295798	1	0.0	3.0	0.3	OK	0.1219040	0.00000050956400	OK
LnQ_base_PELAGO(5)	1.116270	1	-7.0	5.0	0.0	OK	0.2766870	0.00000303950000	OK
LnQ_base_ECOCADIZ(6)	0.864166	2	-7.0	5.0	0.0	OK	0.1613330	0.00000136163000	OK
LnQ_base_BOCADEVA(7)	1.476870	2	-7.0	5.0	0.0	OK	0.1935140	0.00000189311000	OK
LnQ_base_ECORECLUTAS(8)	-0.670434	1	-7.0	5.0	0.0	OK	0.1296960	0.00000013990900	OK
Age_inflection_SEINE_Q1(1)	0.923691	2	0.0	4.0	0.0	OK	0.8599050	0.00000067767000	OK
Age_95%width_SEINE_Q1(1)	0.198601	2	0.1	0.3	0.2	OK	2.2347700	-0.00000001715740	OK
Age_inflection_SEINE_Q2(2)	0.194195	2	0.1	0.3	0.2	OK	2.2130600	0.00000000272771	OK
Age_95%width_SEINE_Q2(2)	0.220030	2	0.0	4.0	0.5	OK	2.3623700	-0.00000000959833	OK
Age_inflection_SEINE_Q3(3)	0.803830	2	0.0	4.0	0.0	OK	0.1409650	-0.00000313695000	OK
Age_95%width_SEINE_Q3(3)	0.611710	2	0.0	4.0	0.5	OK	0.0735133	0.00000403564000	OK
Age_inflection_SEINE_Q4(4)	1.191060	2	0.0	4.0	0.0	OK	0.2792700	-0.00000034081200	OK
Age_95%width_SEINE_Q4(4)	1.238230	2	0.0	4.0	0.5	OK	0.1359800	0.00000024847000	OK
Age_inflection_PELAGO(5)	0.994477	2	0.0	3.5	0.9	OK	0.0946087	-0.00000323867000	OK
Age_95%width_PELAGO(5)	0.253710	2	0.1	0.4	0.3	OK	3.6223100	0.00000000150067	OK
Age_inflection_ECOCADIZ(6)	1.750000	2	0.0	3.5	0.2	OK	39.1278000	-0.00000000363607	OK
Age_95%width_ECOCADIZ(6)	0.204133	2	0.0	3.5	0.5	OK	1.0519800	0.00000380114000	OK
Age_inflection_ECOCADIZ(6)_BLK1repl_2004	0.326222	4	0.0	3.5	0.5	OK	1.6814300	-0.00000248635000	OK
Age_inflection_ECOCADIZ(6)_BLK1repl_2015	0.159927	4	0.0	3.5	0.0	OK	0.8244110	-0.00000071914400	OK

Figure 9: ane.27.9a Southern stock. Parameters estimated by the initial base model.

Model fit and residuals

The Figure 10 shows that the abundance indices from the acoustic surveys exhibit a high level of variability, as reflected by the width of the assumed confidence intervals, with a maximum coefficient of variation of

30%. The model follows the overall trend of the indices, though it encounters some difficulties in accurately fitting the extreme biomass values, both the highest and lowest. However, it adequately reproduces the general trend of variability in biomass levels presented by the survey estimates.

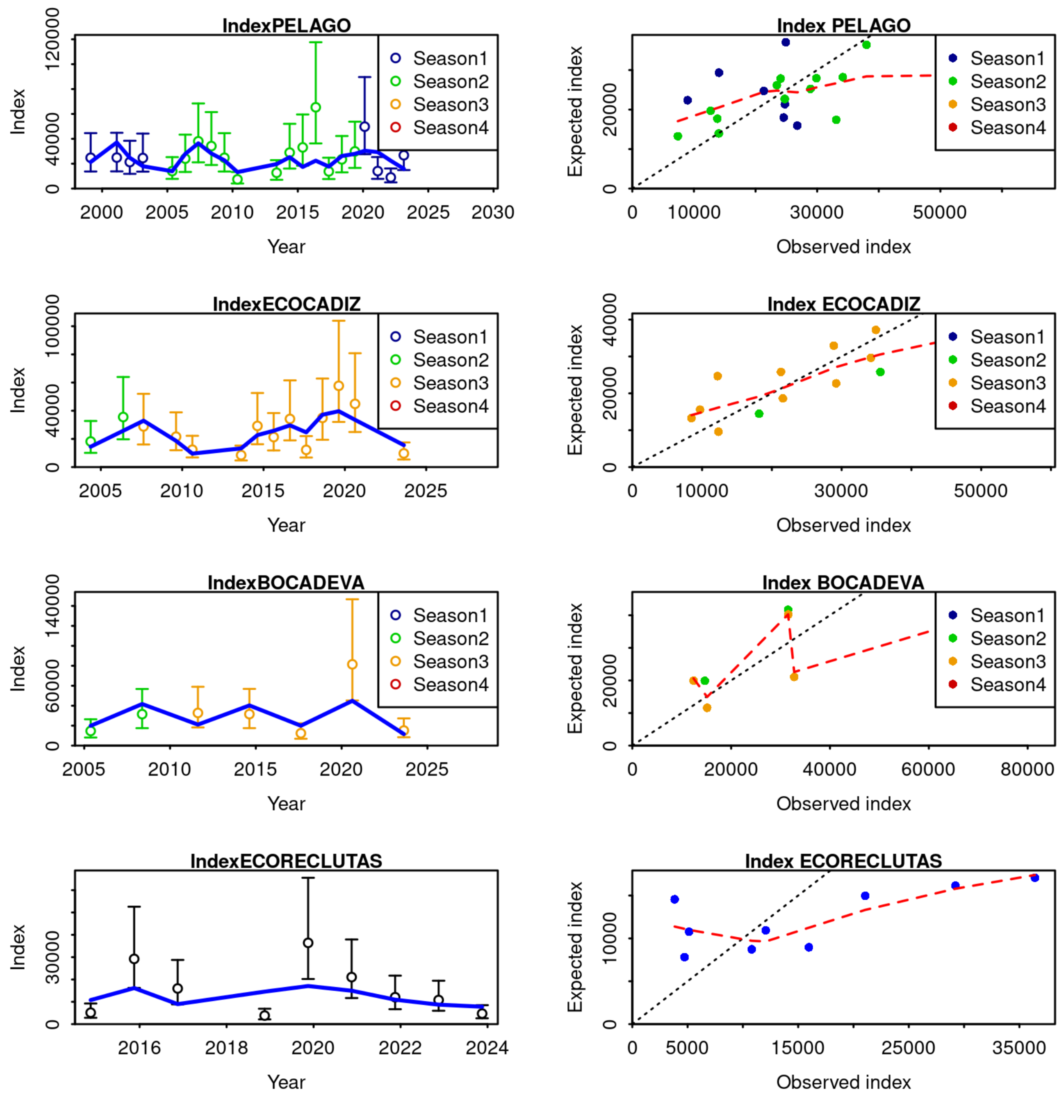


Figure 10: ane.27.9a Southern stock. Model fit to the data (left panel) and observed versus expected values (right panel) of the indices from the surveys *PELAGO*, *ECOCADIZ*, *BOCADEVA* and *ECOCADIZ-RECLUTAS*. The lines indicate a 95% uncertainty interval around the index values based on the lognormal error model assumption.

Figure 11 shows that the residuals from the fit of the biomass indices are randomly distributed, with p-values greater than 0.05 (*PELAGO* = 0.448, *ECOCADIZ* = 0.889, *BOCADEVA* = 0.358, *ECOCADIZ-RECLUTAS* = 0.5). The estimated root mean square error (RMSE) for the joint residual analysis is 46.6%.

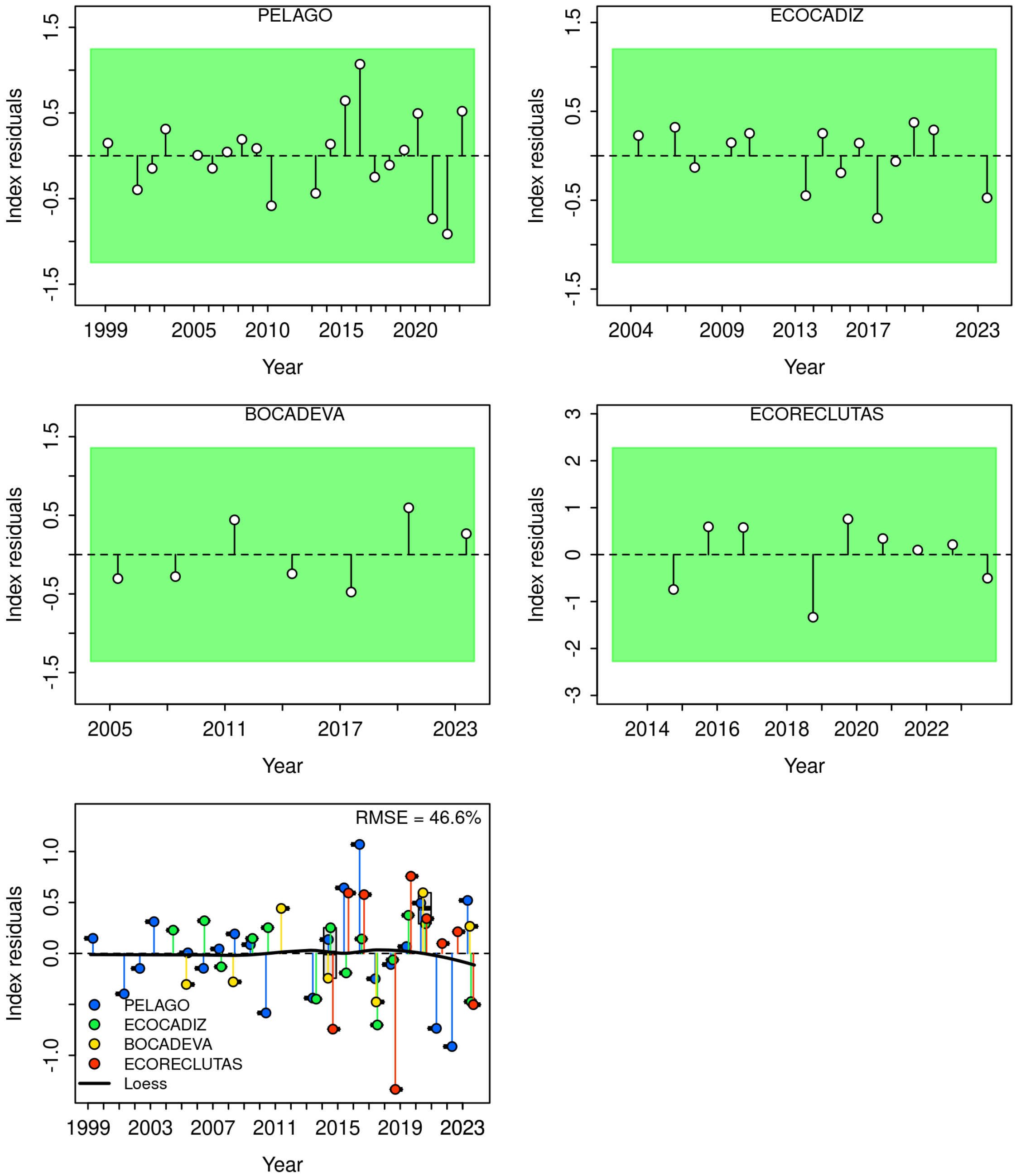


Figure 11: ane.27.9a Southern stock. a) Run test plots for the fit of acoustic and DEPM survey indices. Green shading indicates no evidence (p>=0.05) and red shading indicates evidence (p<0.05) for rejecting the hypothesis of a randomly distributed residual time series, respectively. The shaded area (green/red) spans three standard residual deviations on either side of zero, and red points outside the shading violate the three-sigma limit for that series. b) Joint residual plots for the fit of acoustic and DEPM survey indices (bottom left panel). Vertical lines with points show the residuals, and the solid black line show loess smoother through all residuals. Boxplots indicate the median and quantiles in cases where residuals from multiple indices are available for a given year, with the solid black line showing a loess smoother. The root mean square error (RMSE) is included in the top right corner of the panel.

Estimated mean age for the *SEINE* fleet (one by quarter) with a 95% confidence intervals based on current sample sizes, is presented in Figure 12.

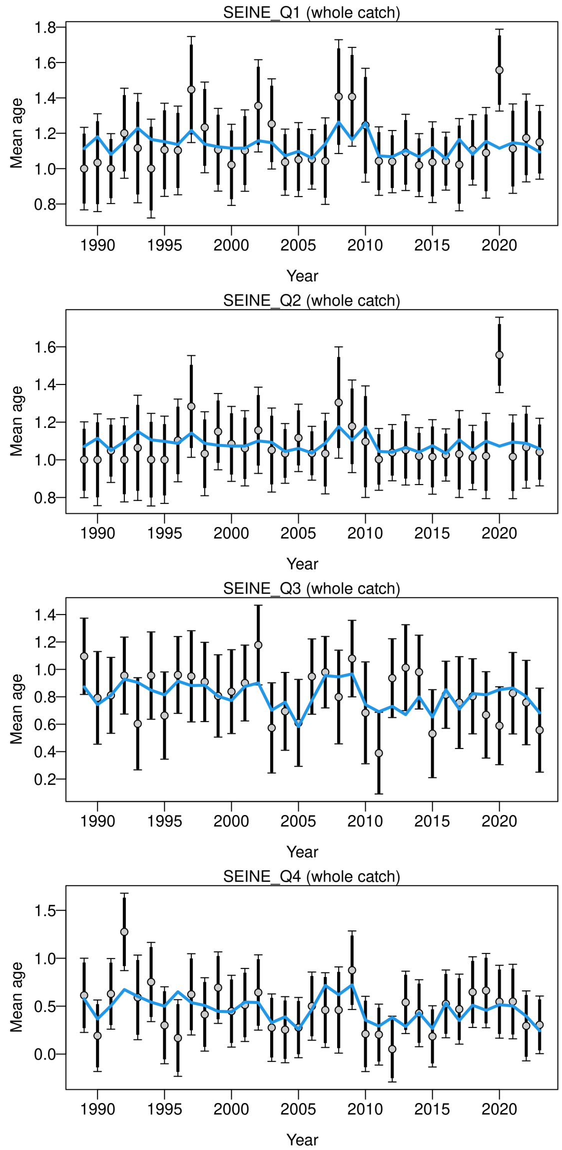


Figure 12: Mean age for commercial fleet by quarters with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.

While mean age for the *PELAGO* and *ECOCADIZ* surveys is presented in Figure 13.

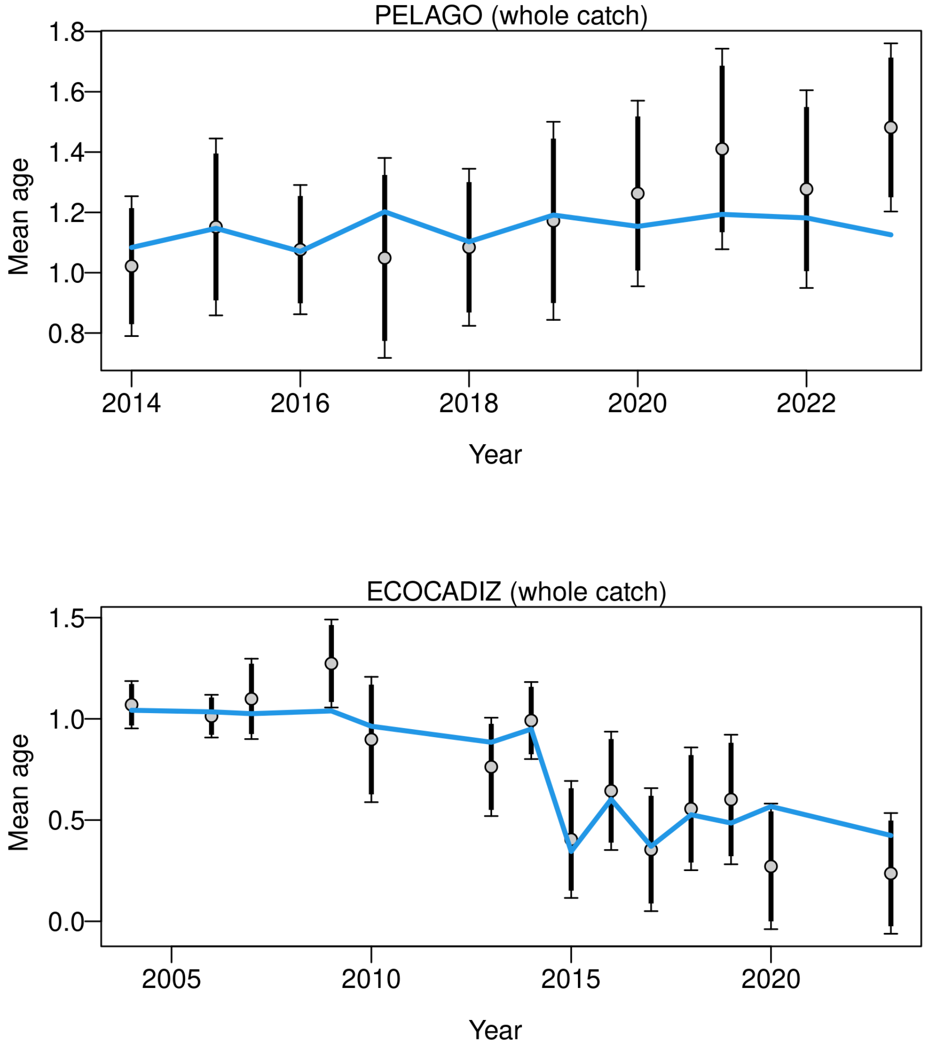


Figure 13: Mean age for *PELAGO* and *ECOCADIZ* with 95% confidence intervals based on current sample sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show the result of further adjusting sample sizes based on the suggested multiplier (with 95% interval) for age data. The blue line corresponds to the estimated mean age.

The Figure 14 shows the estimated age compositions aggregated over time for the different age data sources: *SEINE*, *ECOCADIZ* and *PELAGO*. Overall, a high proportion of young individuals (ages 0 and 1) is observed in both the commercial fleet catches and acoustic surveys, with a significant decline in the proportions of older age classes. The green lines represent the model fits, demonstrating an adequate fit, with the aggregated age compositions well reconstructed.

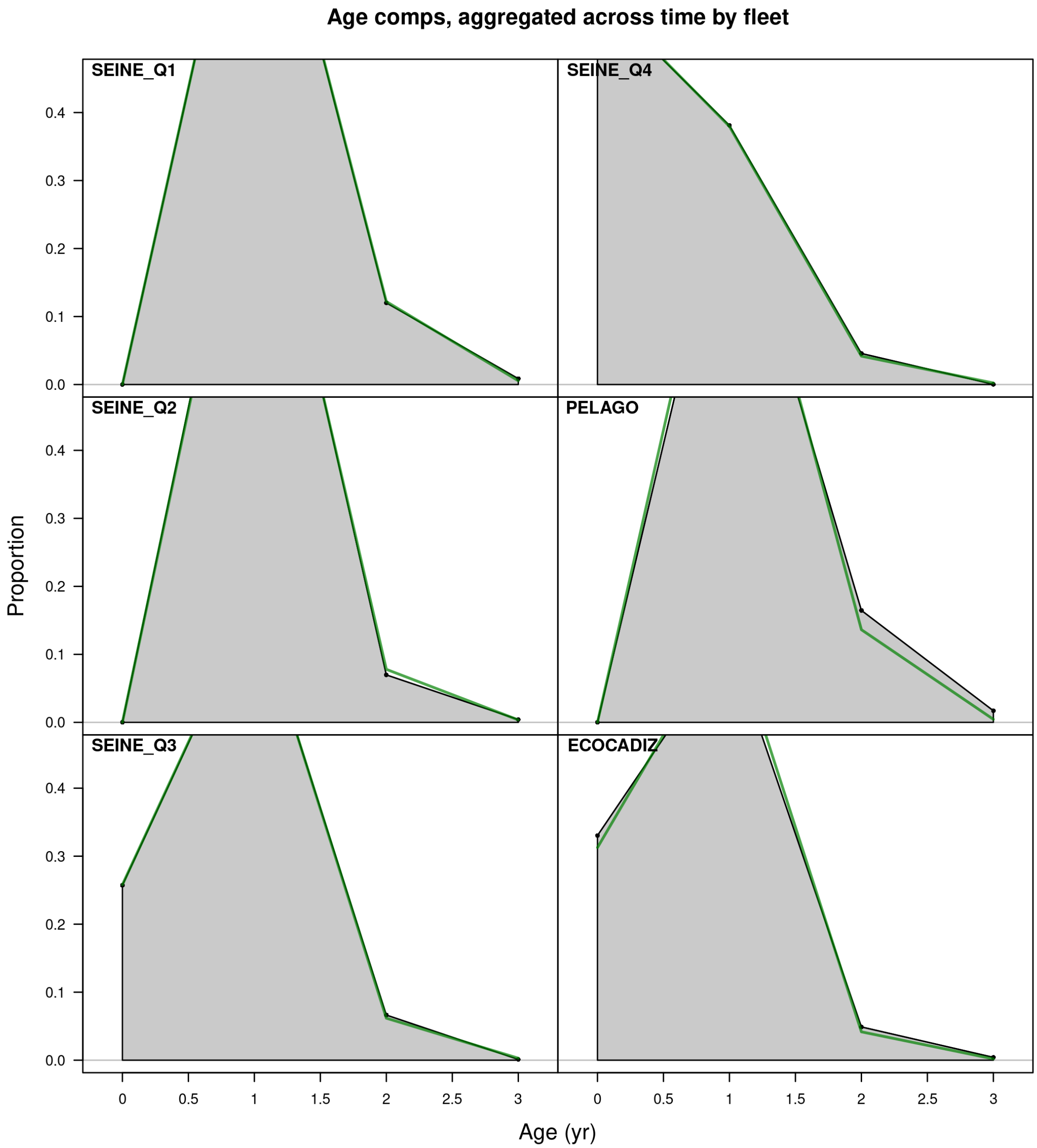


Figure 14: ane.27.9a Southern stock. Model fit to the aggregated age composition data from the *SEINE* fishery, and the acoustic surveys *PELAGO* and *ECOCADIZ*. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 15 shows the estimated age composition for the commercial fleet in the first quarter.

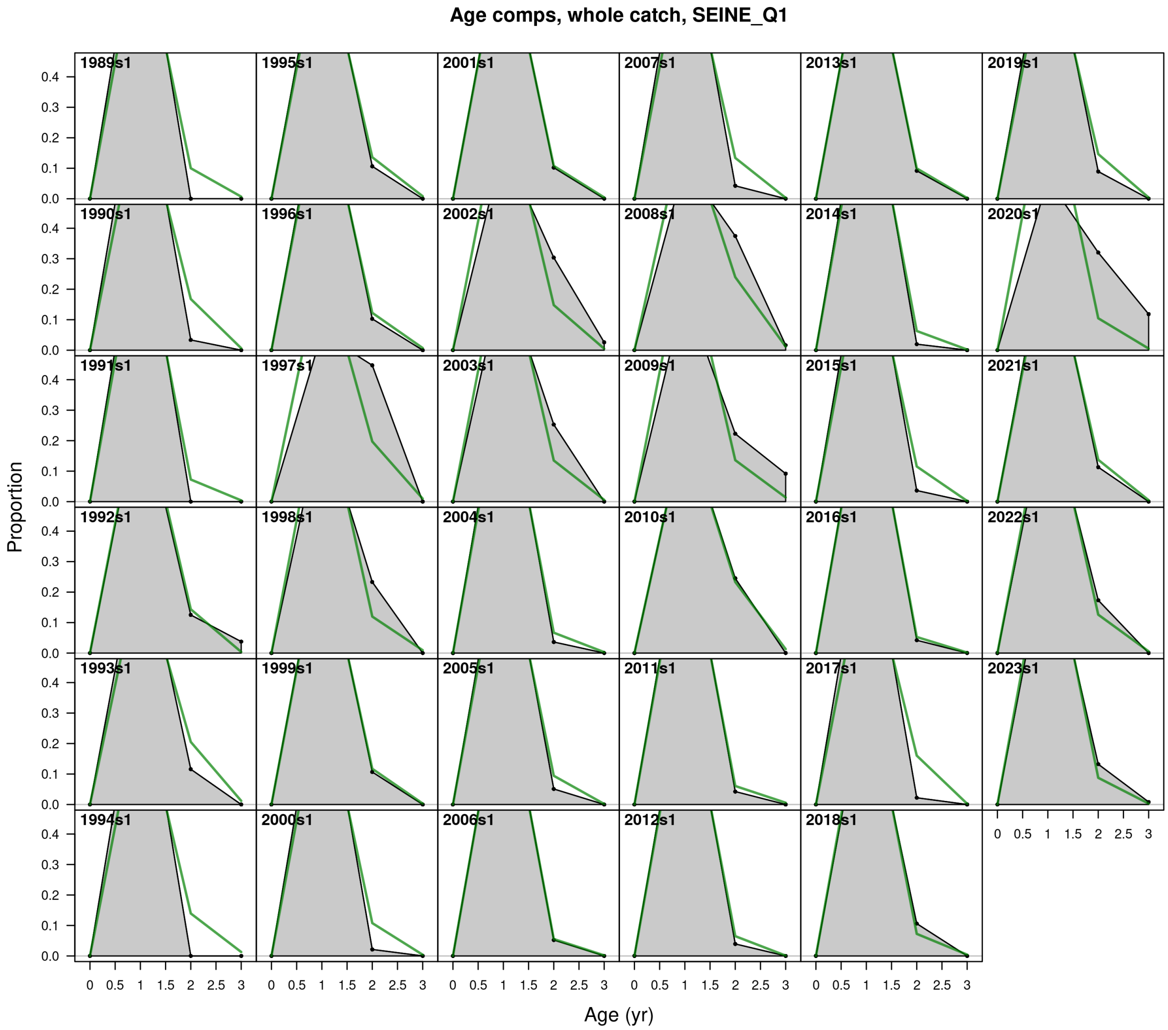


Figure 15: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ1* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 16 shows the estimated age composition for the commercial fleet in the second quarter.

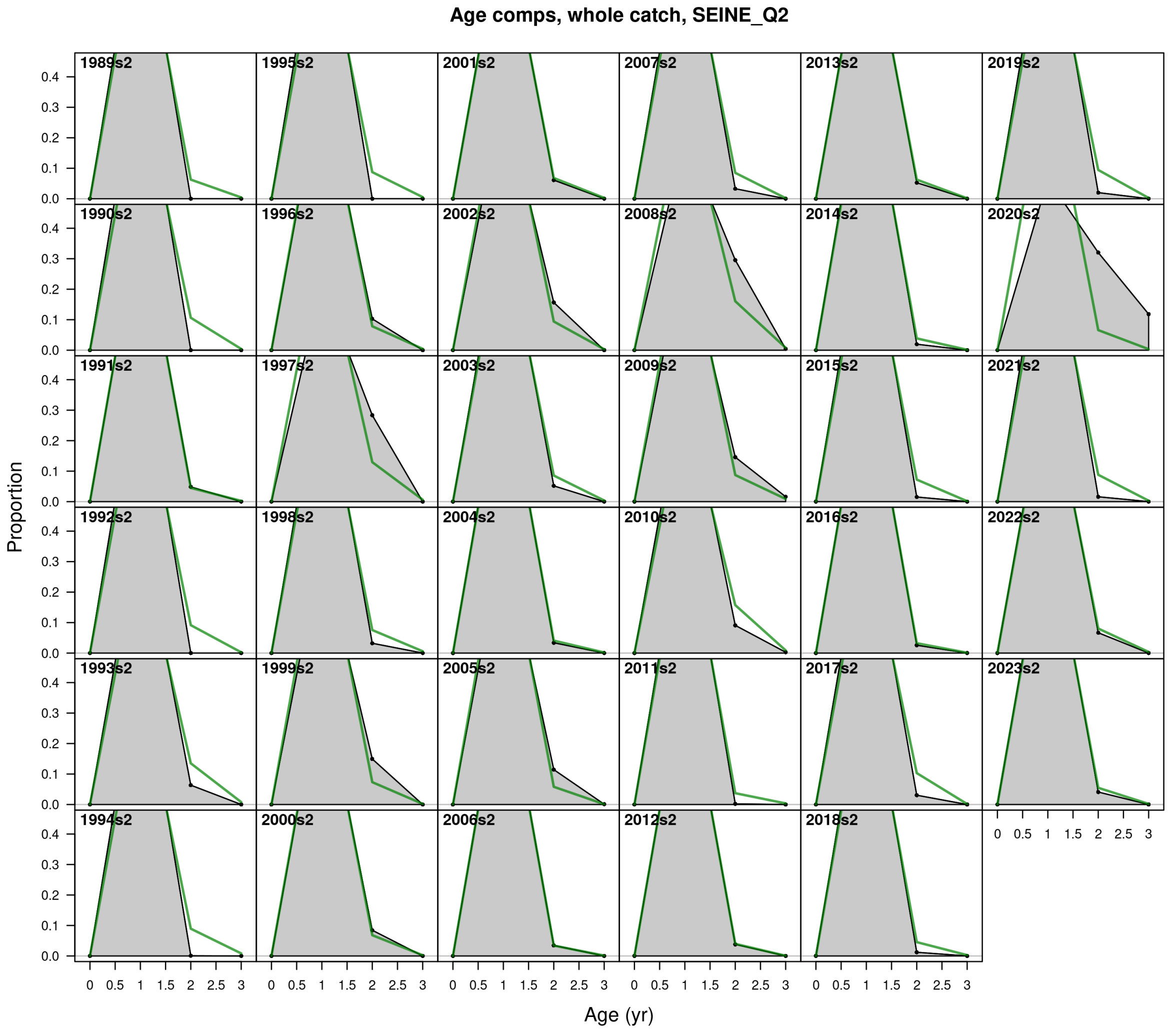


Figure 16: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ2* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 17 shows the estimated age composition for the commercial fleet in the third quarter.

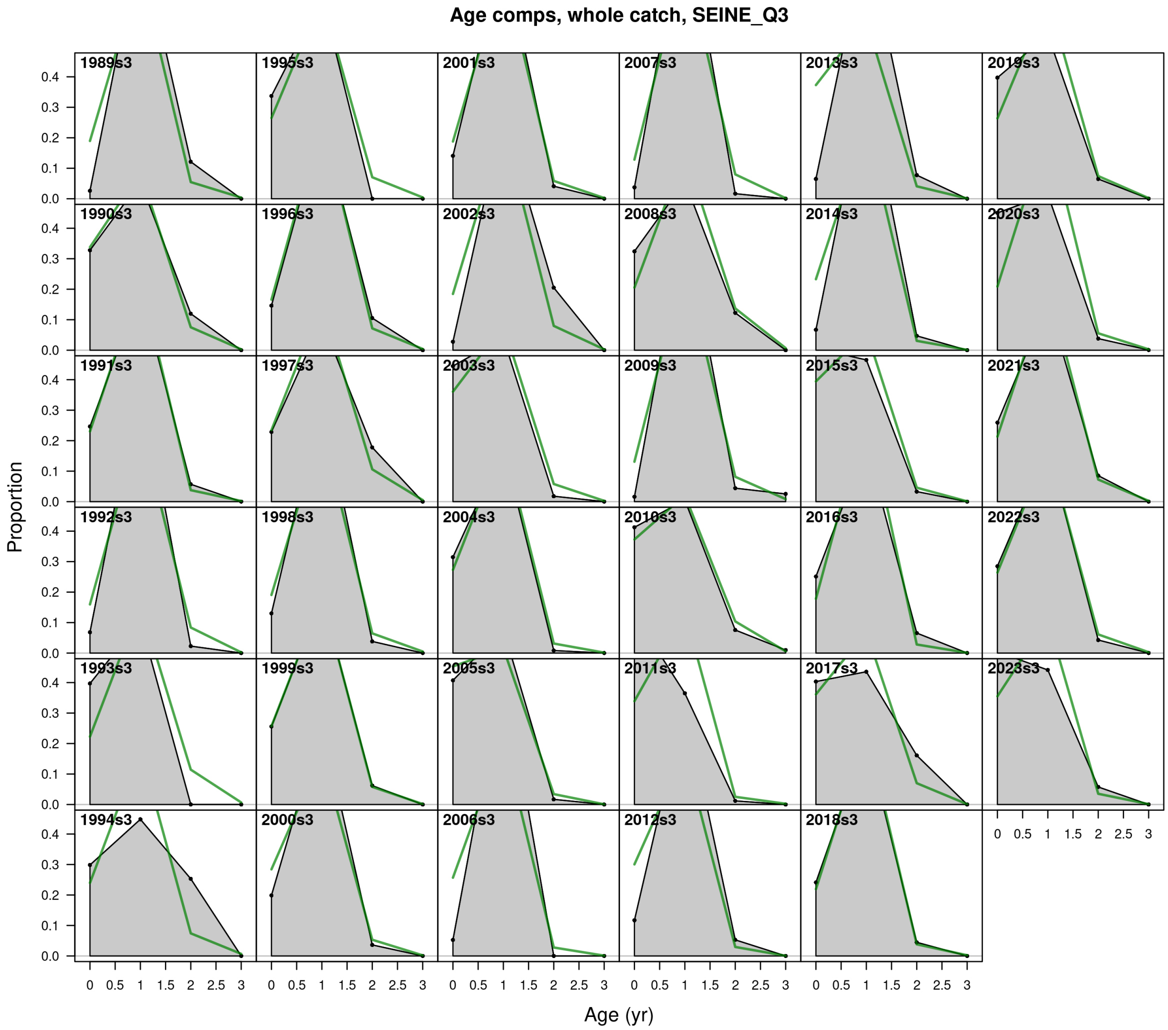


Figure 17: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ3* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Figure 18 shows the estimated age composition for the commercial fleet in the fourth quarter.

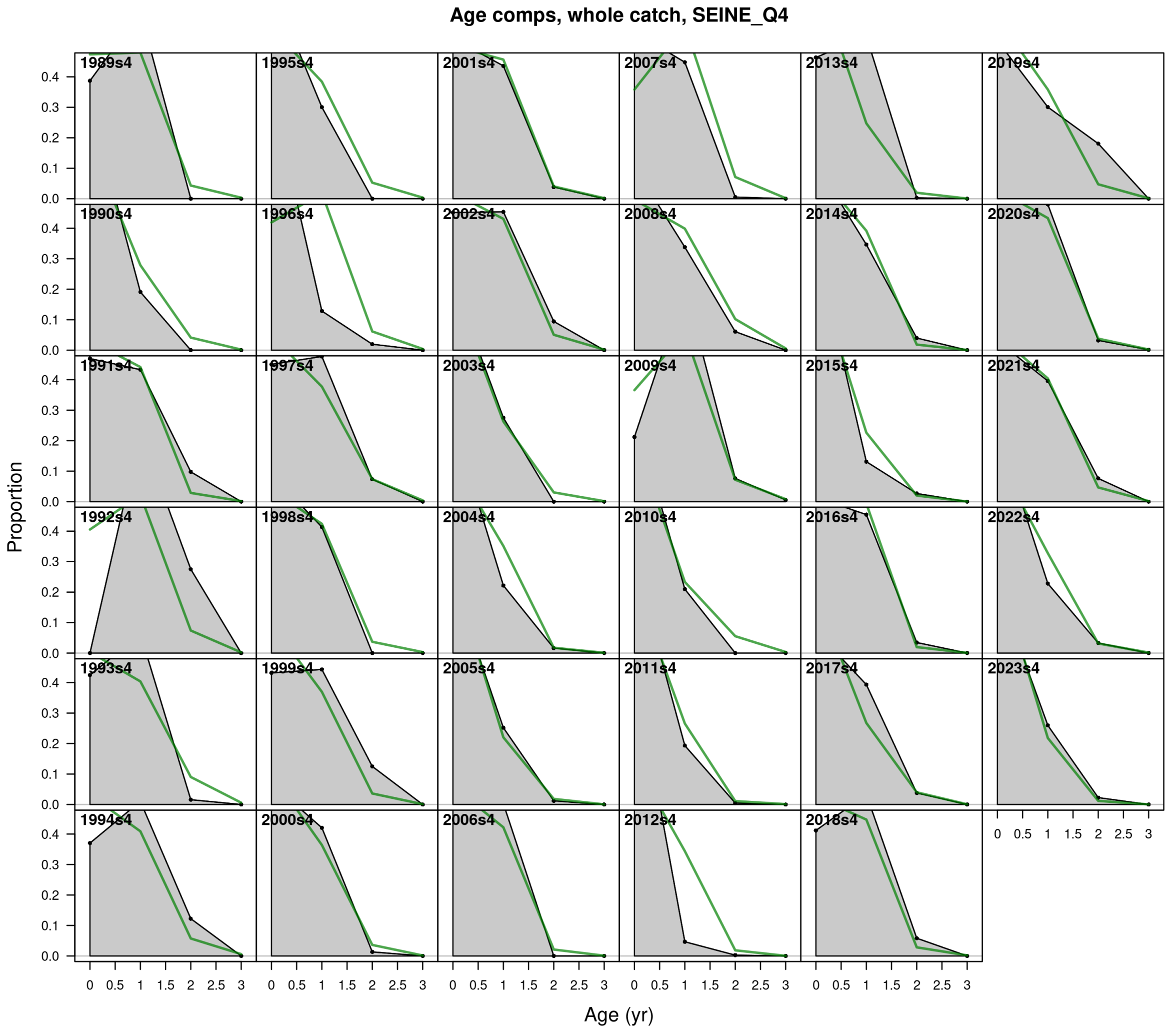


Figure 18: ane.27.9a Southern stock. Model fit to the age composition data from the *SEINEQ4* fishery, by year and quarter. The green line represents the model estimates, while the shaded grey area shows the observed data.

Although the aggregated fits show an overall adequate result, some years exhibit variability in the age composition of the commercial fleet (*SEINE*) catches. This pattern is also evident in the annual data fits for the *PELAGO* survey, especially in the later years of the series (2020-2023), where there is a tendency to overestimate age 1 and underestimate age 2 (Figure 19).

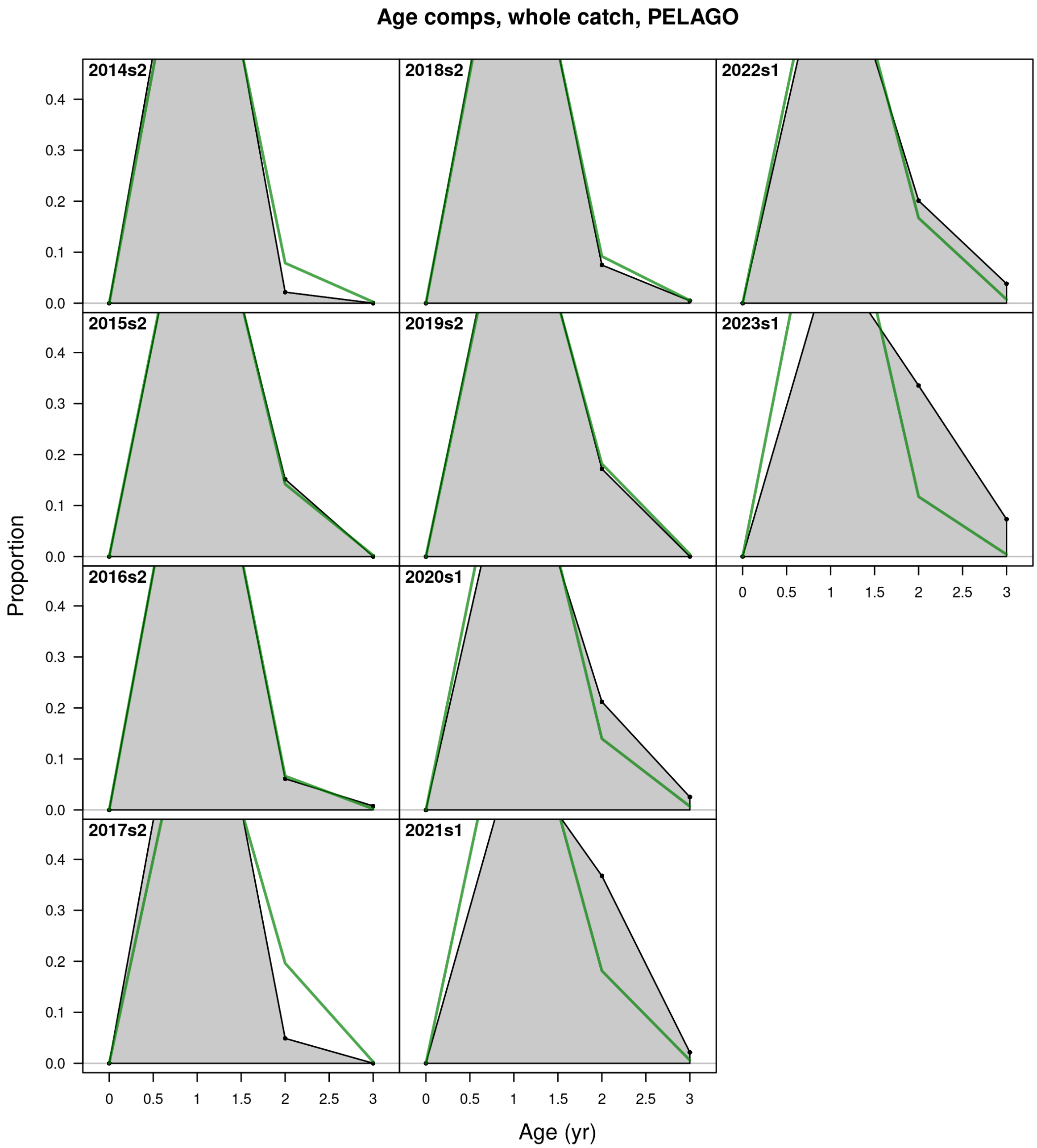


Figure 19: ane.27.9a Southern stock. Model fit to the age composition data from the *PELAGO* spring survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

In the *ECOCADIZ* survey, there are difficulties in estimating ages 0 and 1, with a tendency to underestimate age 0 and overestimate age 1 from 2016 to 2023 (Figure20).

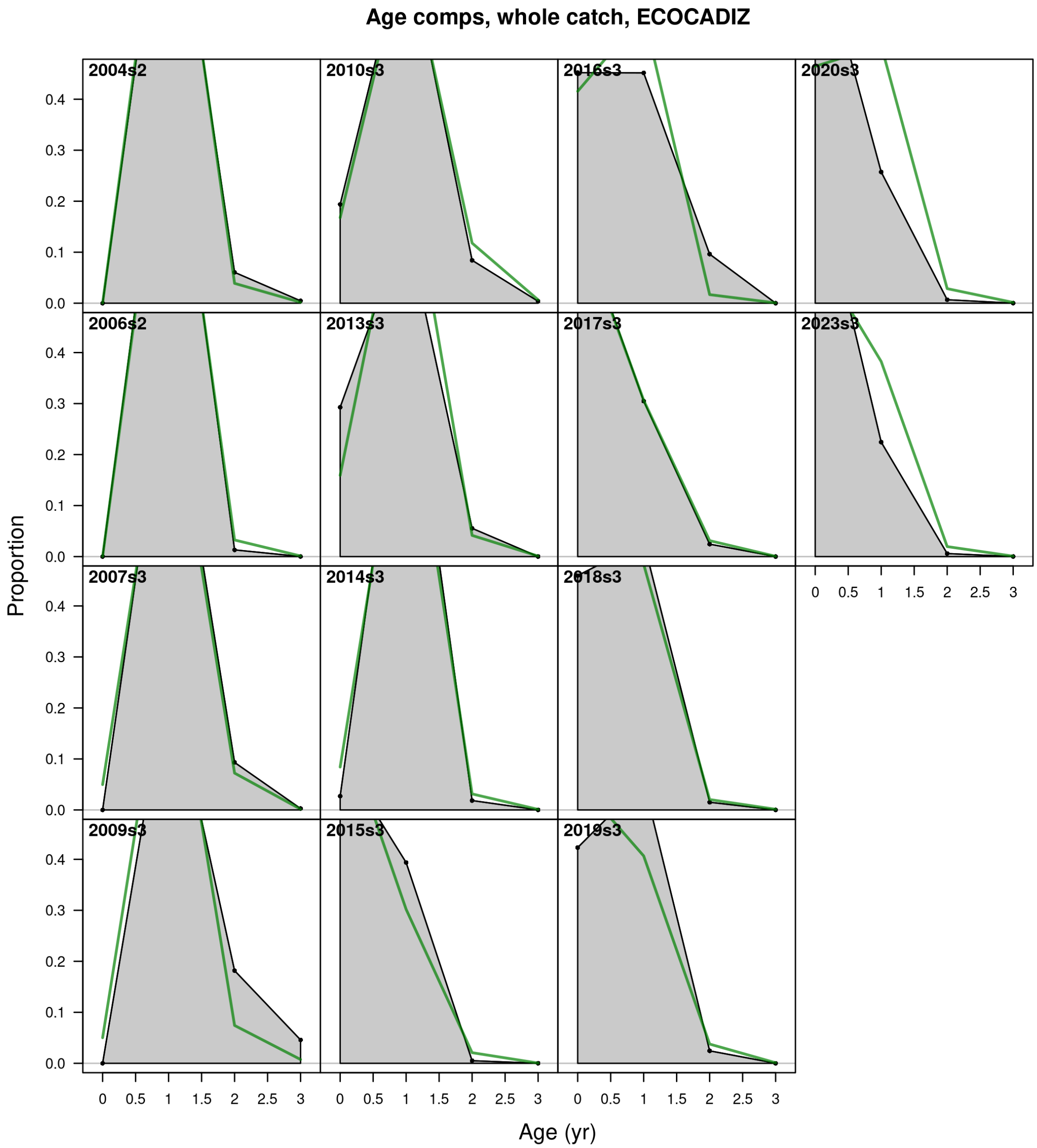


Figure 20: ane.27.9a Southern stock. Model fit to the age composition data from the *ECOCADIZ* summer survey by year. The green line represents the model estimates, while the shaded grey area shows the observed data.

Bubble plots of the residuals corresponding to the fit of the *SEINE* data are presented in Figure 21.

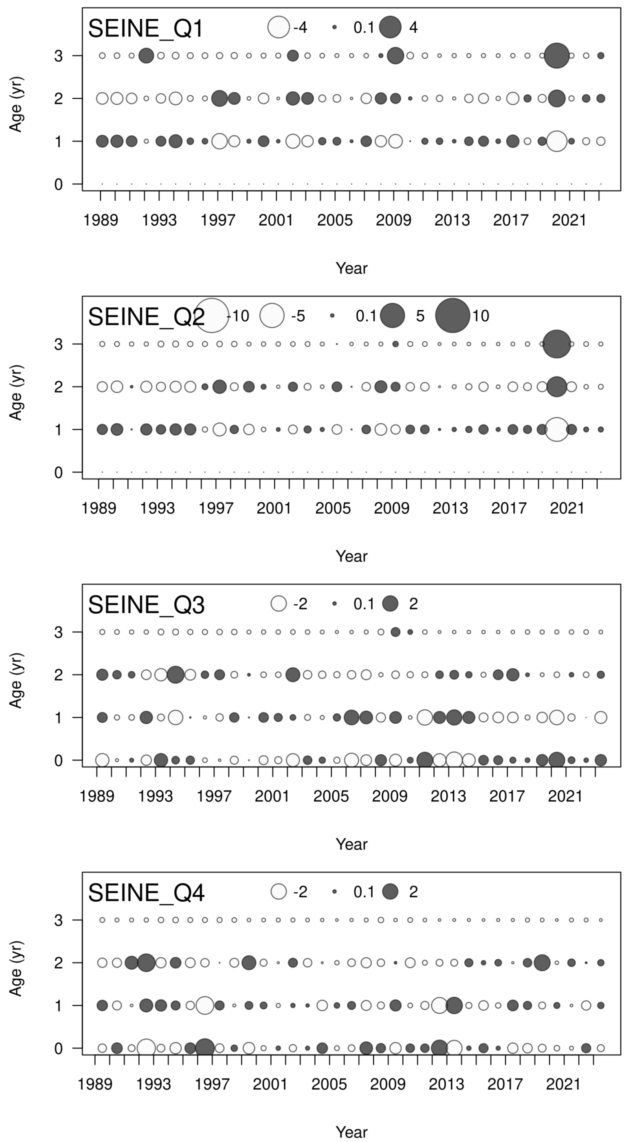
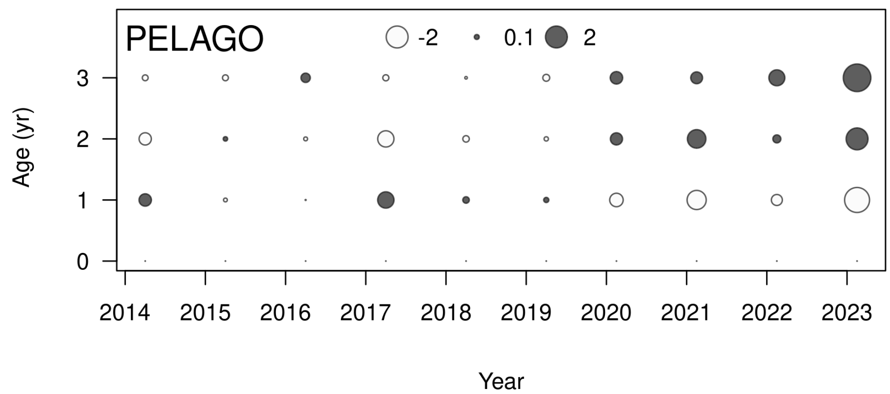


Figure 21: ane.27.9a Southern stock. Pearson residuals, comparing across fleets. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

Bubble plots of the residuals corresponding to the fit of the surveys age-data are presented in Figure 22.



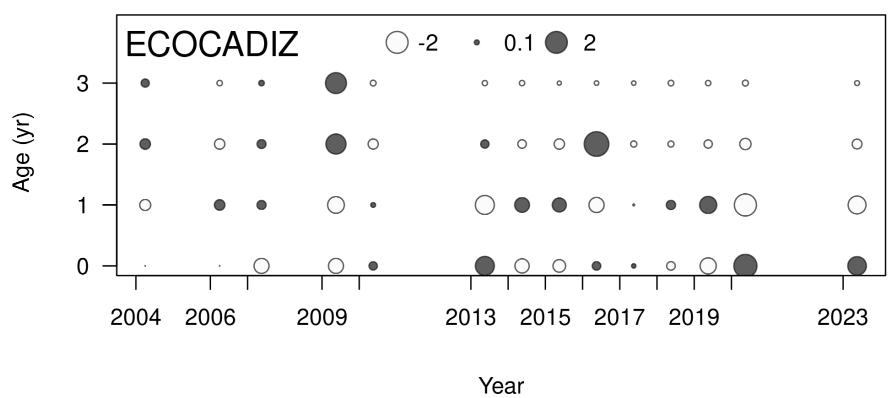


Figure 22: ane.27.9a Southern stock. Pearson residuals, comparing across surveys. Closed bubbles are positive residuals (observed > expected) and open negative residuals (observed < expected).

The Figure 23 shows that the residuals from the fit of the age proportions are randomly distributed, with p-values greater than 0.05 in the case of the commercial fleet (*SEINE_Q1*: 0.202, *SEINE_Q2*: 0.267, *SEINE_Q3*: 0.206, *SEINE_Q4*: 0.806) and the acoustic surveys *ECOCADIZ*: 0.532, and *PELAGO* (0.103). The estimated root mean square error (RMSE) for the joint residual analysis is 27.5%.

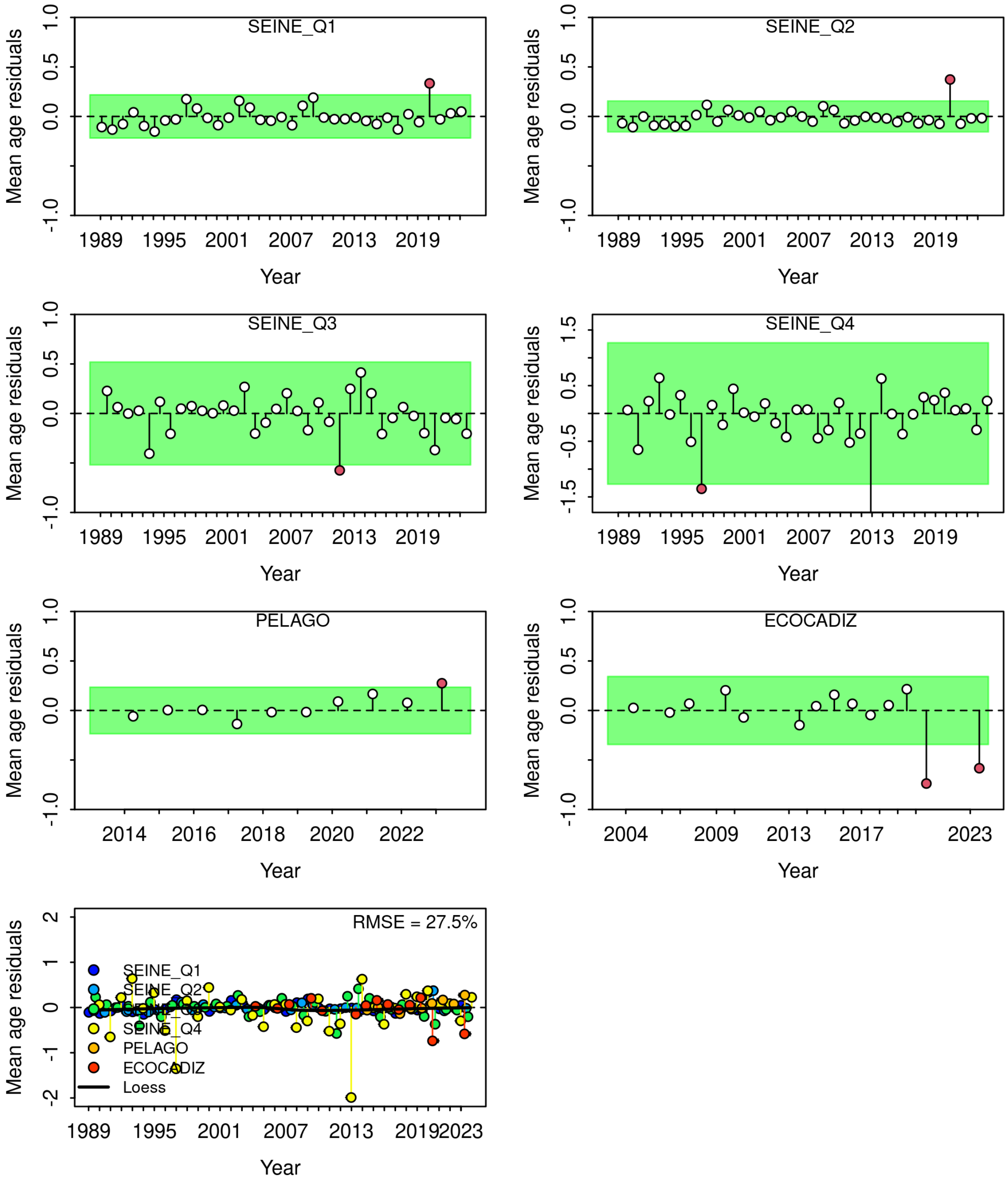


Figure 23: ane.27.9a Southern stock. a) Runs test results for fits to annual mean age estimates for the surveys (*PELAGO* and *ECOCADIZ*), and the fishery (*SEINE*). Green shaded (green/red) area spans three residual standard deviations to either side from zero, and the red points outside of the shading violate the 'three-sigma limit' for that series. b) Joint residual plots for annual mean length estimates for surveys and fishery (bottom left panel). Vertical lines with points show the residuals, and the solid black line show loess smoother through all residuals. Root-mean squared error (RMSE) is included in the upper right-hand corner of the panel.

Retrospective analysis

Figure 24 shows a retrospective pattern in both spawning biomass and fishing mortality in the base model. The retrospective analysis of the assessment model reveals that, in terms of Mohn's rho (mean of retrospective anomalies), the reduction in data leads to a pattern of underestimation in fishing mortality (rho = 0.17961) and overestimation in spawning biomass (rho = -0.084419). These Mohn´s rho values were inside the bounds of recommended values, according to the rule proposed by Hurtado-Ferro *et al.* (2014), which states that Mohn's rho index values should be less than 0.30 and greater than -0.22 for short-lived species.

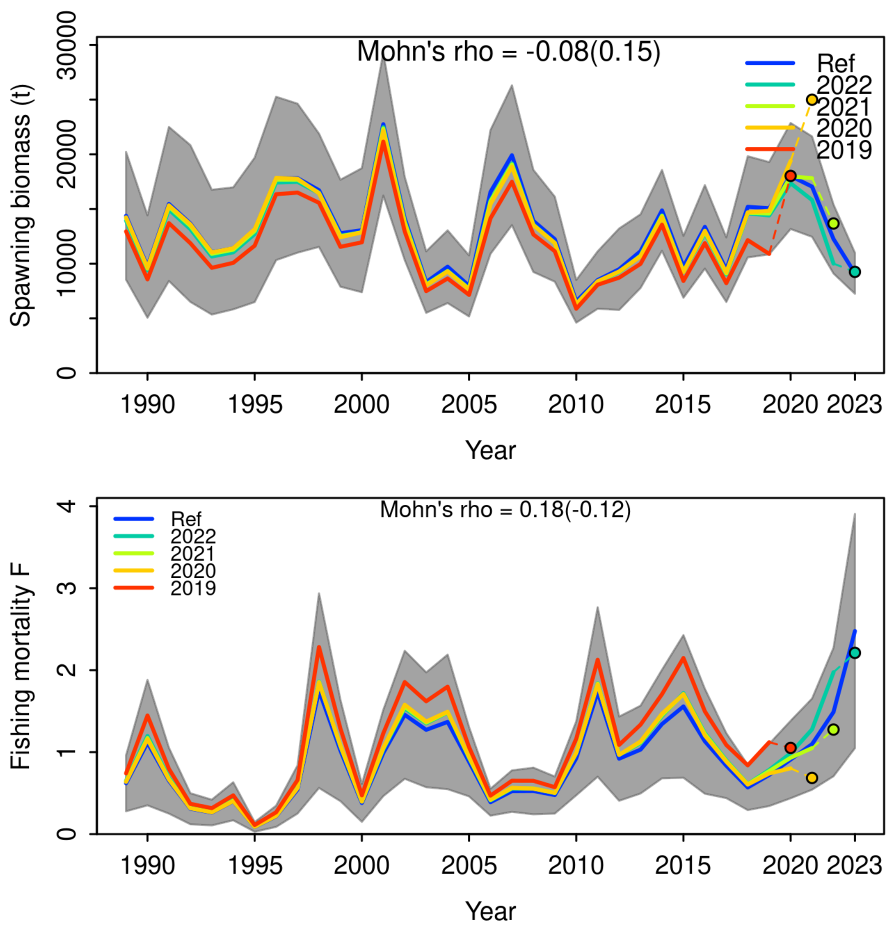


Figure 24: ane.27.9a Southern stock. Retrospective analysis of spawning stock biomass (SSB) and fishing mortality (F). Models conducted by re-fitting the reference model (Ref) after removing five years of observations, one year at a time sequentially. The retrospective results are shown the entire time series. Mohn's rho statistic and the corresponding 'hindcast rho' values (in brackets) are printed at the top of the panels. One-year-ahead projections denoted by color-coded dashed lines with terminal points are shown for each model. Grey shaded areas are the 95% confidence intervals from the reference model.

Results

Stock-recruitment relationship

Recruitment was modeled using a Beverton-Holt stock-recruitment relationship (Figure 25). The assumed level of underlying recruitment deviation error was fixed (σ_R=0.33), equilibrium recruitment was estimated ($log(R_0)$)=15.86) and steepness (h) was fixed at 0.8.

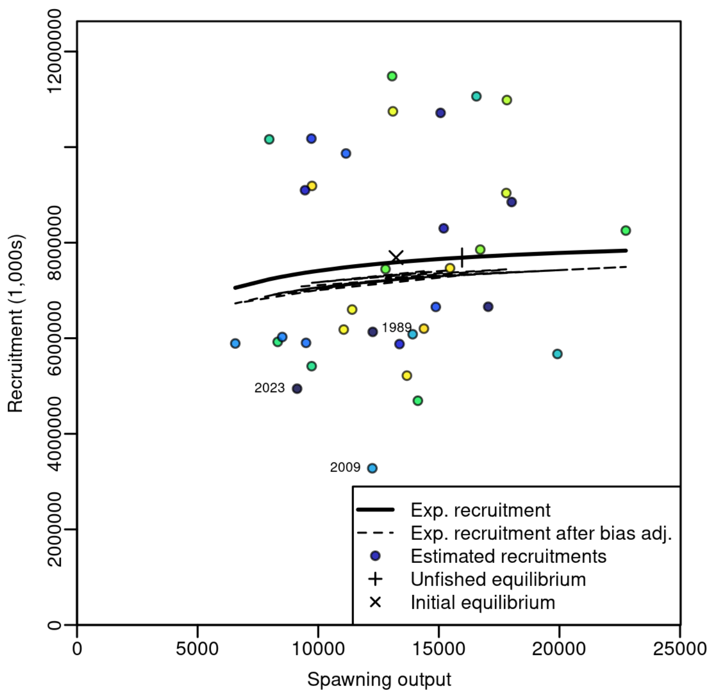


Figure 25: ane.27.9a Southern stock. Stock-recruit curve with labels on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

Recruitment deviations for the early from 1962.1 and main for 1991 - 2023 periods in the model are presented in (Figure 26).

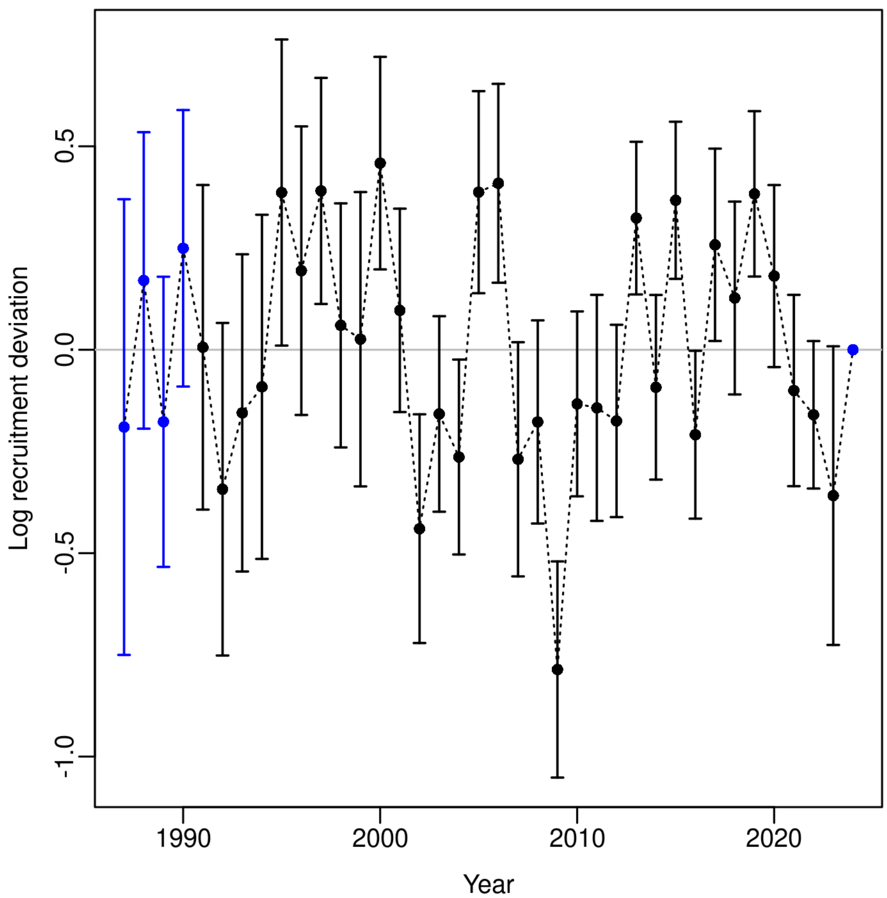


Figure 26: ane.27.9a Southern stock. Recruitment deviations with 95% intervals for the base model (sigmaR = 0.3).

Asymptotic standard errors for recruitment deviations are shown in Figure 27.

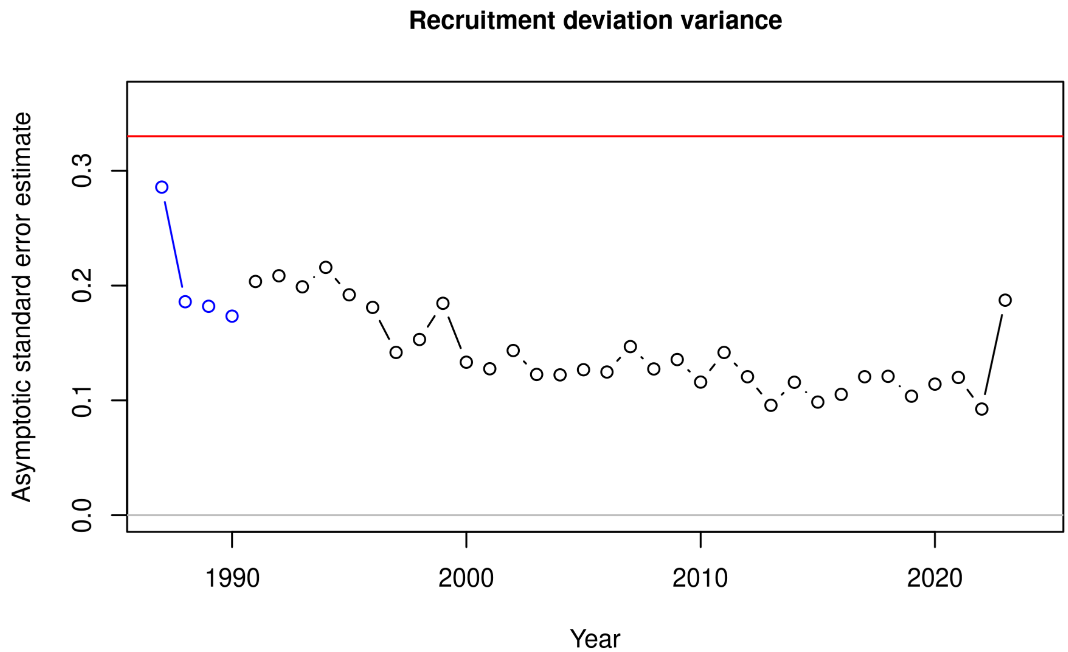


Figure 27: ane.27.9a Southern stock. Asymptotic standard errors for the estimated recruitment deviations.

Recruitment bias adjustment for the different periods is shown in Figure 28.

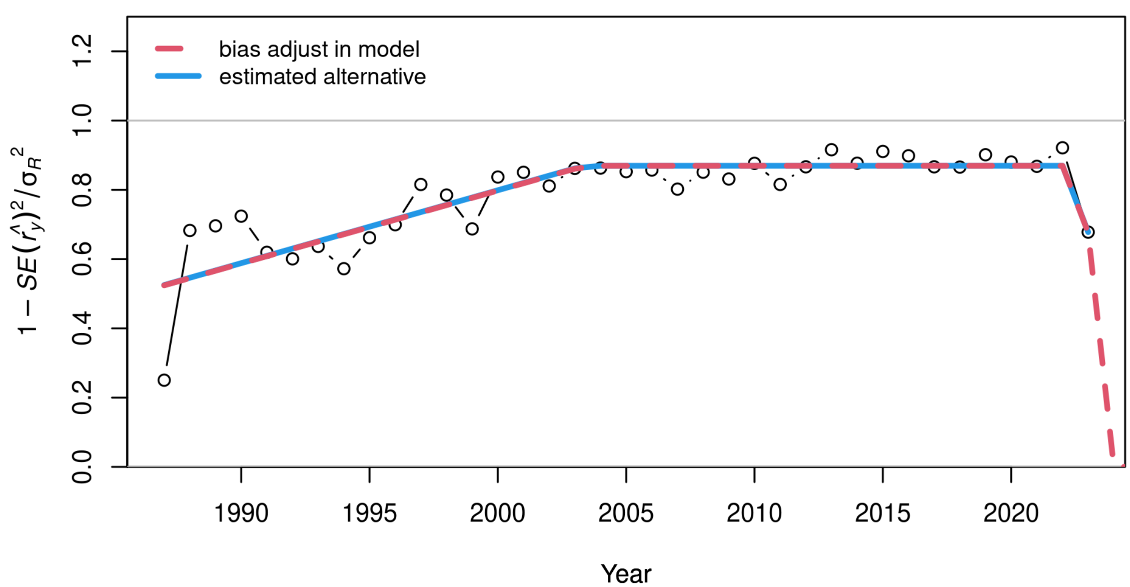


Figure 28: ane.27.9a Southern stock. Recruitment bias adjustment plot for early and main.

Selectivity

Figure 29 shows the estimated selectivity for the age composition of the commercial fleet.

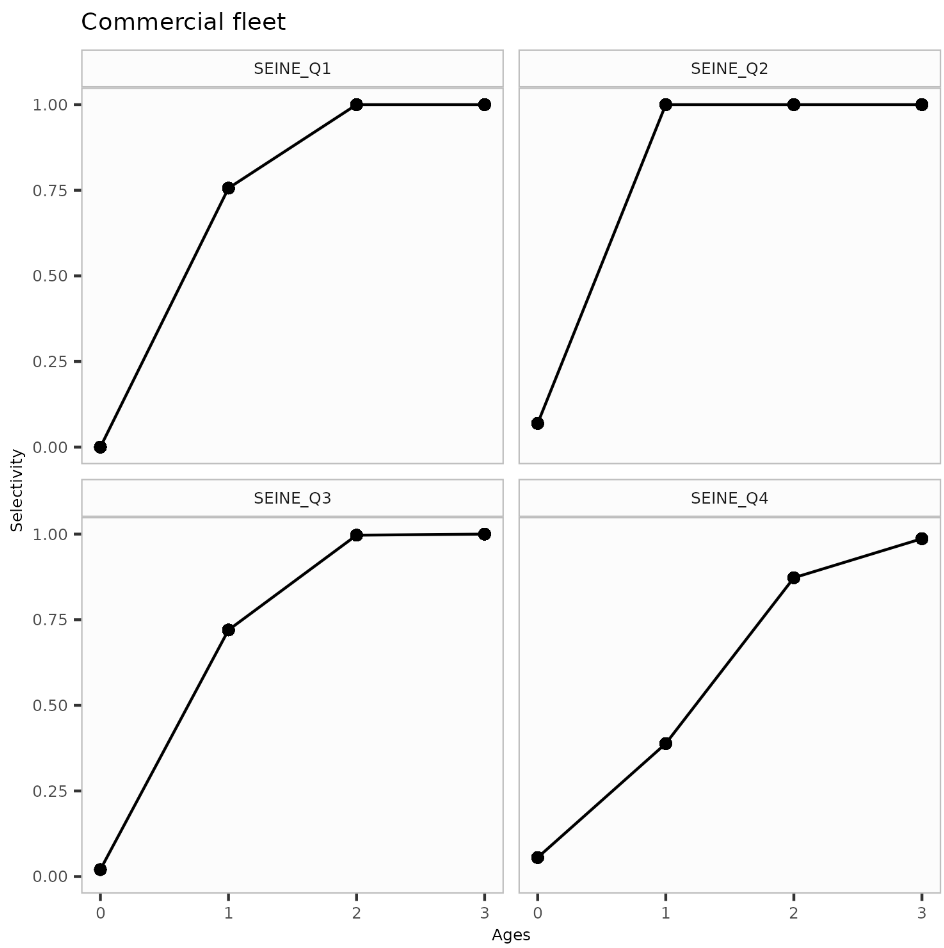


Figure 29: ane.27.9a Southern stock.Estimated selectivity for catch-at-age of commercial fleet (logistic shaped fixed selectivity across all years).

Figure 30 shows the estimated selectivity for the age composition of the acoustic surveys

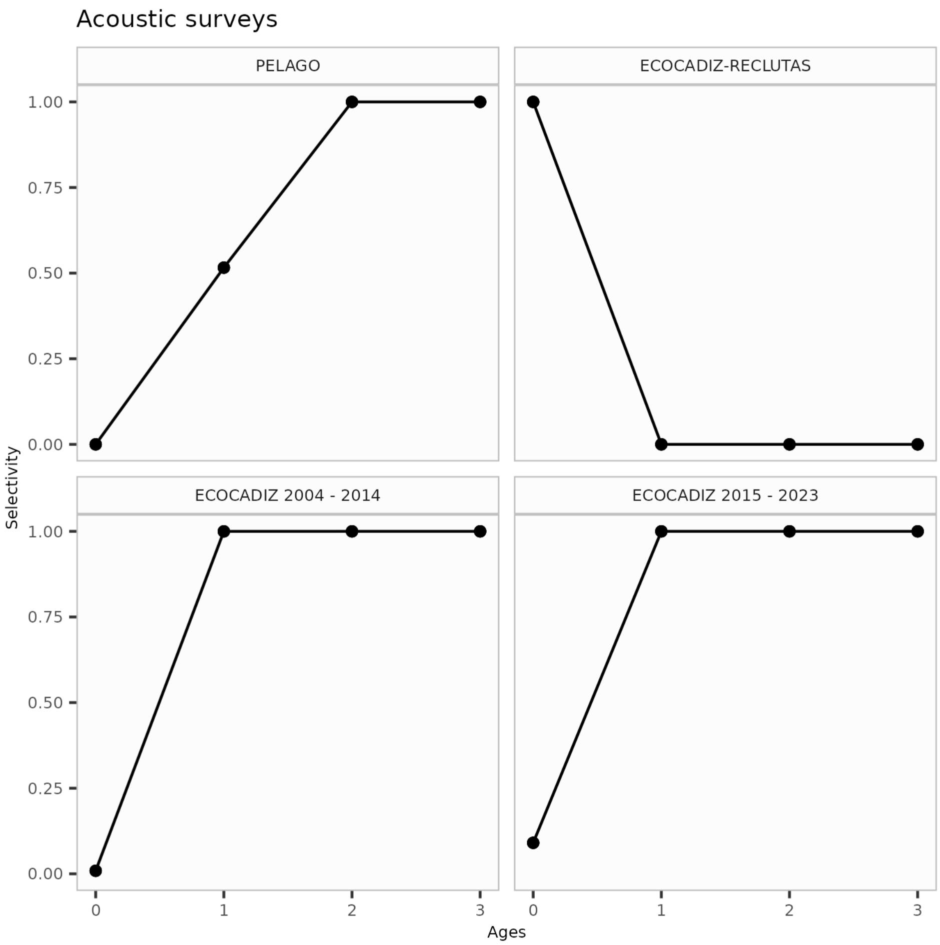


Figure 30: ane.27.9a Southern stock. Estimated selectivity for catch-at-age of surveys (logistic shaped fixed selectivity across all years)

But, it is important to remark that the selectivity assumption for *ECOCADIZ* survey was different from the others, and it was separated into two different periods: 2004 to 2014 and 2015 to 2023, this difference can be appreciated in Figure 31

Catchability

The catchability (q) is adjusted to maintain a consistent relationship between the observed biomass and the vulnerable biomass in acoustic surveys (Figure 31).

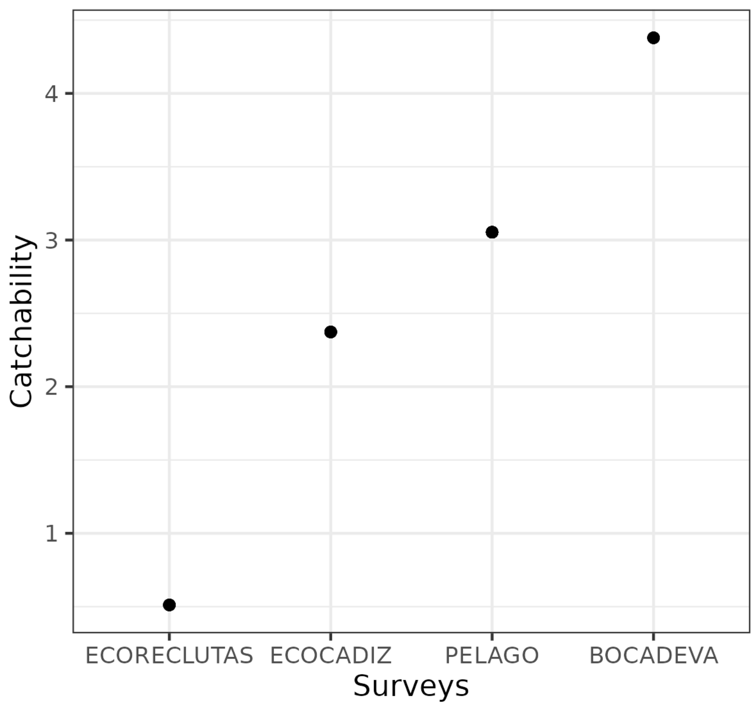


Figure 31: ane.27.9a Southern stock. Estimated catchability parameters for the different surveys indices.

Estimated time series

The Figure 32 shows that total biomass fluctuates around a historical mean of 17.45 thousand tonnes, with a minimum in 2010 of 9.91 thousand tonnes and a maximum recorded in 2001 of 27.91 thousand tonnes. In 2023, the biomass is estimated to be 28% below the historical mean. The catch shows variability around the historical mean of 5.22 thousand tonnes, with a maximum value recorded in 1998 of 9.58 thousand tonnes and a minimum in 1995 of 0.57 thousand tonnes. In 2023, the catch is estimated to be 43% above the historical mean.

The fishing mortality (F_t) fluctuates around a historical mean of 0.91, with a maximum value recorded in 2023 of 2.48 and a minimum in 1995 of 0.09. Confidence intervals range from 0.35 to 0.21, with an average of 0.28. The F_{2023} is estimated to be 171% above the historical mean.

The recruitment (R_t) fluctuates around a historical mean of 7.54 millions recruits, with a maximum value recorded in 2000 of 11.48 millions recruits and a minimum in 2009 of 3.28 millions recruits. Confidence intervals range from 0.26 to 0.09, with an average of 0.17. The R_{2023} is estimated to be 34% below the historical mean.

Finally, the spawning biomass (SSB_t) varies around a historical mean of 13.21 thousand tonnes, with a maximum value recorded in 2001 of 22.75 thousand tonnes and a minimum in 2010 of 6.56 thousand tonnes. Confidence intervals range from 0.27 to 0.1, with an average of 0.18.The SSB_{2023} is estimated to be 31% below the historical mean.

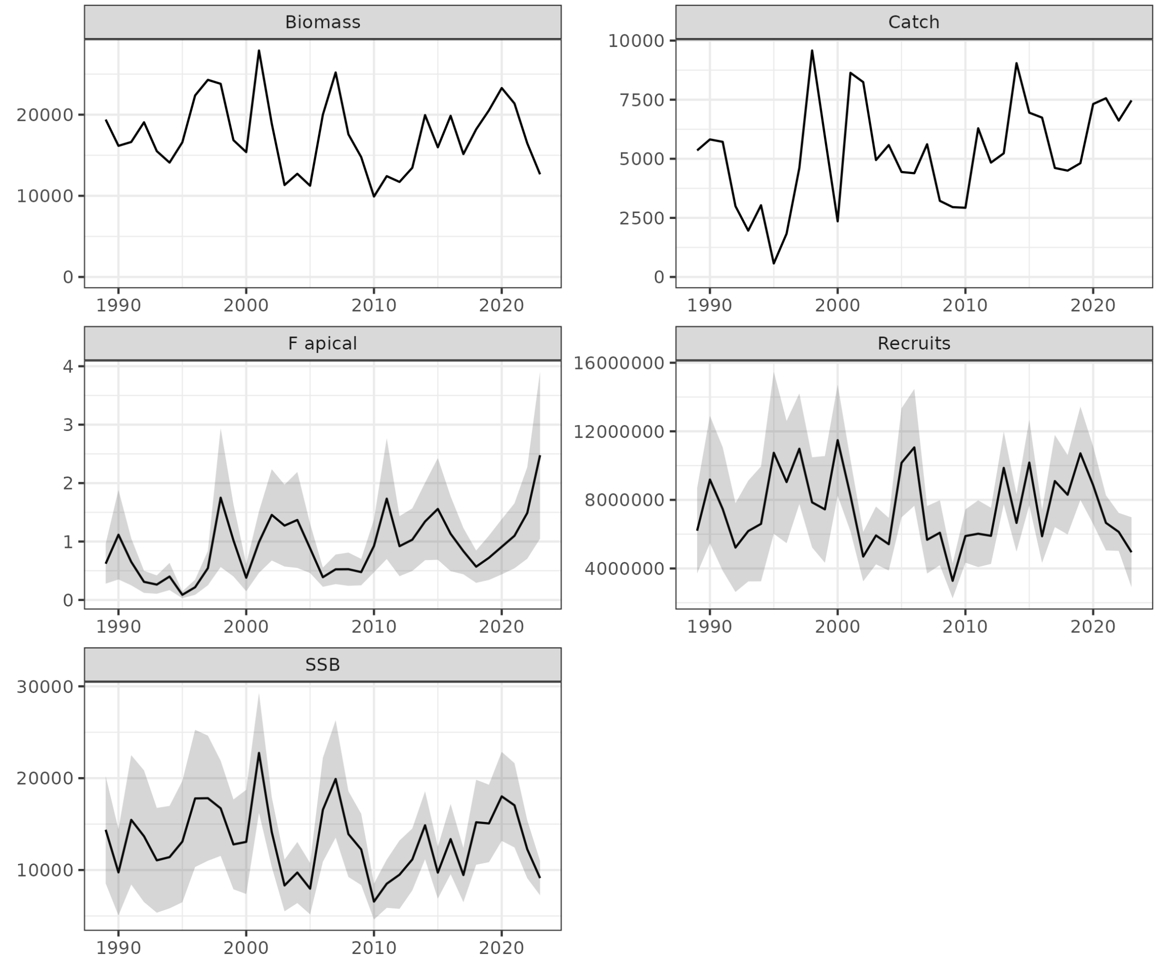


Figure 32: ane.27.9a Southern stock. Time series estimated by the model for annual catches (in tons), recruitment (millions of fish), total biomass and spawning biomass (in tons), and fishing mortality (year-1).

The summarised data resulting from model outputs is shown in Figure 33.

Year	SSB ton	CV SSB	Recruits number	CV Recruits	F apical year-1	CV F apical	Total Biomass ton	Catch ton
1989	14380.10	0.21	6201250	0.20	0.62	0.28	19395.40	5354.25
1990	9740.51	0.24	9187410	0.21	1.12	0.35	16162.30	5819.06
1991	15462.70	0.23	7466690	0.25	0.65	0.31	16635.00	5717.34
1992	13675.60	0.27	5217840	0.25	0.31	0.31	19063.60	2996.70
1993	11056.00	0.26	6181600	0.24	0.26	0.30	15505.90	1959.95
1994	11404.60	0.25	6600600	0.26	0.40	0.29	14093.50	3035.46
1995	13094.20	0.26	10748000	0.22	0.09	0.34	16596.00	570.61
1996	17794.70	0.21	9038790	0.20	0.22	0.30	22371.70	1831.41
1997	17820.00	0.19	10984400	0.15	0.54	0.27	24292.60	4613.21
1998	16716.10	0.16	7854720	0.17	1.75	0.35	23803.70	9582.31
1999	12789.00	0.19	7446860	0.21	1.02	0.31	16858.50	5940.55
2000	13062.70	0.22	11484400	0.14	0.38	0.31	15387.80	2353.44
2001	22750.70	0.15	8253590	0.13	0.99	0.27	27912.10	8636.66
2002	14129.10	0.14	4692490	0.16	1.46	0.27	18900.90	8244.27
2003	8318.54	0.17	5924140	0.15	1.27	0.28	11328.30	4947.81
2004	9726.93	0.17	5415460	0.14	1.37	0.31	12717.80	5581.19
2005	7968.57	0.18	10162500	0.16	0.88	0.24	11244.80	4440.82
2006	16557.40	0.17	11062300	0.16	0.39	0.21	20000.00	4389.09
2007	19915.50	0.16	5671340	0.18	0.52	0.25	25201.00	5616.24
2008	13912.90	0.17	6083980	0.16	0.53	0.28	17583.30	3219.63
2009	12241.10	0.16	3278790	0.16	0.48	0.24	14773.80	2954.92
2010	6560.70	0.15	5890900	0.13	0.92	0.25	9912.18	2927.43
2011	8507.77	0.16	6026020	0.16	1.73	0.30	12425.90	6291.32
2012	9493.58	0.20	5903410	0.14	0.92	0.28	11711.90	4838.21
2013	11149.70	0.15	9866910	0.11	1.03	0.26	13456.80	5231.46
2014	14873.20	0.13	6655410	0.13	1.34	0.25	19950.00	9046.24
2015	9715.99	0.15	10177900	0.13	1.56	0.28	15981.20	6950.09
2016	13368.40	0.15	5878480	0.13	1.13	0.29	19859.10	6741.82
2017	9451.62	0.16	9097890	0.15	0.84	0.24	15144.40	4610.87
2018	15200.90	0.16	8299810	0.14	0.57	0.25	18197.40	4498.81
2019	15071.40	0.14	10715700	0.13	0.72	0.27	20537.50	4813.58
2020	18018.70	0.14	8850730	0.13	0.91	0.26	23286.70	7317.35
2021	17045.80	0.14	6659560	0.12	1.10	0.26	21376.40	7561.60
2022	12258.20	0.13	6132930	0.09	1.49	0.27	16471.40	6615.12
2023	9122.56	0.10	4944900	0.21	2.48	0.29	12651.80	7469.67

Figure 33: ane.27.9a Southern stock. Time series estimated by the model for annual catches (in tons), recruitment (millions of fish), total biomass and spawning biomass (in tons), and fishing mortality (year-1).

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Reference points and short-term forecast for WKBANSP 2024: Anchovy in ICES Subdivision 9a South (ane.27.9a Southern component)

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Biological Reference points

The methodology applied was the same decided in WKPELA 2018 (page 286 of WKPELA 2018 report (ICES, 2018)) following ICES guidelines for calculation of reference points for category 1 and 2 stocks and the report of the workshop to review the ICES advisory framework for short lived species ICES WKMSYREF5 2017 (ICES, 2017).

According to the above ICES guidelines and the $S-R$ plot characteristics (Figure 1), this stock component can be classified as a "stock type 5" (i.e. stocks showing no evidence of impaired recruitment or with no clear relation between stock and recruitment (no apparent $S-R$ signal)).

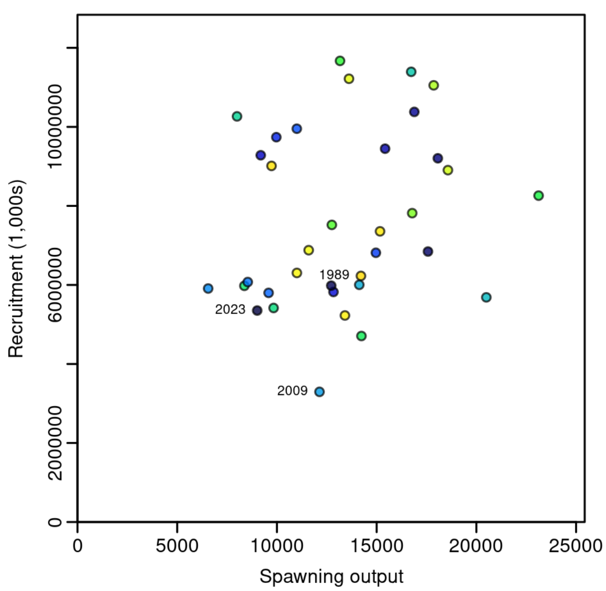

Figure 1: ane.27.9a Southern stock. Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

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The estimation of B_{lim} was carried out assuming $B_{lim} = B_{loss}$. For the 9a South anchovy, B_{loss} was calculated based on the estimated SSB in 2010, with a value of 6552.06 t, representing 39% of the unfished biomass (B_0 = 16865 t). This value falls below the range suggested by WKREF1 and WKREF2 (ICES, 2022), which recommend setting B_{lim} between 10% and 25% of B_0, depending on the species' life-history characteristics.

Three alternative methods were evaluated to calculate B_{lim}: a) $B_{lim} = 0.2 \times B_0$, b) $B_{lim} = B_{loss}$, and c) $B_{lim} = B_{pa} \times e^{-1.645 \times \sigma_B}$, where $B_{pa} = B_{loss}$ and σ_B is the standard deviation of $ln(SSB)$ in the terminal year of the assessment, accounting for uncertainty in the SSB. If σ_B is unknown, ICES guidelines recommend using a default value of $\sigma = 0.20$, or $\sigma = 0.30$ for small pelagic species.

The results of these alternatives are presented in Table 1 and Figure 2. Using $\sigma = 0.2$ provides an intermediate solution between the assessment's estimated value and the recommended value for small pelagic species, ensuring that B_{lim} is calculated in accordance with the stock's biological characteristics and ICES guidelines. Therefore, the recommended value is $B_{lim} = B_{pa} \times e^{-1.645 \times \sigma_B} = 4715$ tonnes, with $B_{pa} = B_{loss}$ and $\sigma_B = 0.2$, as applied in other fisheries.

The adopted approach aligns with guidelines for Type 6 stocks, characterized by a narrow SSB dynamic range and no evidence of impaired recruitment. Notably, using B_{loss} as B_{pa} rather than B_{lim} avoids an excessively high B_{lim}, which would represent approximately 0.4 B_0—indicating a relatively narrow range of biomass values covered in the assessment. This method offers a more suitable baseline for the stock's management.

Table 1: Alternative options for Technical basis for Blim calculation.

Technical basis Blim	SigmaB	Blim (tonnes)	Fraction B0
0.2*B0		3373	0.20
Bloss		6552	0.39
Bpa*exp(-1.654*sigmaB)	0.3	4000	0.24
Bpa*exp(-1.654*sigmaB)	**0.2**	**4715**	**0.28**
Bpa*exp(-1.654*sigmaB)	0.1	5542	0.33

Note: The bold row indicates the recommended method for calculating Blim.

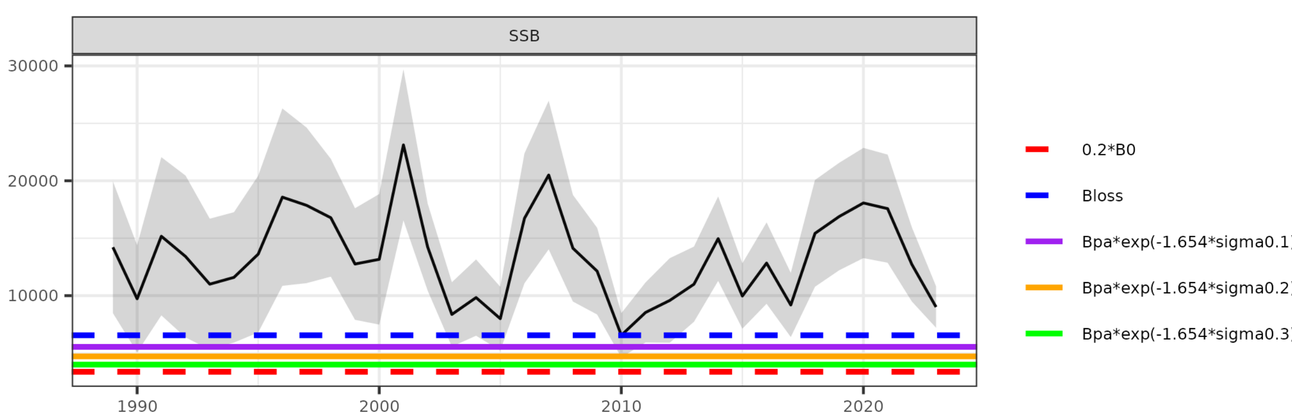


Figure 2: ane.27.9a Southern stock. Time series of estimated spawning biomass (tons) for 9a South anchovy, compared with three methods for calculating B_{lim}: a) $B_{lim} = 0.2 \times B_0$, b) $B_{lim} = B_{loss}$, and c) $B_{lim} = B_{pa} \times e^{-1.645 \times \sigma_B}$, with $\sigma_B = 0.1$, 0.2, and 0.3.

Short-term predictions

The SS3 forecast module was used to perform short-term projections, considering the model's final year conditions, associated uncertainties, and varying fishing intensities. The initial stock size was derived from the abundance at ages 0-3 on January 1 of the final assessment year, while the spawning stock biomass (SSB) was estimated for April 1. Natural mortality and maturity rates were held constant, with selectivity and weight-at-age averaged over the last three years. Recruitment for the forecast year was projected using the Stock Synthesis Beverton-Holt stock-recruitment relationship and the geometric mean of the last three years recruitment.

Status quo fishing mortality (Fsq) was calculated as the average across the last three years, by fleet and season (FfleetQ1=0.29, FfleetQ2=1.65, FfleetQ3=2.93, FfleetQ4=1.7). The Figures 3 and 4 show the short-term predictions of catch and SSB evaluated at different fishing mortality levels, under the recruitment projection scenario based the stock-recruitment relationship used in the model to forecast (Table 2) and the geometric mean of the last three years recruitment (Table 3).

Multipliers of the status quo fishing mortality (Fsq*Mult) of 0, 1, 1.2, 1.6, and 2,0 were evaluated. Additionally, an iterative process was used to identify the multiplier that would achieve a 2024 and 2025 catch with probabilities of 5% and 50% that SSB in 2024 and 2025 would fall below $Blim$ ($p(SSB < Blim) = 0.05$ and 0.5, respectively). These multipliers were adjusted according to the projected recruitment scenarios, providing management options based on different levels of fishing mortality. Tables 4 y 5 presents the management options derived from the short-term forecasts, evaluated at different fishing mortality levels, corresponding to the catch scenarios described previously.

The management options derived from these short-term projections entail shifting the timing of the advice to year-end, with assessments in November and management recommendations for the following calendar year (January to December).

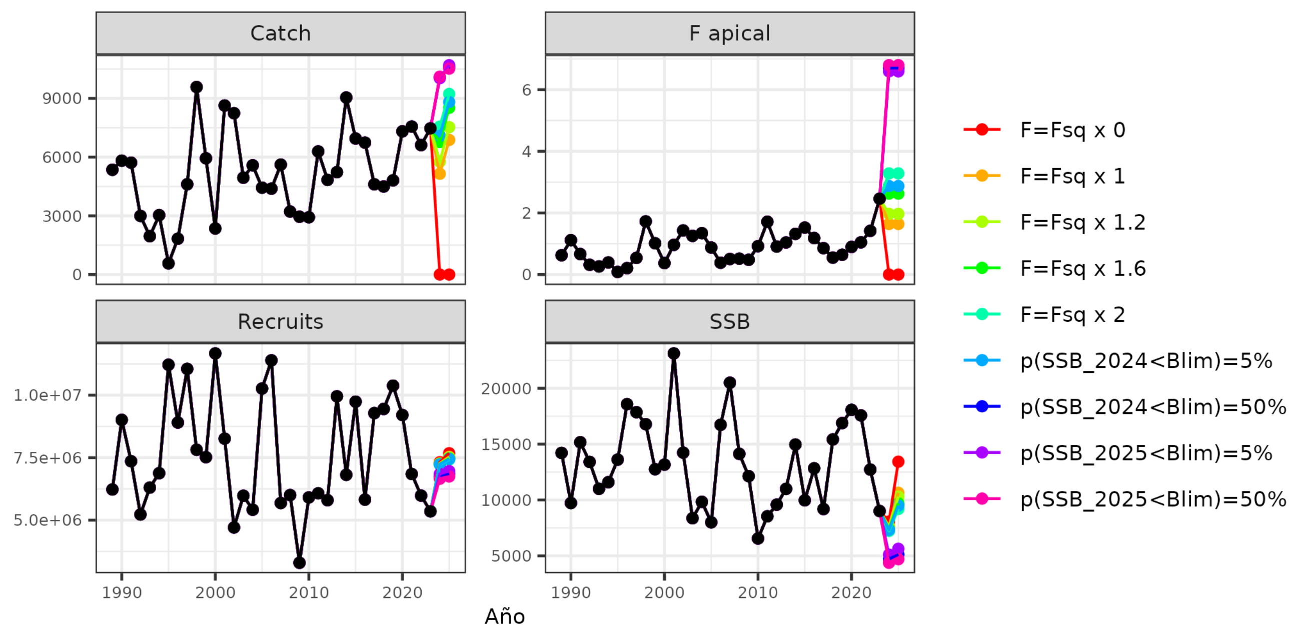


Figure 3: ane.27.9a Southern stock. Short-term predictions of catch and SSB evaluated at different fishing mortality levels, under the recruitment projection scenario based on the **Beverton-Holt (BH)** stock-recruitment relationship.

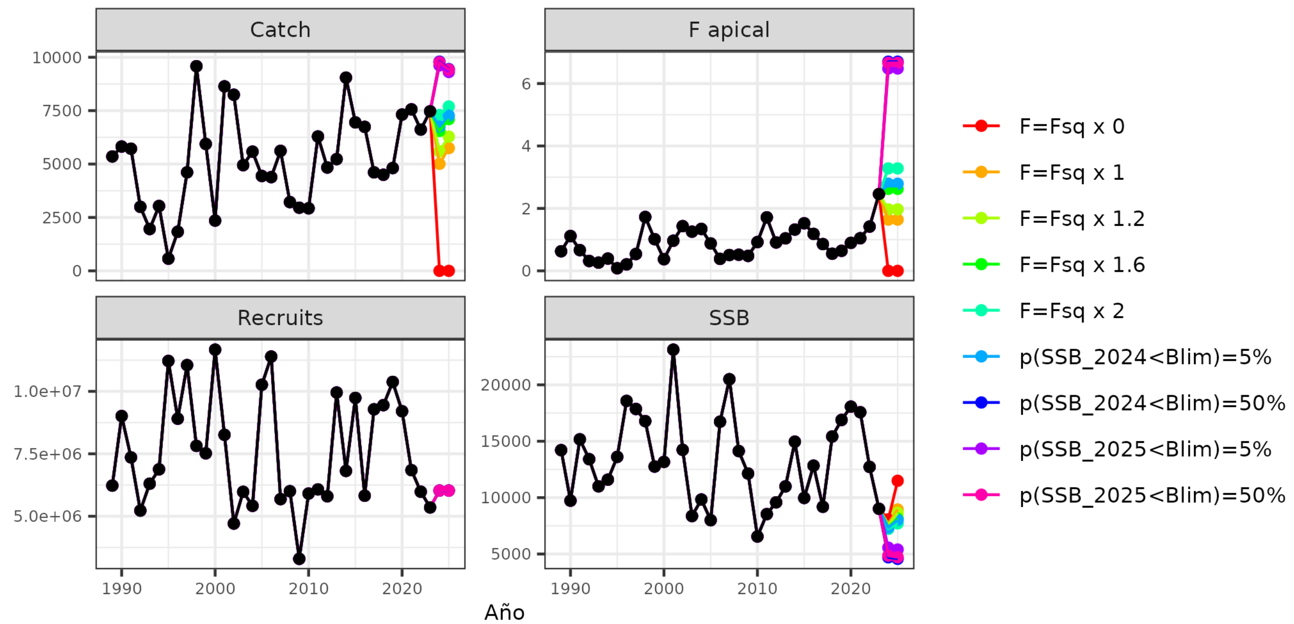


Figure 4: ane.27.9a Southern stock. Short-term predictions of catch and SSB evaluated at different fishing mortality levels, under the recruitment projection scenario based on the **geometric mean** of the last three years recruitment.

Table 2: The table presents apical fishing mortality (F apical 2024), recruitment (Rec) for 2024 estimated as the **Beverton-Holt (BH)** stock-recruitment relationship.

	Fapical 2024	Recruitment 2024
F=Fsq x 0	0.00	7317300
F=Fsq x 1	1.64	7268860
F=Fsq x 1.2	1.97	7258930
F=Fsq x 1.6	2.63	7238820
F=Fsq x 2	3.28	7218390
p(SSB_2024<Blim)=5%	2.87	7231200
p(SSB_2024<Blim)=50%	6.70	6749750
p(SSB_2025<Blim)=5%	6.59	6849810
p(SSB_2025<Blim)=50%	6.80	6656210

Table 3: The table presents apical fishing mortality (F apical 2024), recruitment (Rec) for 2024 estimated as the **geometric mean** of the last three years recruitment

	Fapical 2024	Recruitment 2024
F=Fsq x 0	0.00	6029030
F=Fsq x 1	1.64	6029030
F=Fsq x 1.2	1.97	6029030
F=Fsq x 1.6	2.63	6029030
F=Fsq x 2	3.28	6029030
p(SSB_2024<Blim)=5%	2.79	6029030
p(SSB_2024<Blim)=50%	6.70	6029030
p(SSB_2025<Blim)=5%	6.48	6029030
p(SSB_2025<Blim)=50%	6.66	6029030

Table 4: Short-term management options evaluated for different F multipliers, under the recruitment projection scenario based on the **Beverton-Holt (BH)** stock-recruitment relationship. The table presents, projected catches 2024 in tonnes, spawning stock biomass (SSB) for 2024 and 2025 in ton, and the probability of SSB falling below B_{lim} in 2024 and 2025.

	Fapical 2024	Catch 2024	SSB 2024	SSB 2025	p(SSB 2024 < Blim)	p(SSB 2025 < Blim)
F=Fsq x 0	0.00	0.00	8071.69	13427.50	0.03	0.00
F=Fsq x 1	1.64	5149.28	7639.00	10645.00	0.04	0.00
F=Fsq x 1.2	1.97	5764.95	7555.30	10293.00	0.04	0.00
F=Fsq x 1.6	2.63	6770.10	7390.65	9695.14	0.05	0.00
F=Fsq x 2	3.28	7560.72	7229.62	9196.14	0.06	0.00
p(SSB_2024<Blim)=5%	2.87	7087.19	7329.85	9498.59	0.05	0.00
p(SSB_2024<Blim)=50%	6.70	10077.97	4707.22	5120.50	0.50	0.24
p(SSB_2025<Blim)=5%	6.59	10034.83	5108.24	5632.79	0.36	0.05
p(SSB_2025<Blim)=50%	6.80	10111.38	4376.70	4699.63	0.64	0.51

Table 5: Short-term management options evaluated for different F multipliers, under the recruitment projection scenario based on the **geometric mean** of the last three years recruitment. The table presents, projected catches 2024 in ton, spawning stock biomass (SSB) for 2024 and 2025 in ton, and the probability of SSB falling below B_{lim} in 2024 and 2025.

	Fapical 2024	Catch 2024	SSB 2024	SSB 2025	p(SSB 2024 < Blim)	p(SSB 2025 < Blim)
F=Fsq x 0	0.00	0.00	8071.69	11494.10	0.03	0.00
F=Fsq x 1	1.64	5008.94	7639.00	8949.79	0.04	0.00
F=Fsq x 1.2	1.97	5598.41	7555.30	8642.42	0.04	0.00
F=Fsq x 1.6	2.63	6552.99	7390.65	8130.94	0.05	0.00
F=Fsq x 2	3.28	7295.54	7229.62	7714.61	0.06	0.00
p(SSB_2024<Blim)=5%	2.79	6755.18	7350.06	8019.53	0.05	0.00
p(SSB_2024<Blim)=50%	6.70	9793.97	4703.98	4571.73	0.50	0.63
p(SSB_2025<Blim)=5%	6.48	9619.33	5566.53	5398.19	0.24	0.05
p(SSB_2025<Blim)=50%	6.66	9763.19	4851.67	4713.38	0.45	0.50

Working document to WKBANSP 2024, 5-7 March 2024, online.

Anchovy DEPM in the Bay of Biscay: BIOMAN survey 1987-2023

by

Santos, M., Citores, L. and Ibaibarriaga, L.

1. Introduction

For the Bay of Biscay anchovy, the Daily Egg Production Method (DEPM; Lasker, 1985) has been used to monitor the population on an annual basis since 1987 (Santiago and Sanz 1992, Motos *et al*. 2005, Santos *et al* 2018). The *Bioman* survey (Santos *et al.,* 2023) which use the DEPM to estimate the Bay of Biscay anchovy biomass is one of the three surveys that provide information on the adult anchovy population. Another one carried out at the same time in May is the acoustic French survey *Pelgas.* The third one is *Juvena* survey, it is an acoustic survey to estimate abundance of anchovy juvenile every September-October, with the long-term objective of forecasting the strength of the anchovy recruitment which will enter the fishery the next year.
The adult anchovy biomass indices provided by the acoustic and DEPM surveys and since 2014 the juvenile biomass index provided by the juvenile acoustic survey, together with the catches supplied by the fleet are used as input variables for a two-stage biomass model, a Bayesian base model (CBBM) used to assess the Bay of Biscay anchovy population (Ibaibarriaga *et al*., 2008). Specifically, anchovy total Biomass, % at age 1 and W at age obtained from the DEPM are used as inputs for the assessment at ICES 8abcd.

Since the last benchmark for anchovy in ices area 8 (WKPELA2013) there have been no changes for the DEPM in the series, nor in the data neither in the methodology. However, a study has been carried out using a Bayesian approach to estimate daily egg production (P_0) and egg mortality (Z), implies in the estimation of Total daily egg production (P_{tot}). Estimates of Z are constrained to the correct range by a prior distribution based on the literature, to overcome the biologically implausible Z estimates that can result from frequentist approaches, which have been used to date. This study demonstrates that fitting the egg mortality curve using a Bayesian Generalized Non-Linear Multivariate Multilevel Model framework (Bürkner, 2017) avoids spurious or incorrect egg mortality rates and can reduce the coefficients of variation of the final estimates. As there is just one years (1992) where the Z could be questioned but the results do not change in the series and this approach is statistically more robust, we propose to use it from 2024 onwards.
This working document presents the methods currently used to estimate anchovy biomass in the Bay of Biscay by means of the DEPM and the new Bayesian approach to estimate daily egg production (P_0) and egg mortality (Z). The historical series of the results of each parameter necessary to estimate de biomass by the DEPM, are as well presented.

2. Methods

2.1 DEPM time series

The Daily Egg Production Method (DEPM; Lasker 1985) estimates the Spawning Stock Biomass (*SSB*) as follows:

$$(1) \qquad SSB = \frac{Ptot}{DF} = k \frac{A \cdot P0}{R \cdot S \cdot (F/Wf)} = k \frac{A \cdot P0 \cdot Wf}{R \cdot S \cdot F},$$

where P_{tot} refers to total daily egg production, DF daily fecundity, A to the spawning area, P_0 to the daily egg production per unit area, R is the sex ratio in mass, S is the fraction of mature females spawning per day, F is the batch fecundity or number of eggs released daily per spawning females and W_f refers to the mean weight of mature females.

For the application of the DEPM to obtain the spawning stock biomass, concurrent egg and adult sampling are conducted every year along the spawning area of this stock at peak spawning time (May-June). Since the method is applied at the peak of spawning and at that time the entire population is mature, the total biomass is obtained.
See **Figure 1** as an example of BIOMAN surveys.

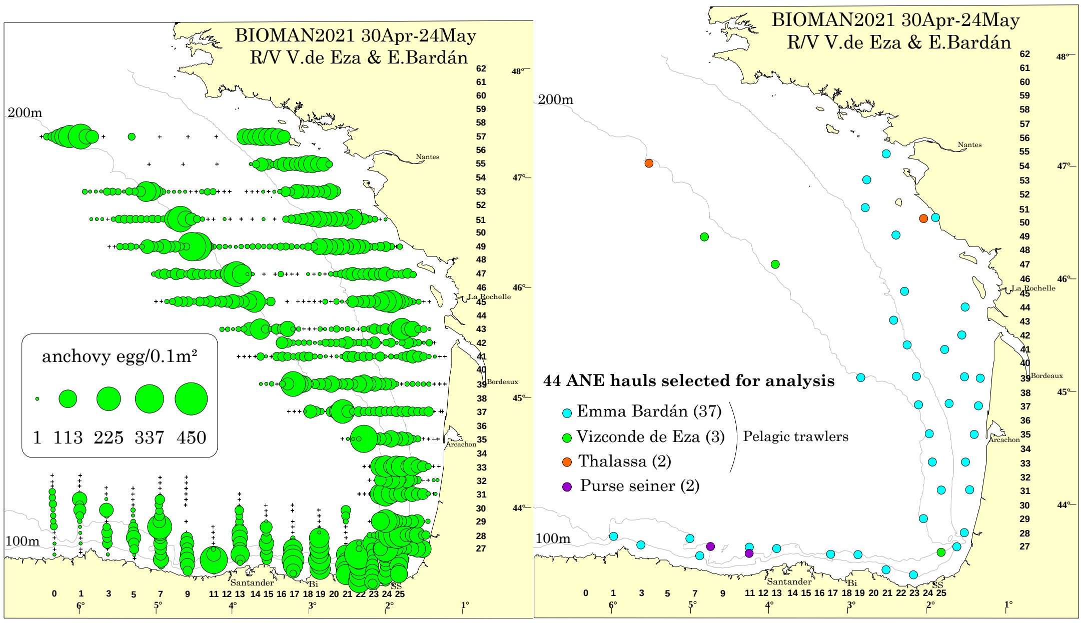


Figure 1: plankton stations with the anchovy egg abundances (left) and adult fishing hauls during BIOMAN 2021, in May (from Santos Mokoroa *et al*. 2021).

For the egg sampling a systematic central sampling scheme with random origin and sampling intensity depending on the egg abundance is applied (Motos 1994). Stations are situated at intervals of 3 nm along 15 nm apart transects perpendicular to the coast. At each station a vertical plankton haul is performed using a PairoVET net (Pair of Vertical Egg Tow, Smith et al. 1985) with a net mesh size of 150 µm for a total retention of the anchovy eggs under all likely conditions.

The adult sampling over the spawning area is obtained for most of the years either by direct fishing from the egg sampling vessel (as in 1991 and 1992) or by collaboration with a French parallel acoustic survey (1994, 1997, 1998, 2001) or with another vessel navigating in parallel to the vessel sampling the plankton (2002-2023). This sampling is complemented with opportunistic samples collected from the commercial fleet operating in the area, although last years, only 1 or 2 samples were requested to the fleet. Samples of two kg are selected at random from each haul. A minimum 60 anchovies are weighted, measured, and sexed and from the mature females the gonads of 25 non-hydrated females (NHF) are preserved for histological examination to determine the spawning fraction. Otoliths are extracted on board and read in the laboratory on land to obtain the age composition per sample.

The survey in this context is aimed to get estimates of the spawning area, total egg production, daily fecundity, population biomass and age composition. The standard methods followed in the application of the DEPM method are detailed in Motos,1994; Somarakis *et al*. 2004 and Santos *et al* 2018.

2.2 Egg parameters estimates.

From the egg surveys the eggs collected at sea after fixation in formaldehyde, are sorted and classified into embryo development stages (Moser and Ahlstrom,1985) which are used to obtain their most likely age in hours.
The daily egg production per area unit (P_0) was estimated together with the daily mortality rate (Z) from a general exponential decay mortality model of the form:

(2) $$P_{i,j} = P_0 \exp\left(-Z\, a_{i,j}\right)$$

where $P_{i,j}$ and $a_{i,j}$ denote respectively the number of eggs per unit area in cohort *j* in station *i* and their corresponding mean age. Let the density of eggs in cohort j in station *i*, $P_{i,j}$, be the ratio between the number of eggs $N_{i,j}$ and the effective sea area sampled R_i (i.e. $P_{i,j} = N_{i,j} / R_i$). The model was written as a generalised linear model (GLM, McCullagh and Nelder, 1989; ICES, 2004) with logarithmic link function:

(3) $$\log\left(E[N_{i,j}]\right) = \log(R_i) + \log\left(P_0\right) - Z\, a_{i,j}$$

where the number of eggs of daily cohort *j* in station *i* (N_{ij}) was assumed to follow a negative binomial distribution. The logarithm of the effective sea surface area sampled (log (R_i)) was an offset accounting for differences in the sea surface area sampled and the logarithm of the daily egg production log(P_0) and the daily mortality Z rates were the parameters to be estimated.

The eggs collected and sorted at sea and classified into morphological stages had to be transformed into daily cohort frequencies and their mean age calculated to fit the above model. For that purpose, the Bayesian ageing method described in Stratoudakis *et al*., 2006 and Bernal et al., 2011 was used. This ageing method is based on the probability density function (pdf) of the age of an egg f (age | stage, temp), which is constructed as:

(4) $$f(age \mid stage, temp) \propto f(stage \mid age, temp)\, f(age)$$

The first term f (stage | age, temp) is the pdf of stages given age and temperature. It represents the temperature dependent egg development, which is obtained by fitting a multinomial model like extended continuation ratio models (Agresti, 1990) to data from temperature dependent incubation experiments (Ibaibarriaga *et al*., 2007, Bernal et al., 2008. The second term is the prior distribution of age. A priori the probability of an egg that was sampled at time τ of having an age is the product of the probability of an egg being spawned at time τ - age and the probability of that egg surviving since then (exp (-Z age)):

(5) $$f(age) \propto f(spawn = \tau - age) \exp(-Z\, age)$$

The pdf of spawning time f (spawn= τ - age) allows refining the ageing process for species with spawning synchronicity that spawn at approximately certain times of the day (Lo, 1985a; Bernal *et al*., 2001). Anchovy spawning time was assumed to be normally distributed with mean at 23:00h GMT and standard deviation of 1.25 (ICES, 2004). The peak of the spawning time was also used to define the age limits for each daily cohort (spawning time peak plus and minus 12 hours). Details on how the number of eggs in each cohort and the corresponding mean age are computed from the pdf of age are given in Bernal *et al* (2011). The incubation temperature considered was the one obtained from the CTD at 10m in the way down.

Given that this ageing process depends on the daily mortality rate which is unknown, an iterative algorithm in which the ageing and the model fitting are repeated until convergence of the Z estimates was used (Bernal *et al*., 2001; ICES, 2004; Stratoudakis *et al*., 2006). The procedure is as follows:

- Step 1. Assume an initial mortality rate value.
- Step 2. Using the current estimates of mortality calculate the daily cohort frequencies and their mean age.
- Step 3. Fit the GLM and estimate the daily egg production and mortality rates. Update the mortality rate estimate.

- Step 4. Repeat steps (1) - (3) until the estimate of mortality converged (i.e. the difference between the old and updated mortality estimates was smaller than 0.0001).

Incomplete cohorts, either because the bulk of spawning for the day was not over at the time of sampling, or because the cohort was so old that its constituent eggs had started to hatch in substantial numbers, were removed to avoid any possible bias. At each station, younger cohorts were dropped if they were sampled before twice the spawning peak width after the spawning peak and older cohorts were dropped if their mean age plus twice the spawning peak width was over the critical age at which less than 99% eggs were expected to be still unhatched. In addition, eggs younger than 4 hours and older than 90% of the survey incubation time (Motos, 1994) were removed.
Once the final model estimates were obtained the coefficient of variation of P_0 was given by the standard error of the model intercept (log (P_0)) (Seber, 1982) and the coefficient of variation of Z was obtained directly from the model estimates.
The analysis was conducted in R (www.r-project.org). The "MASS" library was used for fitting the GLM with negative binomial distribution and the "egg" library (http://sourceforge.net/projects/ichthyoanalysis/) for the ageing and the iterative algorithm.

2.3 Bayesian approach to estimate P_0 and Z

As explained in the section before, the daily egg production (P_0) is obtained from the exponential decay mortality model (Picquelle and Stauffer 1985) fitted as a Generalized Linear Model (GLM, McCullagh and Nelder, 1989) to the egg daily cohorts (Stratoudakis *et al*. 2006). Most usual frequentist approaches for fitting this GLM can occasionally lead to implausible mortality (Z) estimates. Thus, an alternative Bayesian approach is proposed, where estimates of mortality are restricted to the proper domain through a prior distribution based on literature. This Bayesian approach has been applied to anchovy in the Bay of Biscay using the data collected during BIOMAN surveys (Santos *et al*, 2023).

As in frequentist approaches, assuming that the number of eggs in daily cohort j in station i ($N_{i,j}$) follow a negative binomial distribution $N_{i,j} \sim NB(E[N_{i,j}], \phi)$ where ϕ is the shape parameter, the model is written as a generalised linear model (GLM, McCullagh and Nelder 1989; ICES 2004, Bernal *et al*. 2011a) with logarithmic link function as in equation 3. Where the logarithm of the effective sea surface area sampled (log (R_i)) is an offset (i.e., its coefficient is not estimated) that accounts for differences in the sea surface area sampled and the logarithm of the daily egg production log(P_0), the hourly mortality Z rates and the shape. Assuming that each estimate of Z comes from a normal distribution, a mixture of normal distributions was generated, excluding negative values. parameter of the negative binomial distribution are the parameters to be estimated. Data were weighted by the area represented by each station in the estimation process.

In order to define the prior distribution for the mortality parameter, estimates of hourly mortality rate and corresponding standard errors from several case studies were collected from the literature. The following case studies were included: 1) Argentina (*Engraulis anchoita*, Pájaro *et al*. 2009), 2) Patagonia (*Engraulis anchoita*, Pájaro *et al*. 2009), 3) Cadiz (*Engraulis encrasicolus*, Jiménez *et al*. 2018), 4) California (*Engraulis mordax*, Lo 1997), 5) Chile (*Engraulis ringens* Cubillos et al. 2007), 6) Peru (*Engraulis ringens*, Lo 1997) and 7) South Africa (*Engraulis capensis*, Shelton *et al*. 1993). The statistical distribution that best fitted these mixtures were Gamma distributions, with α=1.46 and β=62.48 (**Figure 2**)

(6) $$Z \sim Gamma(\alpha, \beta)$$

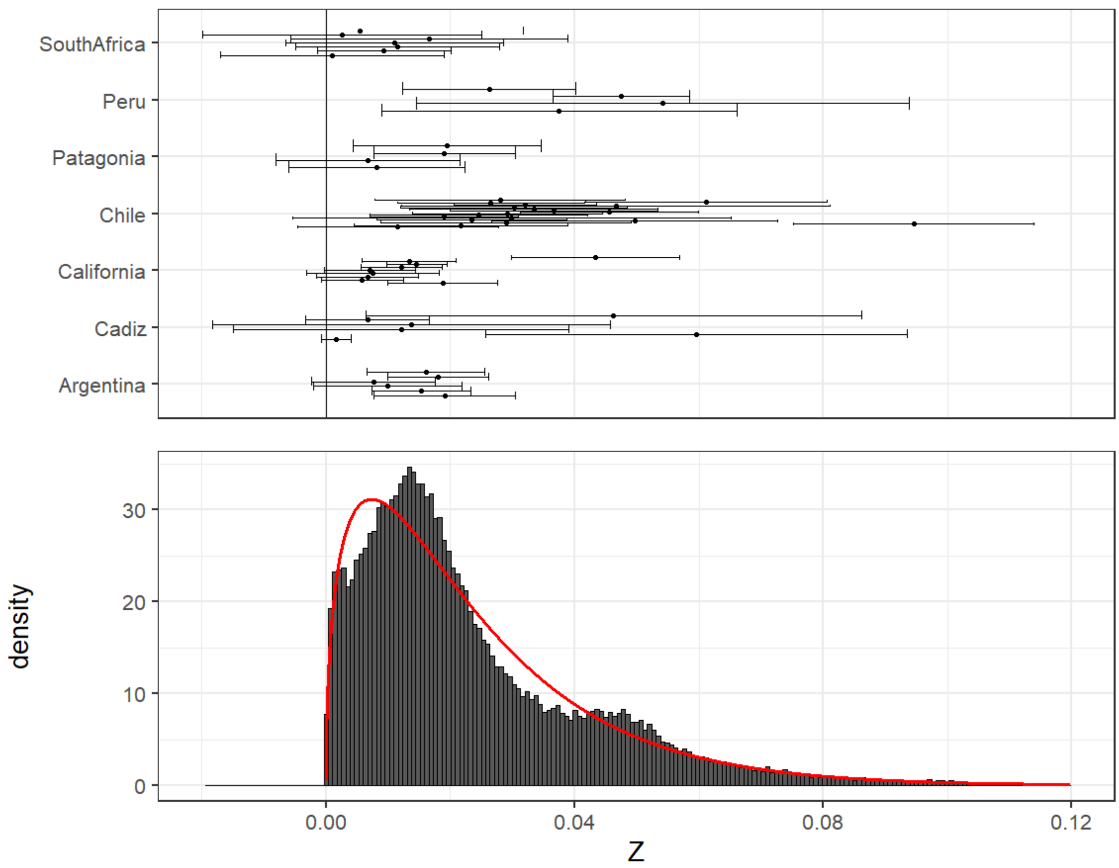


Figure 2: Hourly mortality (Z) point estimates (points) and 95% confidence intervals (horizontal lines) for each year provided by each anchovy case study (upper panel). Density of the empirical mixture distribution in black, and density of the fitted Gamma (1.46, 64.48) distribution in red (lower panel).

The prior distributions for the other two unknown parameters in the GLM, namely the intercept, log(P_0), and the shape parameter of the negative binomial distribution, ϕ, were defined following the default proposal made in the “bmrs” (Bürkner *et al*. 2017) R package, which was used for parameter estimation based on MCMC methods:

(7) $$\phi \sim Gamma(0.01,0.01)$$

$$\log(P_0) \sim Student_{t(3,location,scale)},$$

Following this approach for the dataset, corresponding to each year (from 1989 to 2022) of the BIOMAN survey series, posterior distributions for the parameters of interest, P_0 and Z, were obtained ensuring that the mortality estimated within the model were in the proper domain. Obtained P_0 and P_{tot} estimates with the proposed Bayesian approach agree with the estimates from the previous frequentist approaches (**Figure 3**).

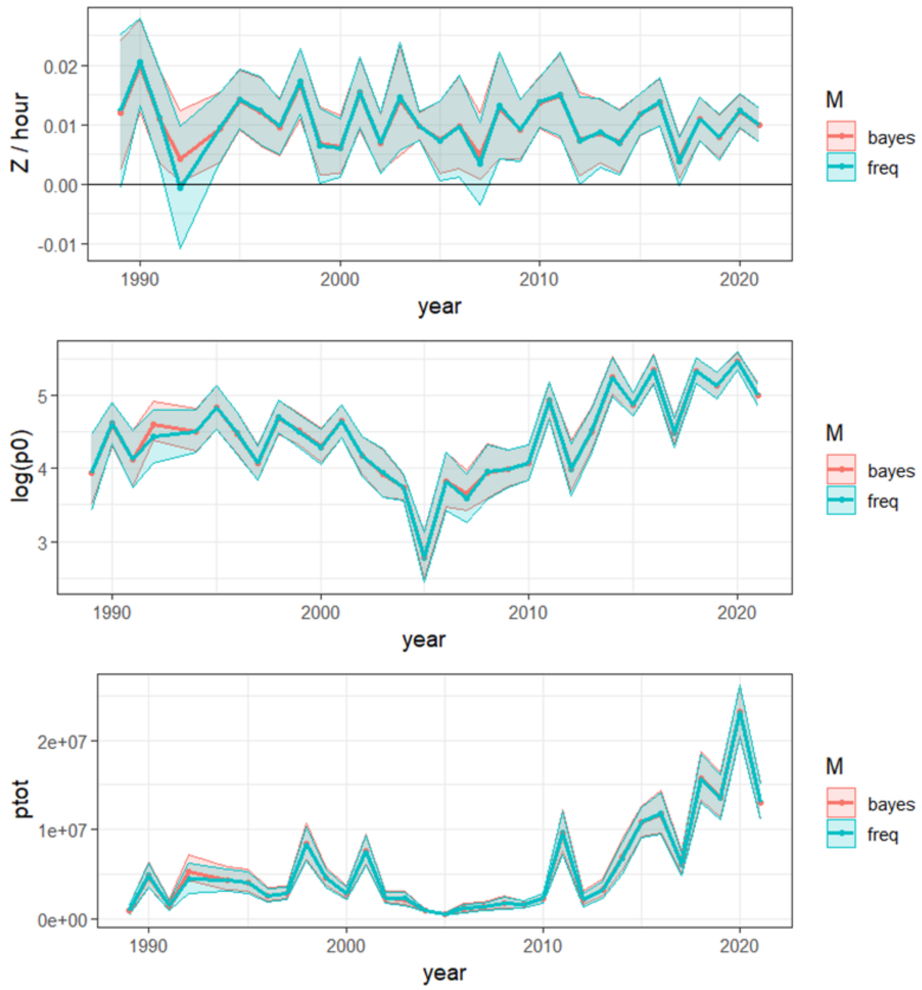


Figure 3: Point estimates (joined points) and 95% confidence intervals (shaded ribbons) for estimated parameters Z, P_0 and P_{tot} for all years and all covered area. Colours represent two different approaches: the Bayesian approach in red and the frequentist approach in blue. Frequentist confidence intervals are computed as mean+- 1.96se.

A sensitivity analysis to the priors for the mortality parameter was carried out comparing the selected Gamma prior distribution based on literature to other alternatives, obtaining that posterior distributions were very similar in all cases.
More details on the anchovy case study are provided in Citores *et al*. 2024.

2.4 Adult parameters estimates.

Regarding adult parameters the Daily Fecundity (*DF*) (eggs per female gram per day) is usually estimated as follows:

(8) $$DF = R * S * \frac{F}{W_f}$$

where R is the sex ratio in weight, *F* is the batch fecundity (eggs per batch per mature female weight), S is the spawning fraction (percentage of females spawning per day) and W_f is the female mean weight.

Mean weight of mature females (W_f) and sex ratio (*R*) per sample were obtained following standard procedures.
From 1987 to 1993 the sex ratio (*R*) in numbers resulted to be not significantly different from 50% for anchovy. Therefore, since 1994 the sex ratio in numbers is assumed to be 0.5 and the sex ratio in weight per sample is estimated as the ratio between the average female weight and the sum of the average female and male weights of the anchovies in each of the samples.

A linear regression model between total weight (*W*) and gonad free weight (*Wgf*) was fitted to data from non-hydrated females:

(9) $$E[W] = a + b * W_{gf}$$

This model was used to correct the weight increase of hydrated anchovies. The female mean weight (W_f) per sample was calculated as the average of the individual female weights.

For the batch fecundity (*F*) the hydrated oocyte method has always been followed (Hunter and Macewicz., 1985). At least 10 hydrated females by each length class representative of the length distribution of the population were select for this analysis. The number of hydrated oocytes in gonads of that set of hydrated females was counted. This number was deduced from a sub-sampling of the hydrated ovary. Three pieces of approximately 0.05g were removed from the extremes and the centre of one of the ovary lobules of each hydrated anchovy. Those were weighted with precision of 0.1 mg and the number of hydrated oocytes counted. Finally, the number of hydrated oocytes in the sub-sample was

raised to the gonad weight of the female according to the ratio between the weights of the gonad and the weight of the sub-samples.
The model between the number of hydrated oocytes and the female gonad free weight was fitted as a Generalized Linear Model with Gamma distribution and identity link:

(10) $$E[F] = a + b * W_{gf}$$

The average of the batch fecundity for the females of each sample as derived from the gonad free weight - eggs per batch relationship was then used as the sample estimate of batch fecundity.
Every year it is checked whether there are statistical differences in the batch fecundity for the different strata defined with particular attention to differences between the major nursery area, the Gironde area, where one year old anchovies predominated, and the remaining areas. In several years, some differences were observed although the difference was not statistically significant. Nevertheless, such spatial differences were taken into account, not to stratify the estimates, but to give different individual weighting factors to the samples from each of the different areas in order to obtain unbiased estimates of the adult parameters. This incorporates the spatial heterogeneity of batch fecundity into the estimation.

Once sex ratio, female mean weight and batch fecundity are estimated per sample, overall mean and variance for each of these parameters are estimated following equations for cluster sampling (Picquelle & Stauffer, 1985):

(11) $$y = \frac{\sum_{i=1}^{n} M_i y_i}{\sum_{i=1}^{n} M_i}$$ and

(12) $$Var(y) = \frac{n \sum_{i=1}^{n} M_i^2 (y_i - y)^2}{\left(\frac{\sum_{i=1}^{n} M_i}{n} \right)^2 n(n-1)},$$

where Y_i and M_i are the mean of the adult parameter Y and the cluster sample size in sample *i* respectively. The variance equation for the batch fecundity was corrected according to Picquelle and Stauffer (1985) to account for the additional variance due to model fitting.
The weights (M_i) were taken to reflect the actual size of the catch and to account for the lower reliability when the sample catch was small (Picquelle and Stauffer, 1985). For the

estimation of W_f, *F* and S when the number of mature females per sample was less than 20 the weighting factor was equal to the number of mature females per sample divided by 20, otherwise it was set equal to 1. In the case of *R* when total weight of the sample was less than 800 g, the weighting factor was equal to the total weight of the sample divided by 800g, otherwise it was set equal to 1.

To estimate spawning frequency (*S*), the percentage of females spawning per day, the classification for oocyte and POFs stage of Alday *et al*. (2008) and the procedures described in Uriarte *et al*. (2012) were applied. The degeneration of postovulatory follicles (POFs) in time at different temperatures was studied for the Bay of Biscay anchovy by Alday *et al*. (2008). A key of seven POF stages, defined on their histological degeneration characteristics, was applied (Alday *et al*., 2008; 2010). This procedure separates staging of POFs from their ageing process. For the range of temperatures examined (13–19˚C), little effect of temperature on the degeneration of POF was noticed.
The procedure to assign mature females to spawning classes was improved by incorporating all the knowledge on oocyte maturation and degeneration of POFs in a matrix system which defines the probabilities of females with those histological indicators belonging to pre- or post-spawning cohort according to the time of capture (Uriarte *et al*., 2012).
Finally, the selected estimator was the mean of S (day 0) and S (day 1).

Potential spatial differences in *S* estimates are routinely checked in all surveys, with particular attention to differences between the main nursery areas and other areas. In several years, some differences were observed between the S estimates in the Gironde area, where one year old anchovies predominated, and the remaining areas, with lower S values in the former area, although the difference was not statistically significant. Nevertheless, such spatial differences were taken into account, not to stratify the estimates, but to give different individual weighting factors to the samples from each of the different areas in order to obtain unbiased estimates of the adult parameters.

3. Results

On average, the surveys covered a total area of 80 000 km^2 (range of 35 000 -118 000 km^2), of which about 60%, 50 000 Km^2 corresponded with the mean spawning area of anchovy in the historical series, as evidenced by the occurrence of anchovy eggs. Some regular areas with relevant spawning grounds can be highlighted: the influence of the Gironde and the Adour rivers. These are the typical spawning areas, as previously described (Motos *et al*., 1996 and 2005), situated mainly in coastal regions and around the river mouths, that correspond to nursery areas with 1- year-old fish. Older fish are frequently found over the shelf and shelf-edge regions. At the beginning of the historical series in 1987, there was evidence of spawning in the Cantabrian Sea area until year 2000, when the anchovy disappeared from this area. It reappeared in 2015 until 2023. (**Figure 4**).

Anchovy total daily egg production (p_{tot}) was very low in the period of the closure of the fishery in comparison with historical series. After that, the trend was upwards until 2020 when the highest peak of the century occurred and when the spawning area also expanded offshore and north, making it the maximum positive area of the series in 2020 (**Figure 4**).
The egg abundance in the Cantabrian Sea disappeared in 2000 and did not reappear until 2015, when it began to appear little by little until reaching its maximum in 2020 and in the last three years. In the area of the French shelf, we can also see the decrease in the years of closure and the increase and expansion towards the North in recent years. (**Figure 8**)

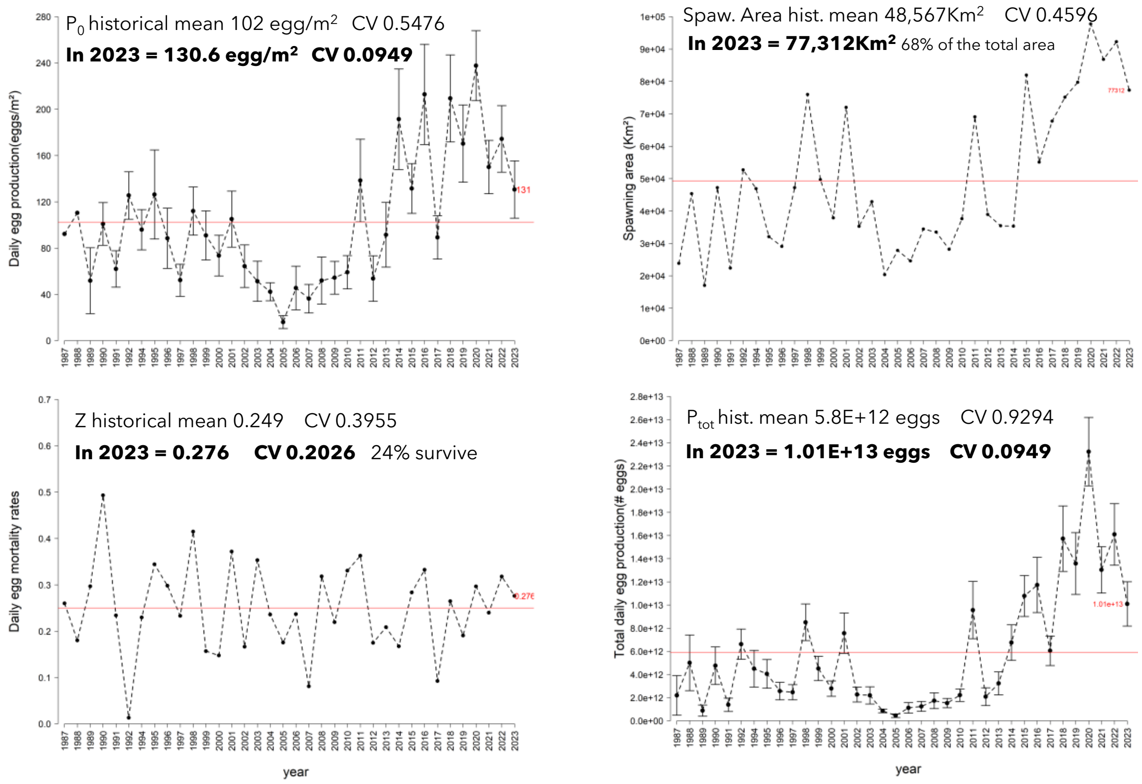


Figure 4: Historical series of anchovy egg parameters to apply the DEPM: (*P₀*) daily egg production (egg m-2 day -1), spawning area Km², (z) daily egg mortality rates and (P_{tot}) total daily egg production (number of eggs). The red line is the historical mean in each case.

Regarding the adult reproductive parameters (**Figure 5**), the sex ratio (*R*) in mass is basically a constant around its long-term mean 53.7%, given our own assumption of an invariant sex ratio 1:1 in numbers.
The tendency of female mean weight (W_f) is downwards since 2003 but more pronounced since 2010 after the reopen of the fisheries that is below the mean (22.6g).
As expected, batch fecundity: (eggs/batch/mature female) (*F*) was closely related to the mean weight of females and the tendency is as well downwards specially since 20210.
Spawning fraction: fraction of females spawning per day (*S*), before the reopen of the fishery in 2010 tended to be around 40% that means that the anchovy spawns each 2.5 days. But after the reopen of the fishery it was around 34%, below the average, that means anchovy spawn each 3 days.

According to all these results, daily fecundity (*DF*) was in general above the mean (90eggs/g per day) before the reopen of the fishery and below the mean afterwards with a parallel trend to the spawning fraction.

In all years, the weighting factors per adult sample were differentiated according to the abundance of eggs in the area where they were collected and the number of adult samples per area. Although the results of the DF did not vary much depending on whether these weighting factors were applied, they were applied to avoid potential bias in the results. These results suggest that in several years, at the time of the survey, smaller anchovies in the Gironde area tended to have slightly lower DFs than the larger anchovies from other areas.

Mean weight and mean length by age showed a clear downward trend. Biomass series, weight-at-age, and population in numbers-at-age are presented in Figures 6 and 7. Between 2003 and 2009, the DEPM biomass estimates were below 20,000 tonnes. During this period, the fishery was unable to achieve normal catch levels. In 2003, the Spanish fishery was in deep crisis (STECF, 2003) and later, in 2005 and 2006, the fishery collapsed completely, with no significant catches. This led to repeated closures of the fishery, first in June 2005 and again in June 2006, which lasted until January 2010. The DEPM estimated a recovery of the population in 2010 (31 300 t, CV = 16%) and peaked in 2020, with about 334 300 t (CV = 12%).

Overall, the DEPM has proved to be a very useful system for monitoring anchovy biomass in the Bay of Biscay (ICES 8abcd) providing inputs for assessment in terms of total Biomass, percentage at age 1 and weight at age.

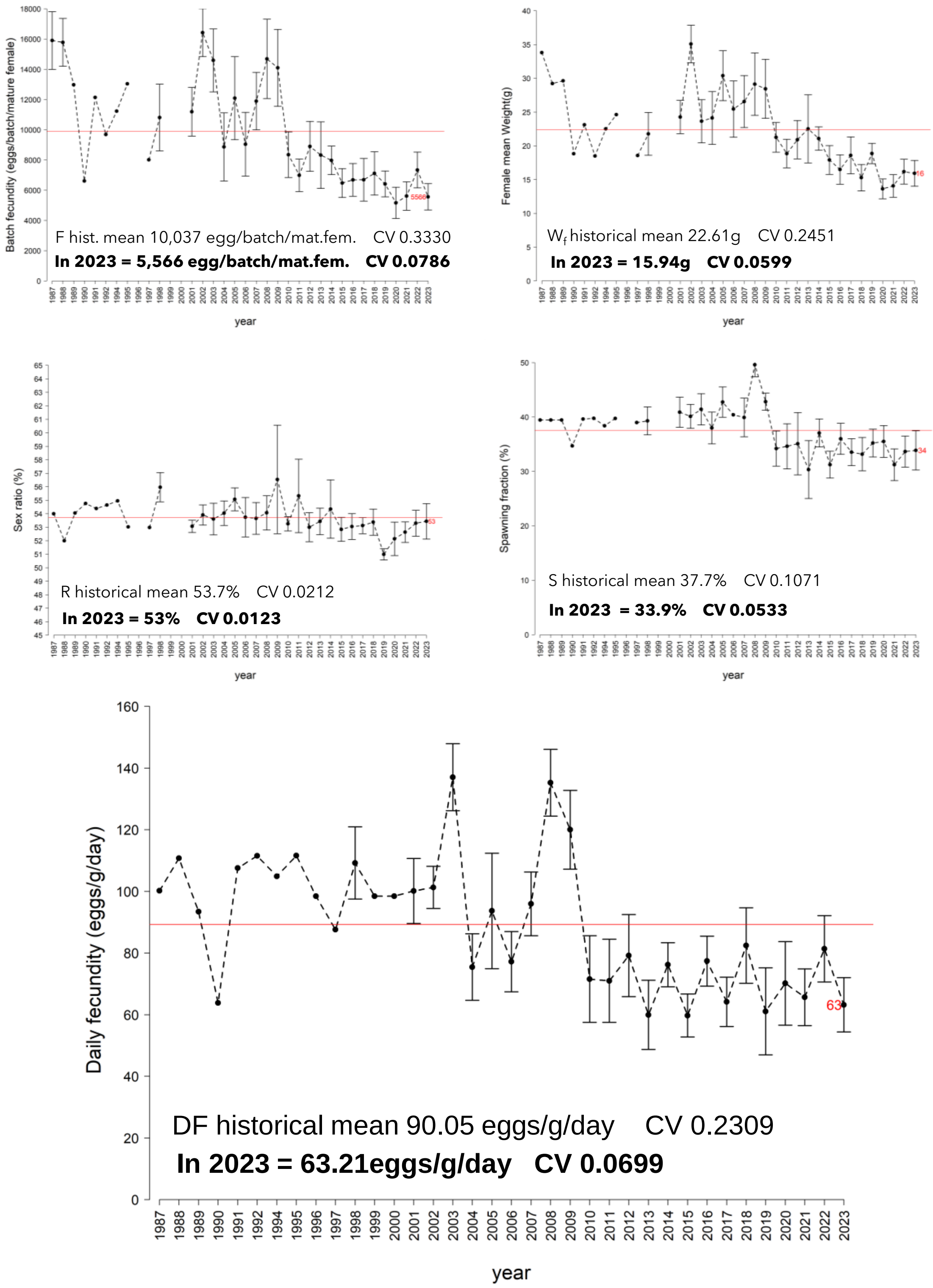


Figure 5: Historical series of the adult parameters to apply the DEPM: *F* (batch fecundity) (eggs/batch/mature female); W_f (female mean weight) (g); *R* (sex ratio) (% in weight of females); *S* (Spawning fraction) (% spawning females per day), the result *DF* (Daily fecundity) ($DF=RFS/W_f$). The red line is the historical mean in each case.

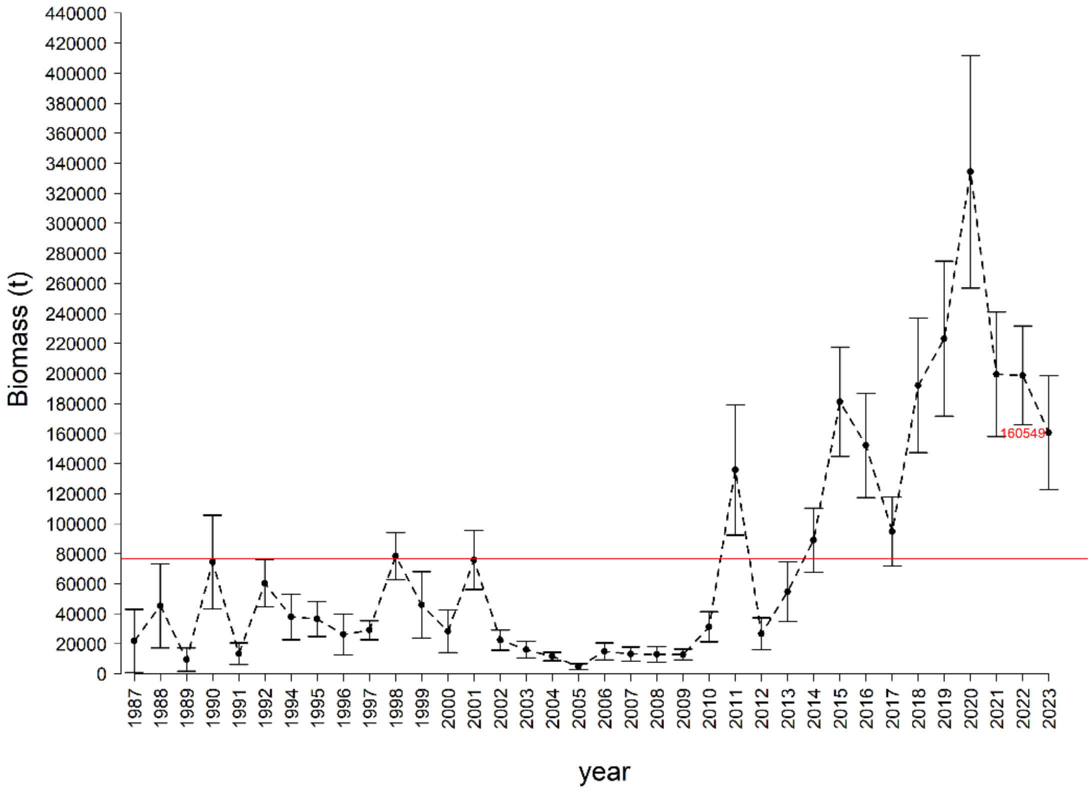
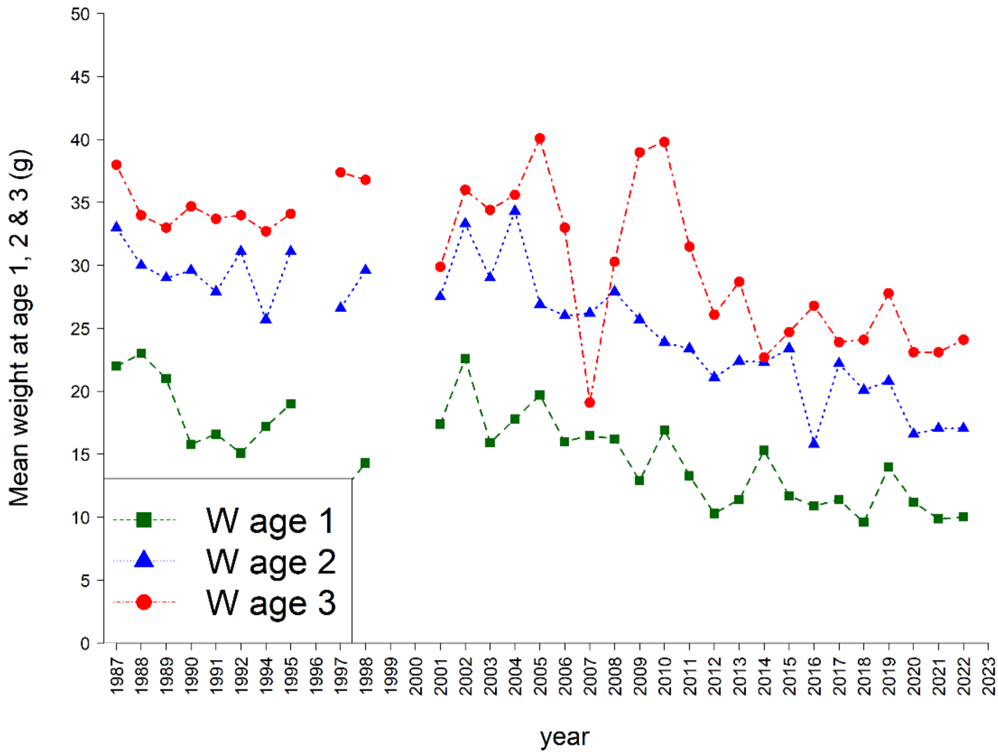
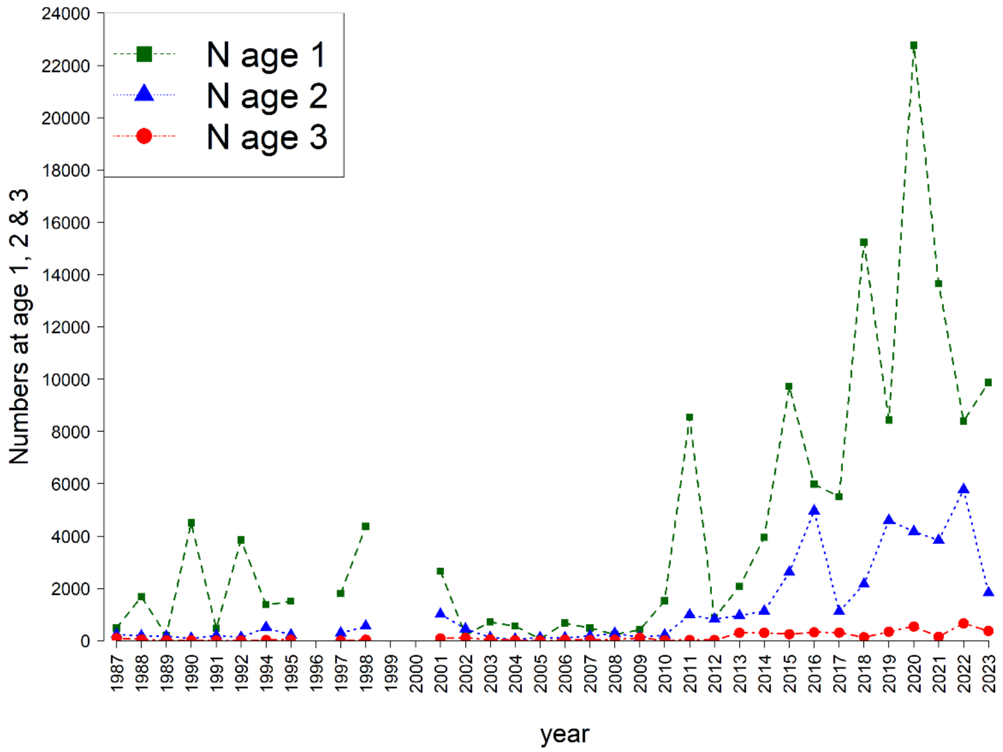


Figure 6: Historical series of total biomass estimates for anchovy in the Bay of Biscay applying the DEPM. The red line is the mean of the historical series.





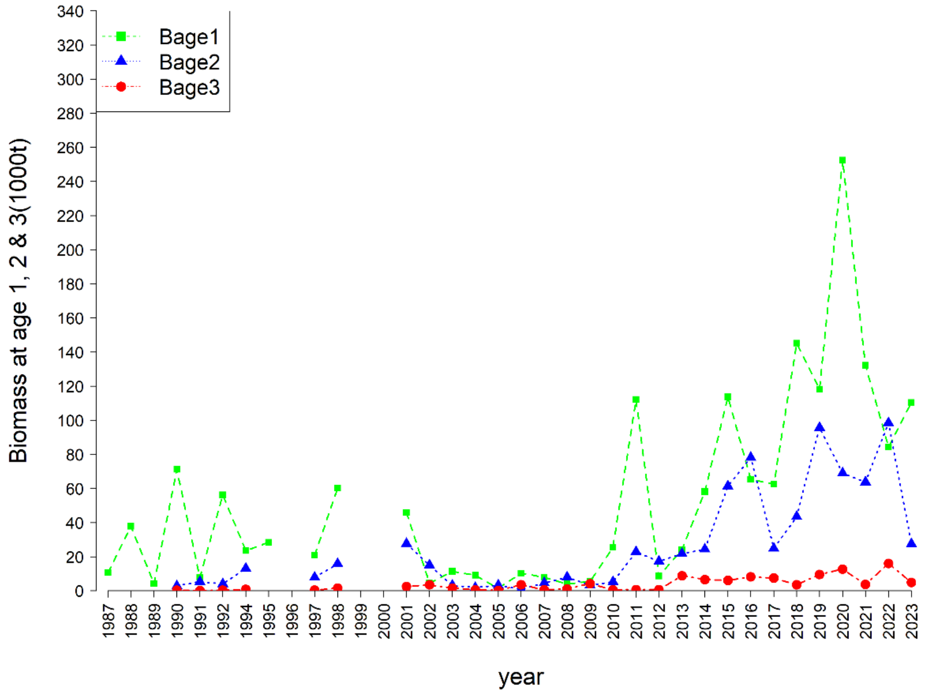
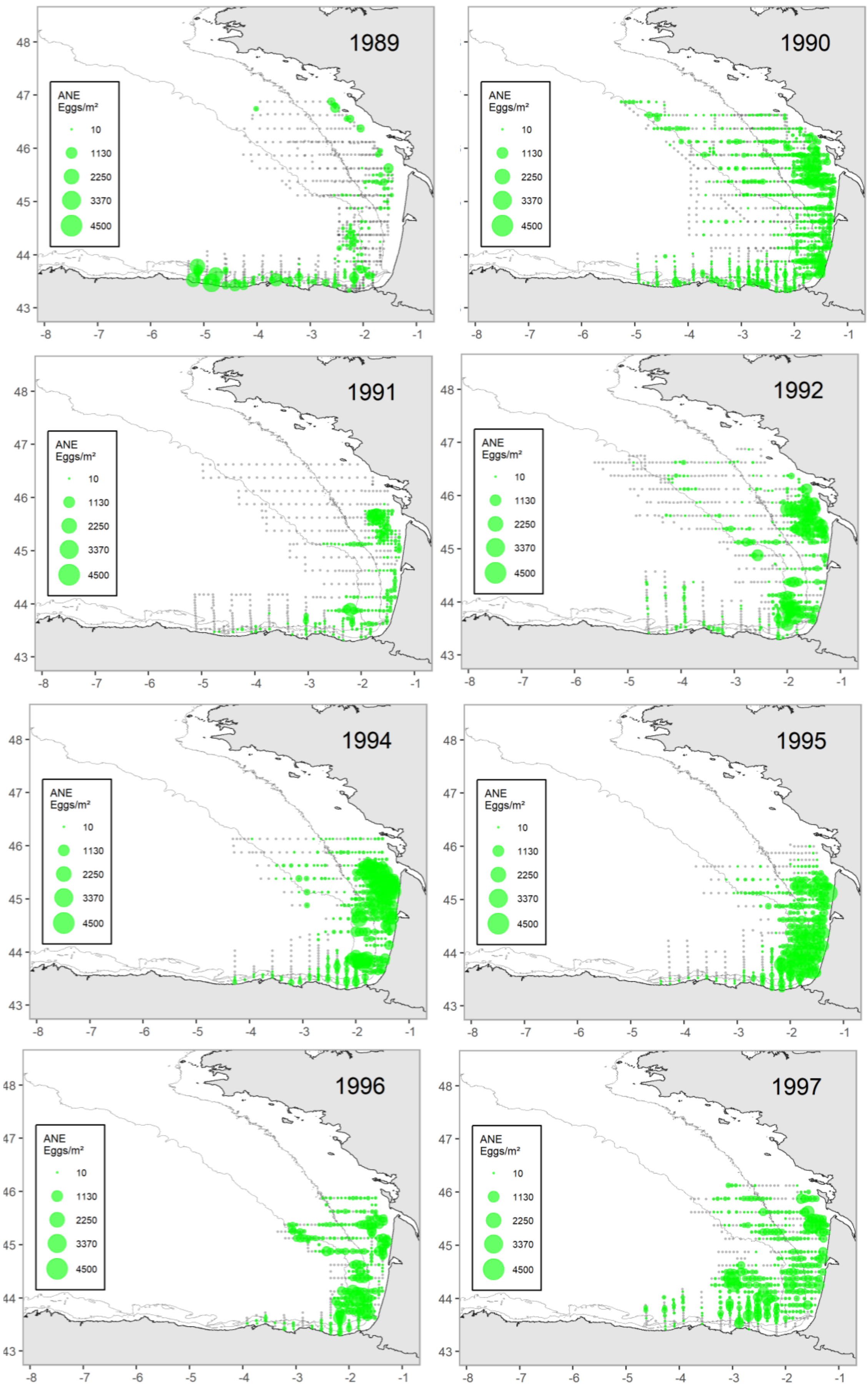


Figure 7: Historical series of mean weight at age, numbers at age and biomass at age estimates for anchovy in the Bay of Biscay.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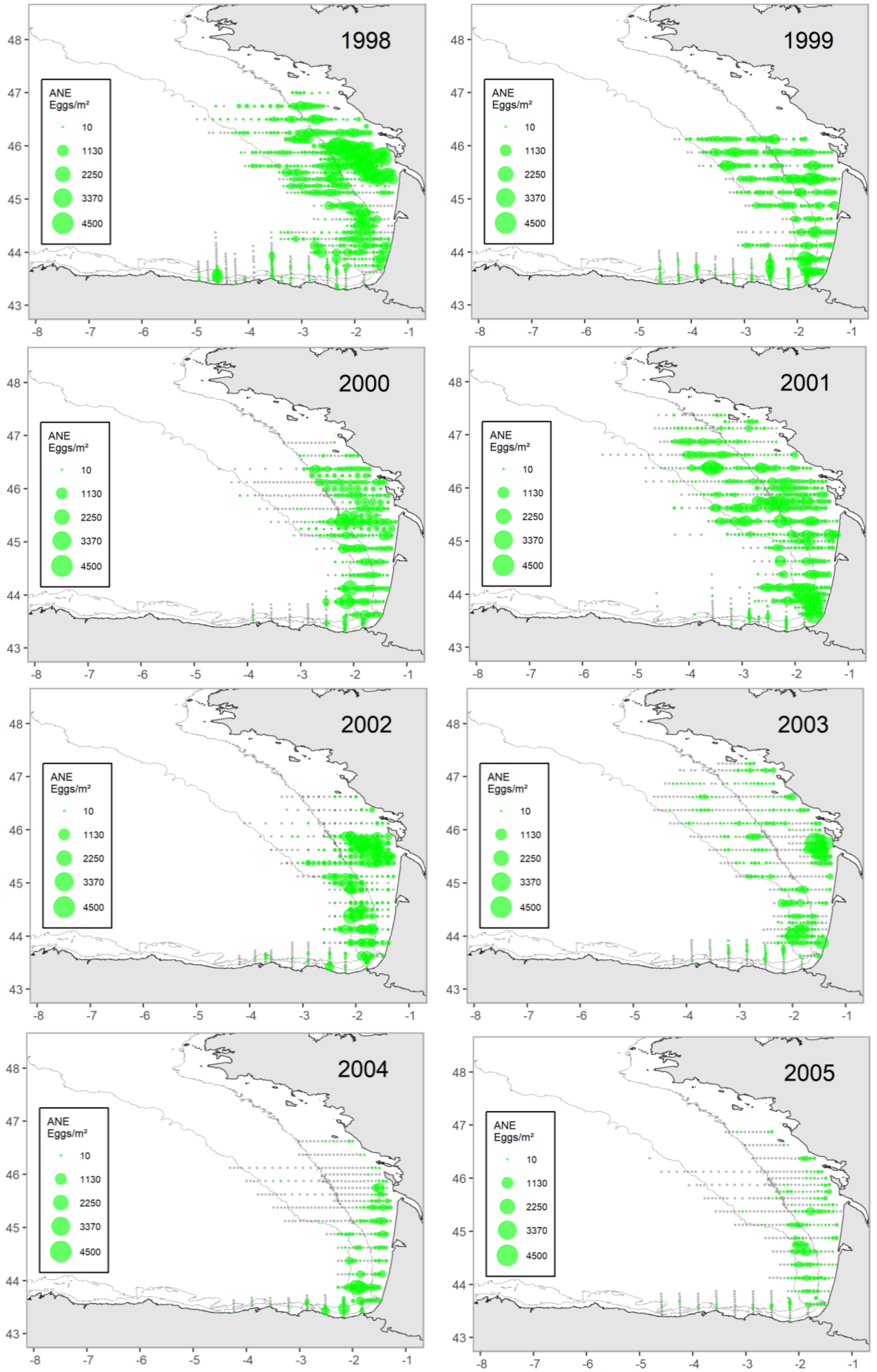
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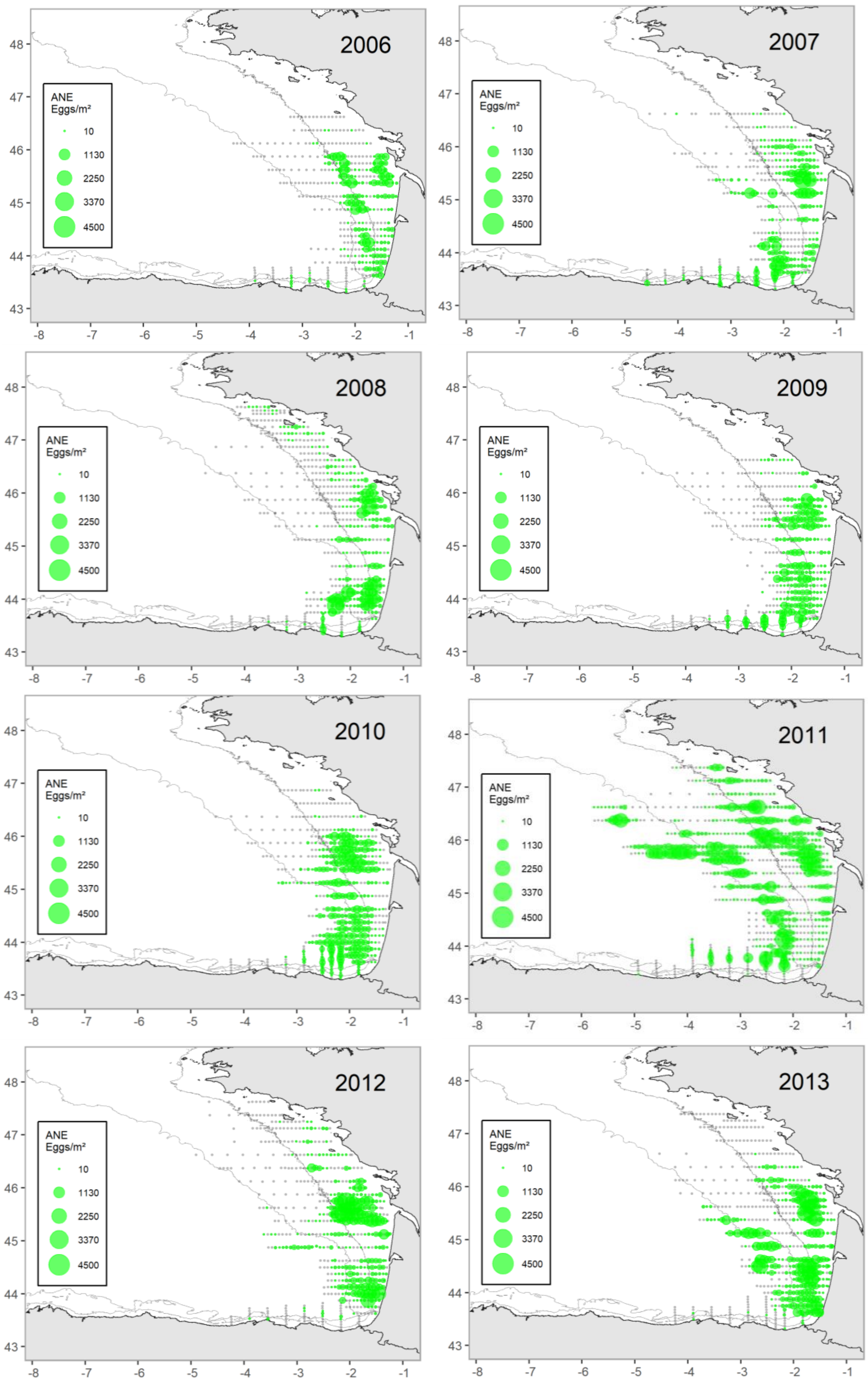
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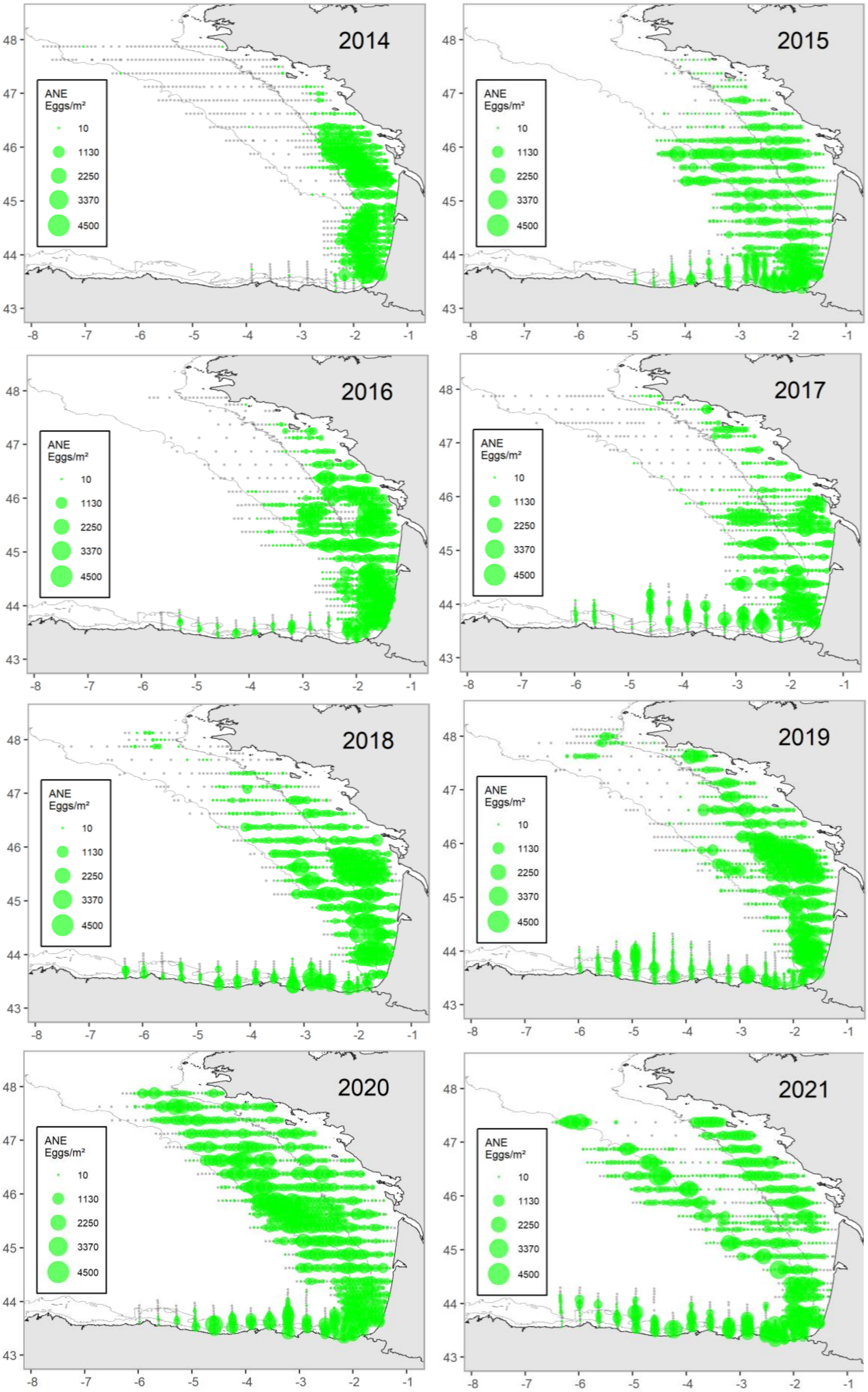
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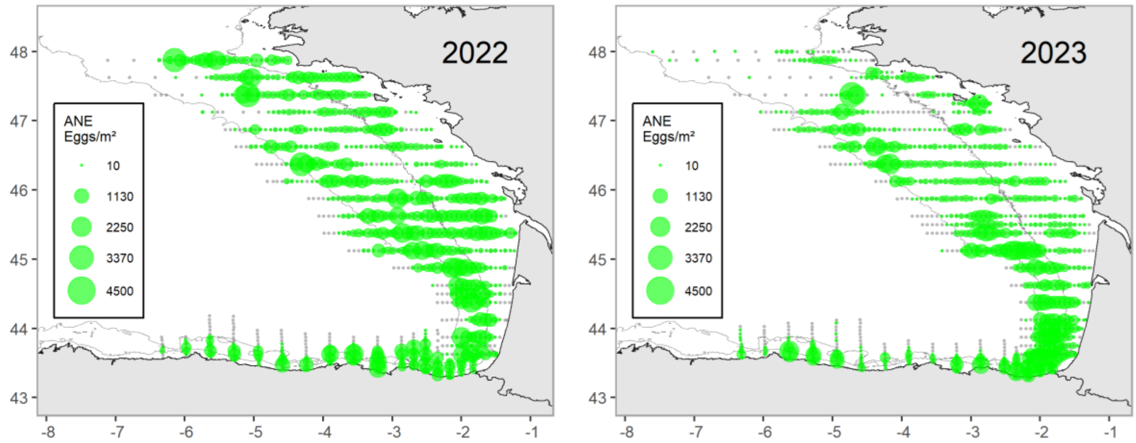

Figure 8: Historical series of anchovy eggs spatial distribution and abundance in the Bay of Biscay.

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Reference points for anchovy in the Bay of Biscay

2024/10/11

Leire Citores, Leire Ibaibarriaga

1. Reference points

Anchovy is a short-lived species with a life-span of 3-5 years. This type of species is characterized by high natural mortality rates and highly variable recruitments dependent on the environmental conditions. According to the ICES technical guidelines for fisheries management reference points for category 1 and 2 stocks (ICES, 2021), Blim is calculated in the same manner as for long-lived species. Then, Bpa is estimated from Blim, using the same methods as for long-lived stocks, but with a default $\sigma = 0.3$, if the terminal year SSB uncertainty is not available from the assessment. The main difference with respect to long-lived species is that ICES does not utilize F reference points to determine exploitation status of short-lived species.

After a series of consecutive low recruitments, the Bay of Biscay anchovy fishery crashed in 2005 and the fishery was closed from 2005 to 2009. After the reopening of the fishery in 2010, the stock recovered and in the last years it has reached the highest SSB and recruitment levels of the time series, well above the historical averages (Figure 1). The five largest values of recruitment success (R/SSB) corresponded to years 2010, 1989, 1991, 2009 and 1997 (Figure 2). Overall, the stock has shown a wide dynamic range of SSB with evidence of impaired recruitment in the late 2000s. Therefore, the stock can be classified as Type 2 (stocks with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired). Along this line, the new stock assessment model includes the fit of a Ricker stock-recruitment model within Stock Synthesis (Figure 3). The maximum recruitment value is reached at SSB around 140 600 t, after which recruitment starts to decline smoothly. This pattern may be ecologically explained by the cannibalism on eggs observed for this stock (Bachiller et al. 2015).

Given the difficulties to correctly identify Type 1 spasmodic stocks, the method developed by Silvar-Viladomiu et al. (2022) and used also in ICES WKNEWREF was applied. Results indicated that the stock showed lower variance for both detrended and scaled recruitment, confirming that this stock is not spasmodic (Figure 4).

Several options were explored to estimate Blim:

a) Breakpoint of the segmented regression: The proposed option to estimate Blim for Type 2 stocks is to fit a segmented regression model to the stock-recruitment estimate pairs. In this case, the breakpoint was estimated around 141 100t, which is approximately the 95th percentile of the range of SSBs. This was deemed unrealistically high and this option was not further considered.

b) Empirical Blim: Based on the lowest observed spawning stock biomass producing a “large” recruitment, which is defined as recruitments above the median recruitment (van Deurs et al., 2020). This value corresponded to the SSB in 1991 which was estimated at 27 300 t.

c) Empirical Blim (3 points): To avoid the empirical Blim depending on a single point, the empirical Blim was calculated as the average of the three lowest SSB leading to "large" recruitment. This resulted in 34 900 t, which is the average of 1991, 1997 and 2010.

d) Empirical Blim accounting for uncertainty (3 points): To account for the uncertainty of the recruitment estimates, the average of the lowest SSBs whose confidence intervals at 95% included or were above the median recruitment was calculated. This resulted in 20 500 t, which is the average of 2009, 1989 and 1991.
e) Empirical Blim accounting for uncertainty (similar to option d but removing closure year 2009): To account for the uncertainty of the recruitment estimates, the average of the lowest SSBs whose confidence intervals at 95% included or were above the median recruitment was calculated. This resulted in 23 000 t, which is the average of 1989 and 1991.
f) Cumulative recruitment quantiles: As an alternative to proposed methods, we calculated the cumulative distribution of recruitment for each observed SSB, and we calculated the SSB at which the cumulative recruitment distribution includes the median recruitment. This value was 25 900 t (interpolated between the SSBs in 2007 and 1991). In other words, all the SSB levels below 25 900 t resulted in "low" recruitments (recruitment values below the median).
g) Fraction of B0 in integrated models WKREF1 (ICES, 2022) and WKREF2 (ICES, 2022) suggested that Blim could be set as a fraction of B0, where the specific fraction could be within the range of 10-25% B0 depending on the life-history characteristics. In this case B0 is estimated around 197 100 t. Fractions of 10%, 15%, 20% and 25% resulted in values of 19 700, 29 600, 39 400 and 49 300 t respectively.
h) Fraction of Rmax from Ricker. According to the Ricker model fitted within Stock Synthesis, Rmax is around 16007293 (after the bias-correction) and it is reached at SSB around 140 600 t. Myers et al (1994) suggested Blim could be calculated as 50% of Rmax, while van Deurs et al (2021) suggested a value of 83% of Rmax based on an empirical study. The first fraction would lead to Blim around 32 600 t. The second fraction would lead to an unrealistically high value of 71 250 t.

From all the options tested, the proposed option is 23 000 t.

Then, following the guidelines, Bpa is calculated as:

$$B_{pa} = B_{lim} \exp\{1.645\ \sigma\},$$

with σ estimated from the assessment uncertainty in SSB in the terminal year (σ is the estimated standard deviation of ln(SSB) in the final assessment year). In this case the coefficient of variation of SSB in the terminal year is 0.29. This value is very close to the default value of 0.3 set for short-lived species. Therefore, Bpa was 37 777 based on $\sigma = 0.3$.

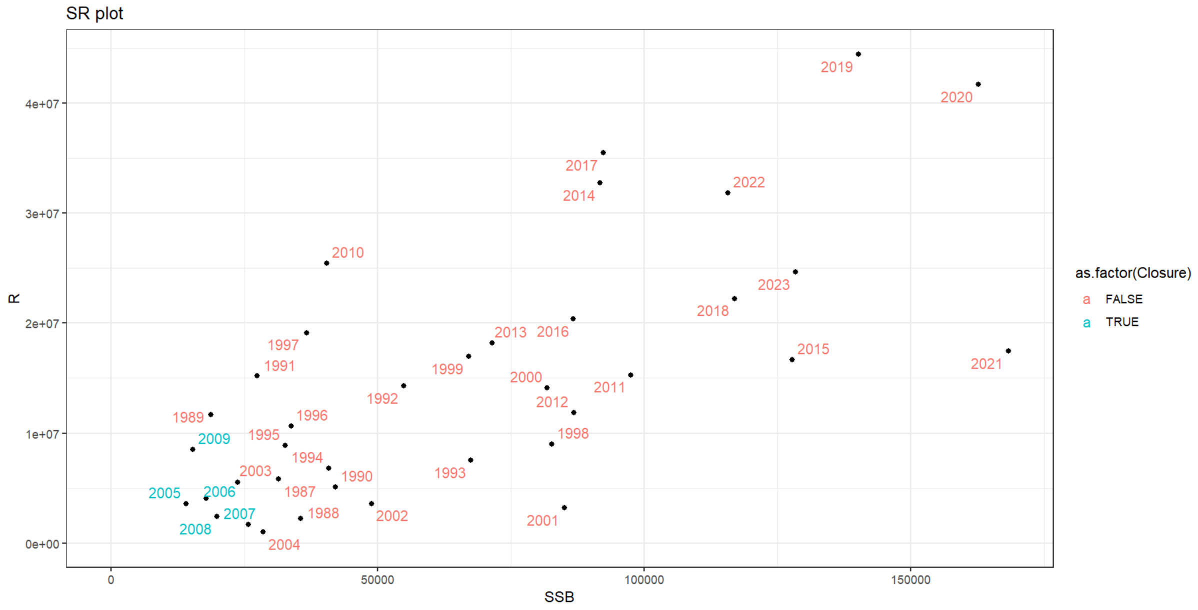

Figure 1. Stock-recruitment plot for anchovy in the Bay of Biscay. Labels in blue indicate the years in which the fishery was closed.

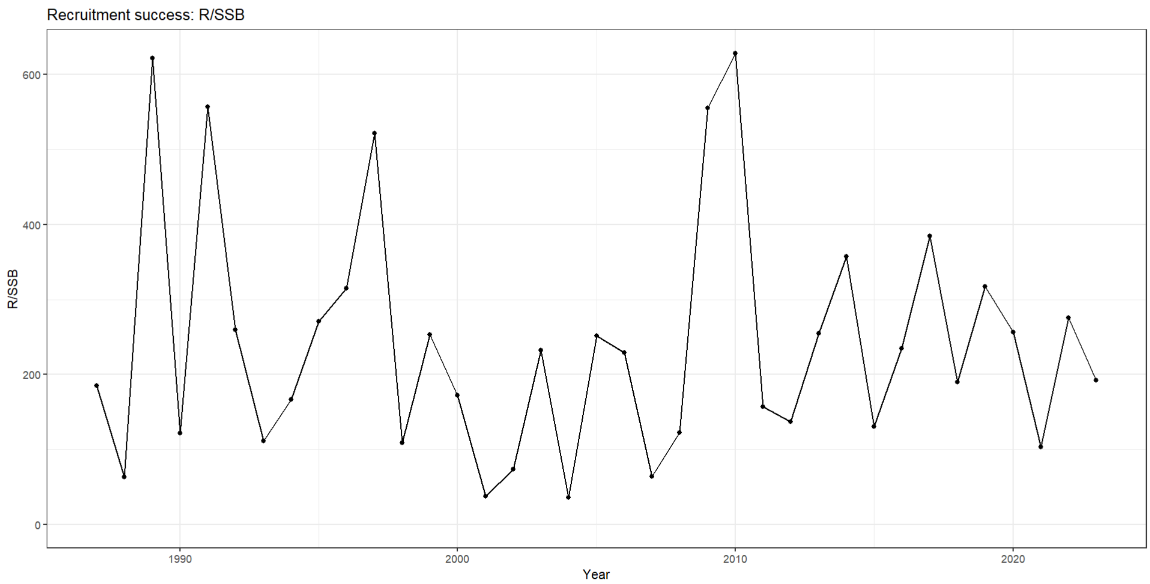

Figure 2. Time series of recruitment success (ratio R/SBB) for Bay of Biscay anchovy.

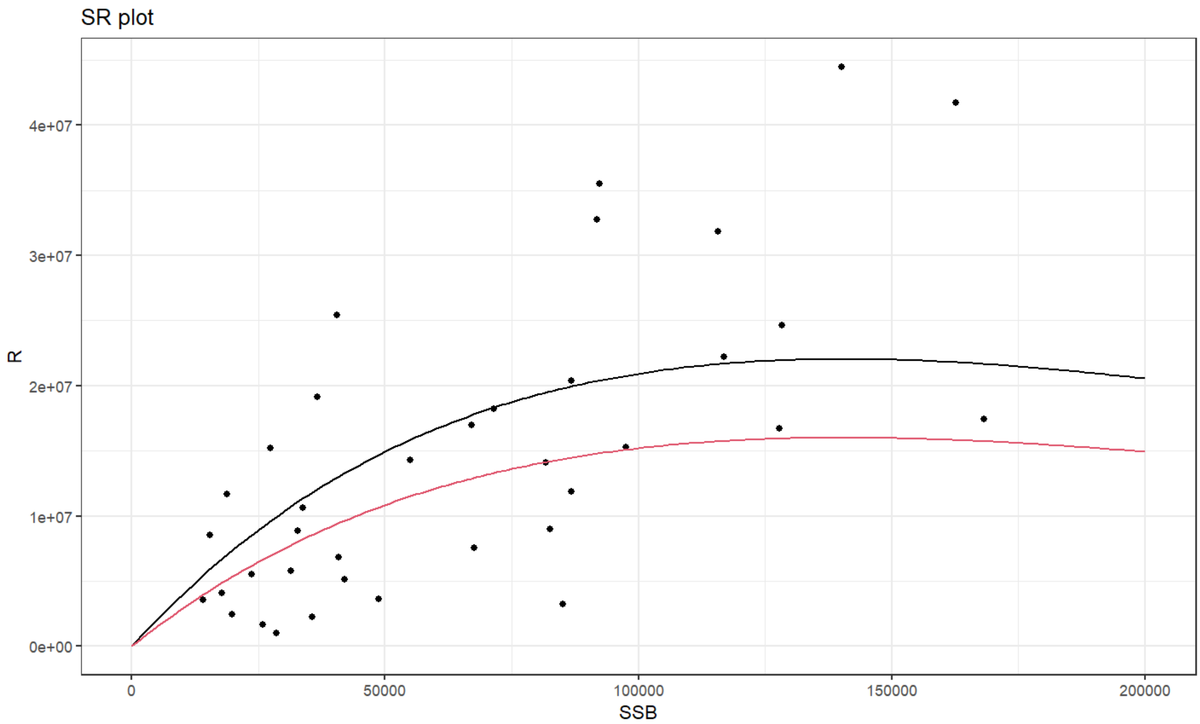

Figure 3. Ricker stock-recruitment model for Bay of Biscay anchovy fitted within the stock assessment model. The red line is bias-corrected.

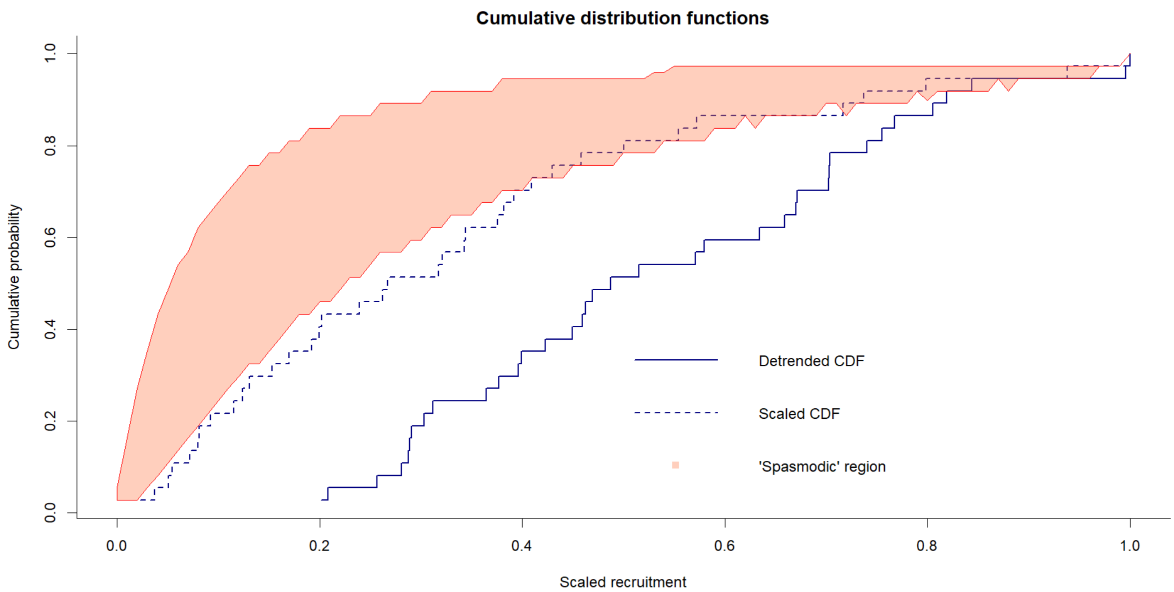

Figure 4: Application of the method developed by Silvar-Viladomiu et al (2022) to identify spasmodic stocks.

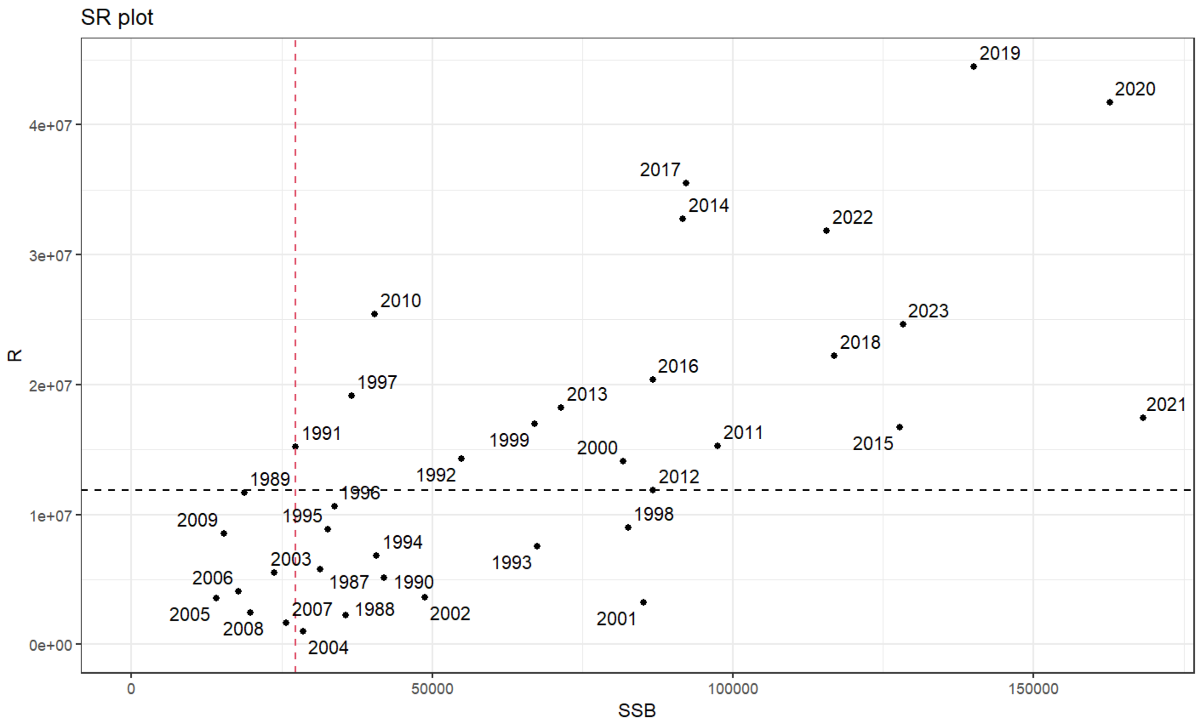

Figure 5. Graphical representation of empirical Blim. The horizontal line represents the median recruitment, while the vertical line is the lowest observed SSB producing a "large" recruitment (above the median recruitment).

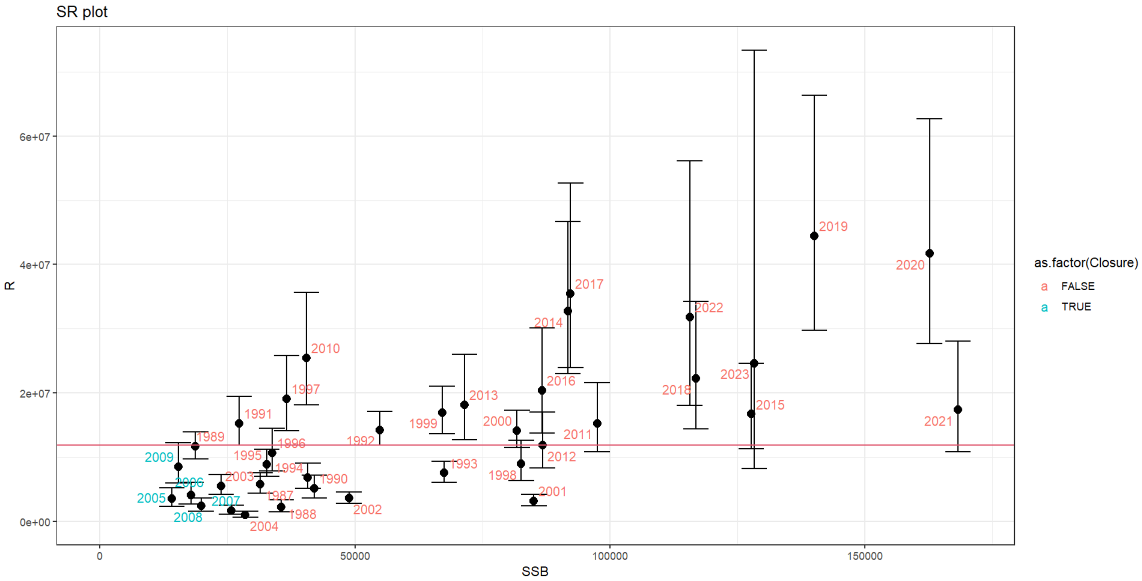

Figure 6. Stock recruitment plot. The vertical error bars represent the uncertainty around the recruitment estimates according to a lognormal distribution. The red horizontal line is the median recruitment.

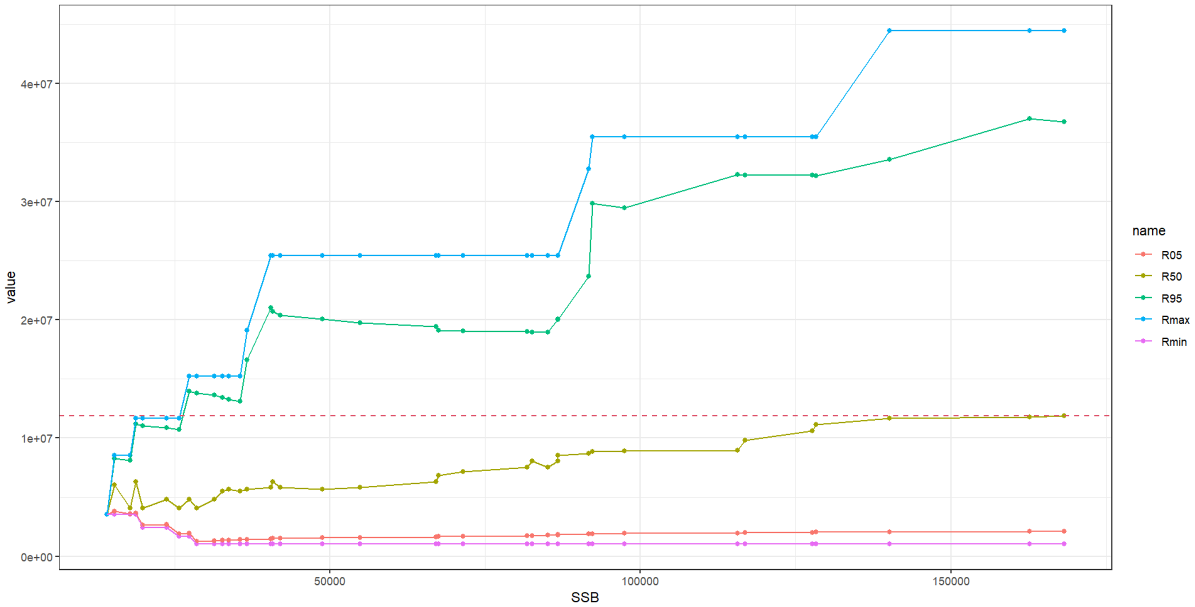

Figure 7. Cumulative recruitment distribution (i.e. percentiles 0, 5, 50, 95 and 100 of recruitment for SSB values at or below each observed SSB). The recruitment percentiles for the highest biomass correspond to the whole time series.

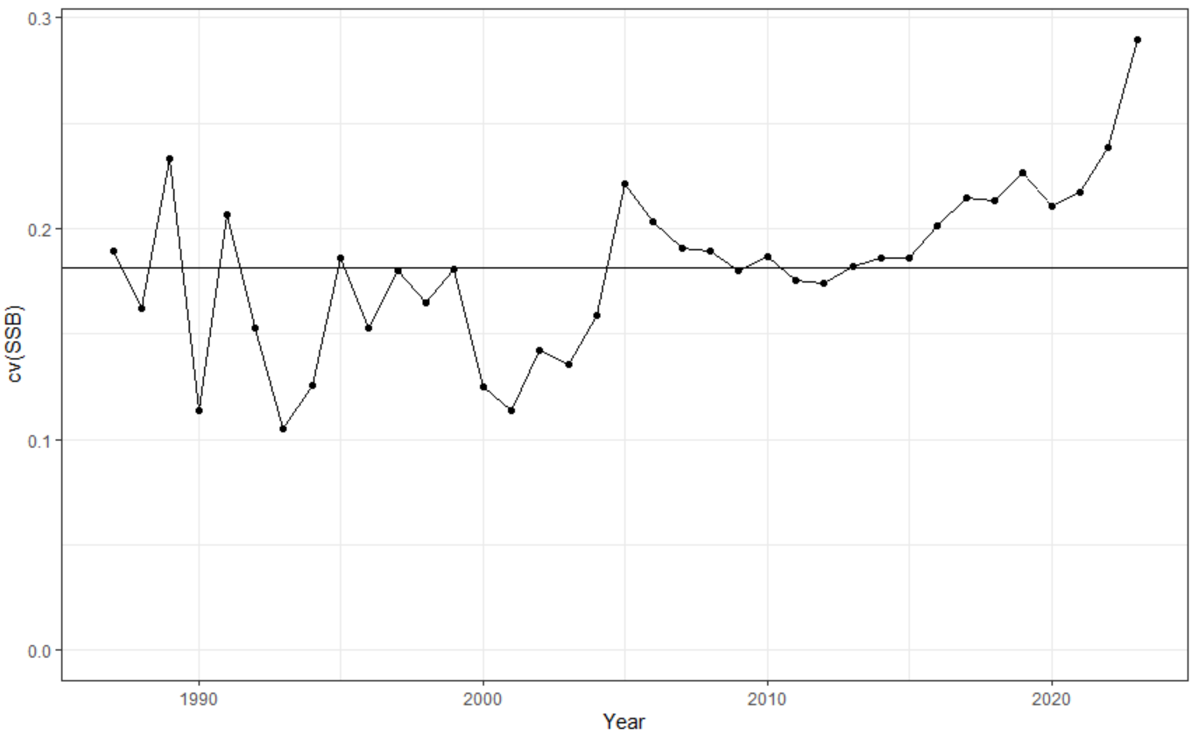

Figure 8. The coefficients of variation of SSB estimated from the stock assessment.

Table 1. Alternative options for defining Blim for Bay of Biscay anchovy.

Basis	**Value (tonnes)**
Breakpoint of segmented regression	141 100
Empirical Blim (single value 1991)	27 300
Empirical Blim (average 1991, 1997, 2010)	34 900

Empirical Blim with uncertainty (average 2009, 1989, 1991)	20 500
Empirical Blim with uncertainty (average 1989, 1991, after removing closure year 2009)	23 000
Cumulative recruitment quantiles (interpolated between 2007 and 1991)	25 900
Fraction of B0 (0.1, 0.15, 0.2, 0.25)	19 700, 29 600, 39 400 and 49 300
Fraction of Rmax (bias corrected) from Ricker (0.5, 0.83)	32 600, 71 250

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Updates on the assessment model for anchovy in the Bay of Biscay

2024/10/02

Last update: 2024/10/11

Leire Citores, Leire Ibaibarriaga

1. Description of the last decision taken by the group on Friday 27th of September

The proposed SS3 model had the following settings:

- No stock recruitment function included in the model. Recruitment deviations (no-bias correction).
- Catchability for all aggregated indices (acoustic, DEPM and juvenile) modelled using a linear relationship.
- Selectivities for the fishery (fleet1 and fleet2) for ages 1 and 3+ modelled using two time blocks (before and after the fishery closure: 1987-2009 and 2010-onwards).
- Selectivity for the acoustic survey estimated for age 1 in two blocks (1987-2006 and 2007-onwards when commercial vessels joined the survey) and fixed at 1 for ages 2 and 3+.
- Selectivity for the DEPM survey fixed at 1 for ages 1,2 and 3+.
- Natural mortality for age 3+ estimated within the model, while for the other ages they are fixed as M0=2.17, M1=0.8, M2= 1.2.
- Sample sizes for the age composition data were adjusted based on the proposed weights from one iteration of the Francis method, with a starting sample size of 100 for all fleets (commercial fishery 1st semester, commercial fishery 2nd semester, acoustic, DEPM).
- Extra standard error was estimated for all the aggregated indices (acoustic, DEPM and juveniles).

Once these main settings were agreed in the group, we followed the following steps:

- Run the model with the agreed options, letting the model estimate natural mortality at age 3+ (M3+).
- Run one iteration of the Francis reweighting method, starting from a sample size of 100 for all fleets.
- Fix the natural mortality M3+ to the estimated value by the model.
- Look at the model fit diagnostics and perform retrospective runs for the model with the new weights and fixed M3+.

The above-described model showed bad retrospective analysis, with a Mohn` s rho for SSB >0.6 (Figure 1). We conducted a leave one out analysis, leaving one dataset out of the fitting and the corresponding retrospective analysis at a time. The exercise showed that age composition from the fisheries was the data source that was mostly affecting the retro pattern. Thus, it was decided to model the fishery selectivity as a random walk in time for ages 1 and 3+ (instead of the two time blocks). The fishery selectivity for age 2 was fixed at 1 for both semesters.

The model was run again with the implementation of the random walk for the commercial fishery fleets selectivities for ages 1 and 3+, but convergence could not be achieved. The time block for the acoustic survey selectivity was removed so that convergence could be achieved. The steps described above were followed again: The natural mortality was estimated using this new configuration of the model and the Francis method was applied as well. This was the model selected by the group on Friday 27th of September. This chosen model presented a Mohn's rho for SSB of 0.37.

2. New updates on the model

After the meeting,the chosen model was revised and it was detected that the presented model (and the uploaded model to the sharepoint) was not the last version. The natural mortality had been updated to the estimated value but the sample size weighting from the Francis method had not been updated, so the presented final model was not the correct one. Once the weighting from the Francis method was updated, the resulting SSB Mohn`s rho increased from 0.37 to 0.43. Moreover, the Francis method, in this case, suggested very high weights for the sample sizes of the fishery in the first semester compared to the rest of the fleets, reaching the upper bound (initial sample size of 100). When trying to apply the method starting from higher sample sizes, convergence was not achieved. This suggested that the model with this configuration might not be very stable.

On the other hand, looking at the estimated recruitment and SSB values, we considered the option of including a stock-recruitment relationship in the assessment model. In a first fast trial, it seemed that the model was able to estimate SR parameters and that it could give some stability to the model, improving the retrospective analysis. Thus, we fitted a similar model to the first proposed one (two blocks in commercial fishery selectivities), but including a stock-recruitment function. The new proposed model has the following settings:

- Ricker stock recruitment relationship with the beta parameter estimated within the model (bias correction applied as suggested by SS3)
- Catchability for all aggregated indices (acoustic, DEPM and juvenile) modelled using a linear relationship.
- Selectivities for the fishery (fleet1 and fleet2) for ages 1 and 3+ modelled using two time blocks (before and after the fishery closure: 1987-2009 and 2010-onwards).
- Selectivity for the acoustic survey estimated for age 1 in two blocks (1987-2006 and 2007-onwards when commercial vessels joined the survey) and fixed at 1 for ages 2 and 3+.
- Selectivity for the DEPM survey fixed at 1 for ages 1,2 and 3+.
- Natural mortality for age 3+ estimated within the model, while for the other ages They are fixed as M0=2.17, M1=0.8, M2= 1.2.
- Sample size weighting is done using one iteration of the Francis method, with a staring sample size of 100 for all fleets.
- Extra standard error was estimated for all the aggregated indices (acoustic, DEPM and juvenile).

As before, we followed these steps when running the model:

- Run the model with the agreed options, letting the model estimate natural mortality at age 3+ (M3+) and the beta parameter of the Ricker function.

- Run one iteration of the Francis reweighting method, starting from a sample size of 100 for all fleets.
- Fix the natural mortality M3+ and the beta parameter of the Ricker function to the estimated values by the model.
- Look at model fit diagnostics and perform retrospective runs for the model with the new weights and fixed M3+ and beta parameters.

The retrospective analysis showed again high values for the SSB Mohn` s rho (0.48). This is a lower value than the previously obtained 0.61 for the first proposed model. However, in order to improve these retro patterns and knowing that the age composition from the fishery has an effect on retro patterns, random walks in time for the selectivities (ages 1 and 3+) of the fishery fleets were included. The natural mortality for age 3, the beta parameter for the Ricker function and the proposed weights from the Francis method obtained in the previous step were kept fixed (Table 1).

With this new configuration, the retrospective analysis improved, with a Mohn` s rho for SSB of 0.3 (Figure 2). The rest of the diagnostics and estimated parameters presented similar values to the ones shown during the meeting for the chosen model. Estimated selectivities and SR function are shown in Figure 3 and Figure 4. The estimated SSB values with respect to the initial run and the current CBBM estimates are compared in Figure 5. The complete output and plots from this new run are available at the sharepoint (personal folders/ run_ss3_ane8_20241001.zip).

2.1. Alternative SR function: Beverton-Holt (B-H)

The estimation process described above was repeated using the Beverton-Holt SR function (estimating the steepness parameter) instead of the Ricker function.

The retrospective analysis when including a B-H SR function to the first proposed model resulted in SSB Mohn` s rho of 0.5. Again, lower that the pervious 0.61 value but still very high. Thus, random walks in time for the selectivities (ages 1 and 3+) of the fishery fleets were included (as done with the model that used the Ricker SR function). The natural mortality for age 3, the steepness parameter for the B-H function and the proposed weights from the Francis method obtained in the previous step were kept fixed (Table 1).

With this new configuration with random walks for commercial fishery selectivity and the B-H SR function, the retrospective analysis improved, with a Mohn` s rho for SSB of 0.3 (Figure 2).

Estimated selectivities and SR function are shown in Figure 3 and Figure 4. The estimated SSB values with respect to the initial run and the current CBBM estimates are compared in Figure 5.

2.2. Fitting SR model outside SS3

The Ricker SR model fitted within the new proposed SS3 model has been compared to a Ricker SR model fitted outside the model using FLSR R library**. Resulting fits not similar** as shown in Figure 6. However, **there are many publications that advocate internal fitting**

(Maunder and Thorson, 2019; Punt, 2023), thus, we will continue with the SR model fitted within the SS3 model.

2.3. Update on recruitment deviations

Recruitment deviations in SS3 can start before the first data year. They can be included either as main recruitment deviations (they are enforced to sum to zero for this period) or as early recruitment deviations (not enforced to sum to zero). According to SS3 manual: "The early and last eras are optional, but their use can help prevent balancing a preponderance of negative deviations in early years against a preponderance of positive deviations in later years."

The models presented above, were configured so that the recruitment deviations before the first data year (1984-1986) were included as main recruitment deviations, however, after the online meeting (2024/10/03), as it was suggested that this may have an effect on the estimated stock-recruitment relationship, we reviewed this part of the model, and decided to change this configuration, so that these recruitment deviations were included as early recruitment deviations instead of main deviations. The option not including any recruitment deviation before the first data year (1987) was also tested. Estimated SR functions, recruitment deviations and SSB values are shown in Figure 6 and Figure 7. **Looking at the results and the suggestions in the manual, <u>we think that for the final model the best option is to include early recruitment deviations from 1984 to 1986 and main recruitment deviation from 1987 to 2023.</u>**

2.4. Recruitment bias correction

SS3 suggests applying a time variant bias correction for recruitment in order to deal with data years that can be more or less informative for recruitment. ***For the Bay of Biscay anchovy case study, all the years are informative for recruitment, so we decided not to apply the time variant bias correction***. Looking at results in Figure 9, we see that when a bias correction is applied (time variant or constant in time) the expected recruitment after applying the bias correction is very similar to the expected recruitment when no bias correction is applied. However, if no bias correction is applied for the forecast year, it implies an upwards jump in the expected recruitment. Thus, in order to avoid this jump, **we prose to use a constant bias correction in time including also the forecast years.**

3. Selected configuration (2024/10/09)

After the exploration on stock recruitment functions, recruitment deviations and bias correction options, the following model configuration was selected:

- Ricker stock recruitment relationship with the beta parameter estimated within the model (constant recruitment bias correction applied)
- Main recruitment deviations defined from 1987 to 2023 and early recruitment deviation from 1984 to 1986 (one lifespan before the fist data year)
- Catchability for all aggregated indices (acoustic, DEPM and juvenile) modelled using a linear relationship.

- Selectivities for the fishery (fleet1 and fleet2) for ages 1 and 3+ modelled using two time blocks (before and after the fishery closure: 1987-2009 and 2010-onwards).
- Selectivity for the acoustic survey estimated for age 1 in two blocks (1987-2006 and 2007-onwards when commercial vessels joined the survey) and fixed at 1 for ages 2 and 3+.
- Selectivity for the DEPM survey fixed at 1 for ages 1,2 and 3+.
- Natural mortality for age 3+ estimated within the model, while for the other ages They are fixed as M0=2.17, M1=0.8, M2= 1.2.
- Sample size weighting is done using one iteration of the Francis method, with a staring sample size of 100 for all fleets.
- Extra standard error was estimated for all the aggregated indices (acoustic, DEPM and juvenile).

As before, we followed these steps when running the model:

- Run the model with the agreed options, letting the model estimate natural mortality at age 3+ (M3+) and the beta parameter of the Ricker function.
- Run one iteration of the Francis reweighting method, starting from a sample size of 100 for all fleets.
- Fix the natural mortality M3+ and the beta parameter of the Ricker function to the estimated values by the model.
- Include random walks for the commercial fleets selectivities and run the model again.
- Look at model fit diagnostics and perform retrospective runs for the model with the new weights and fixed M3+ and beta parameters.

Final estimates (SSB, SR, selectivities) are shown in Figure 10, Figure 11, Figure 12and retros in Figure 13. Inputs, outputs and all SS3 generated plot are available at the sharepoint, in the personal folder under the name “run_ss3_ane8_20241009”.

4. Deterioration of the retrospective pattern along time

The retrospective pattern in the last years of the assessment has been consistently found in most of the model configurations tried. Furthermore, this was also detected in the last years of the current assessment model (CBBM). The leave-on-out analysis suggested that this was partly explained by changes in selectivity of the commercial fishery data. Including a SR model also helped to improve the retrospective pattern. However, the resulting Mohn’s rho values are still in the borderline of currently established limits for short-lived species (0.3 for SSB).

We analysed how the retrospective pattern has changes along years. The Mohn’s rho was calculated for previous assessment years in order to see how the SSB Mohns’ rho has evolved in time, both for the first proposed model and the new proposed model (Figure 13). Overall, there has been a degradation of the retrospective pattern, as it has been observed also in the CBBM. This suggests that there may be ongoing changes in the population or in the fishery, which may violate some of the model assumptions. So, this pattern should be further monitored and analysed in the near future.

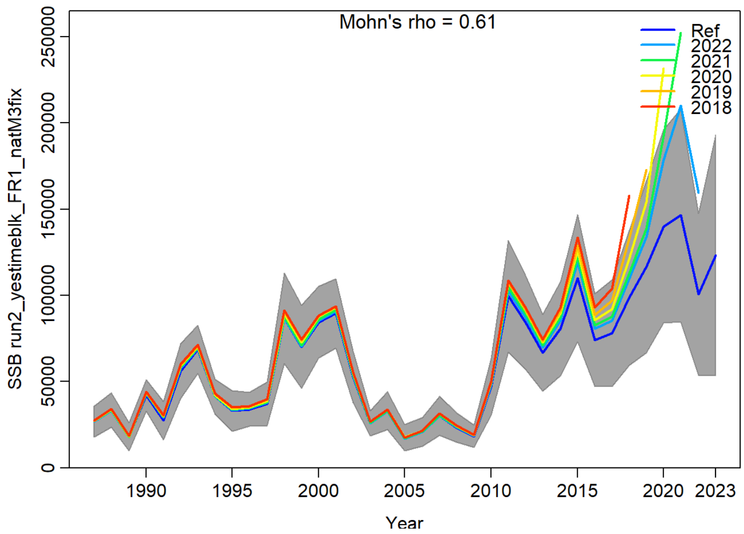

Figure 1: Retrospective SSB for the first proposed model (two blocks in commercial fishery selectivity for ages 1 and 3+).

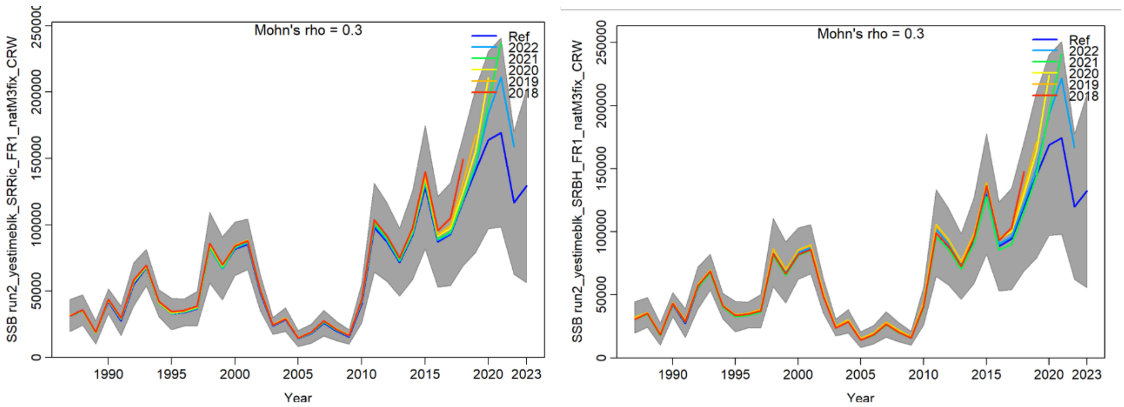

Figure 2: Retrospective SSB for the new proposed model (random walk in commercial fishery selectivity for ages 1and 3+ and Ricker SR model (left), or B-H SR model (rigth).

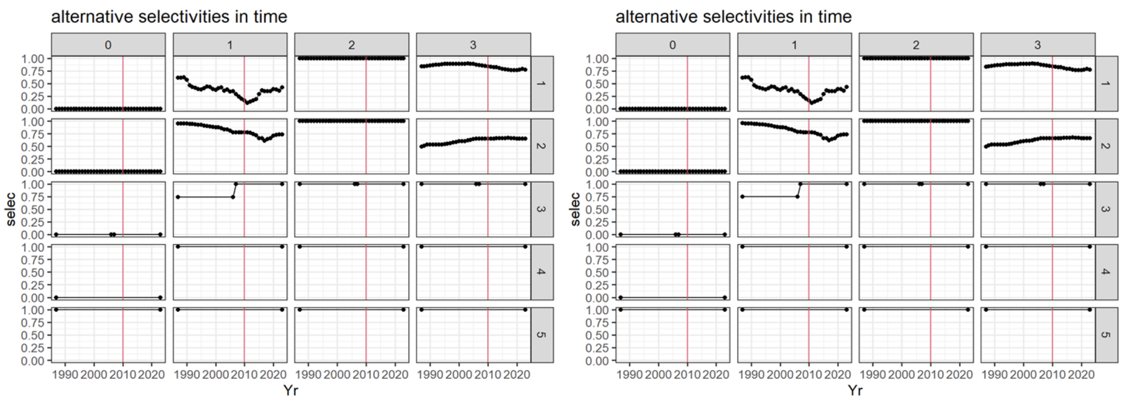

Figure 3: Estimated selectivities by fleet (rows) and ages (columns) for the new proposed models. Fleet 1: fishery in the 1st semester, Fleet 2: fishery in the 2nd semester. Fleet 3: Acoustic survey. Fleet 4: DEPM survey. Fleet 5: Juvena recruitment survey (selectivity does not apply). New proposed model with Ricker SR model (left) and B-H SR model (right).

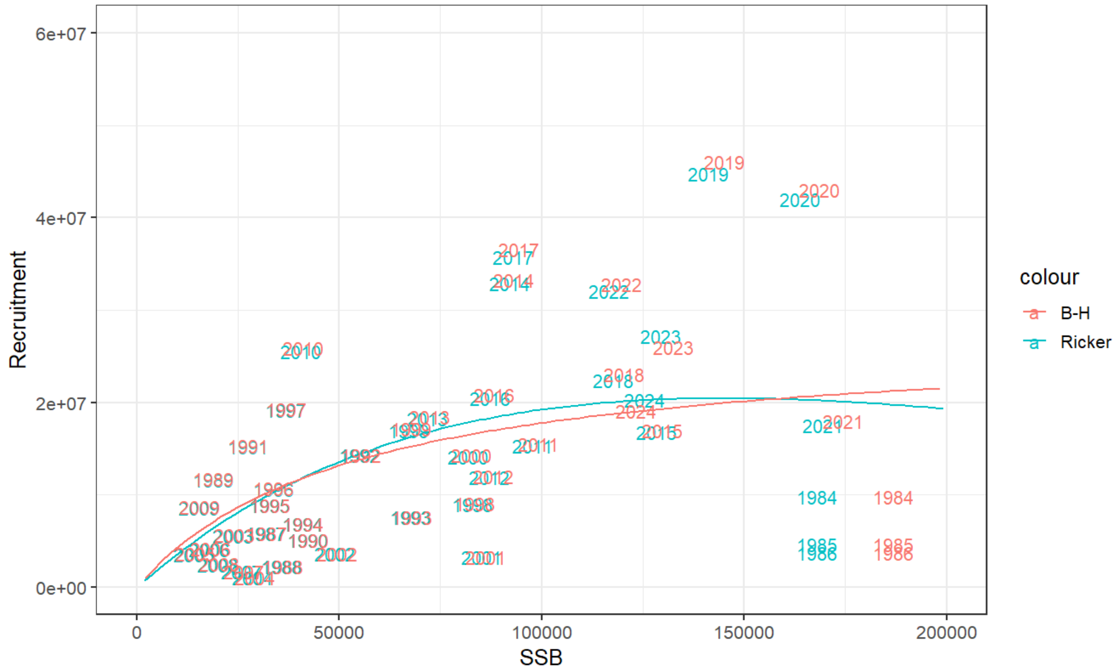

Figure 4: Fitted Ricker and B-H SR functions within the new proposed models as estimated in SS.

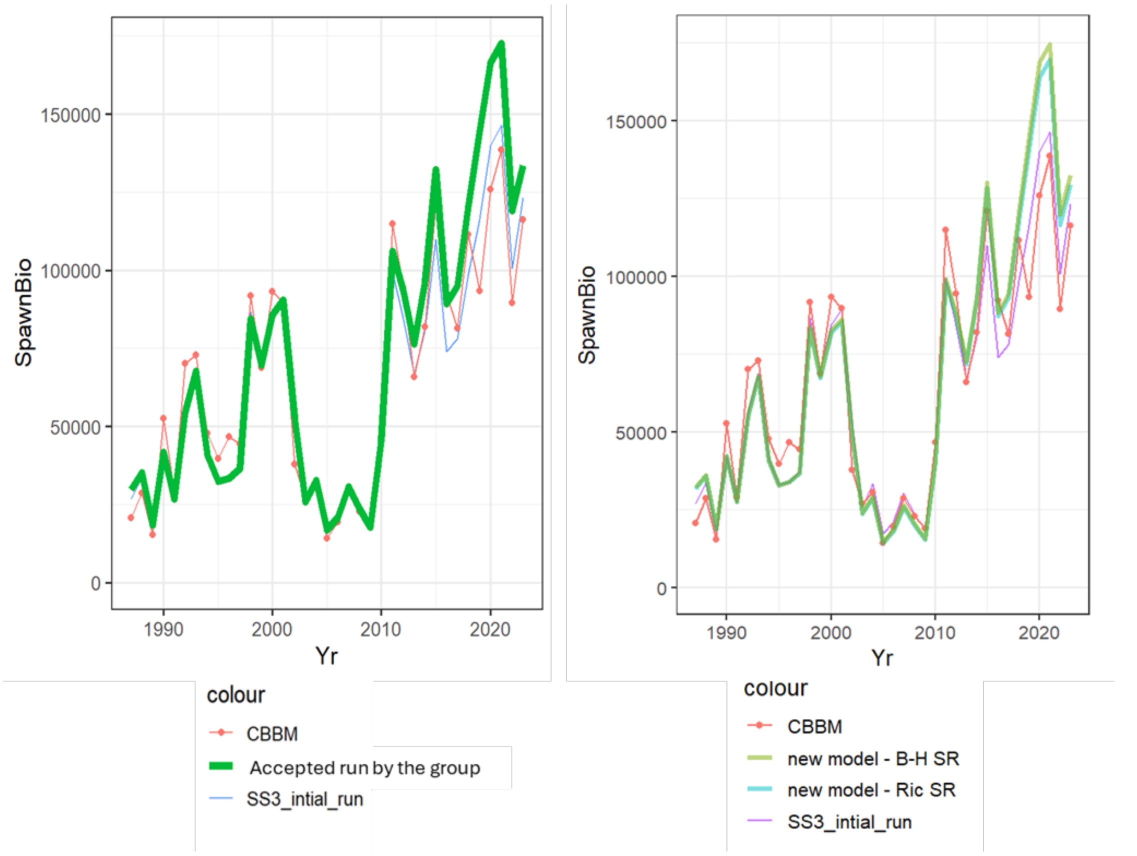

Figure 5: Resulting SSB from the accepted final model by the group (left) and the SSB from the new proposed model (right) in comparison to the previous model (CBBM) output SSB and the SSB from the first proposed model (SS3_initial_run).

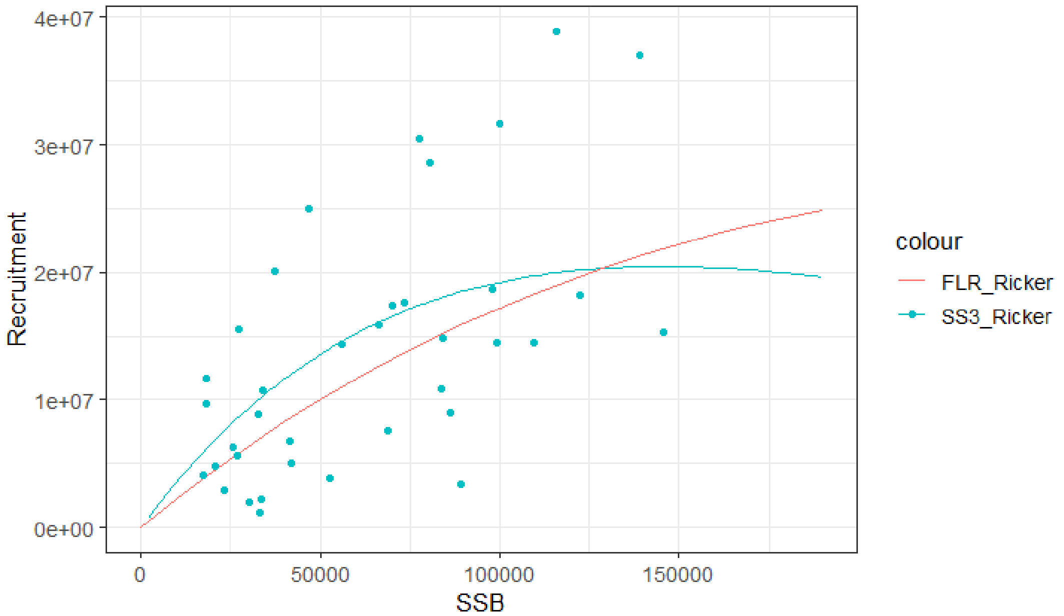

Figure 6: Fitted Ricker SR function within the new proposed model as estimated in SS (blue) and fitted Ricker SR model outside SS· (using FLRS R library).

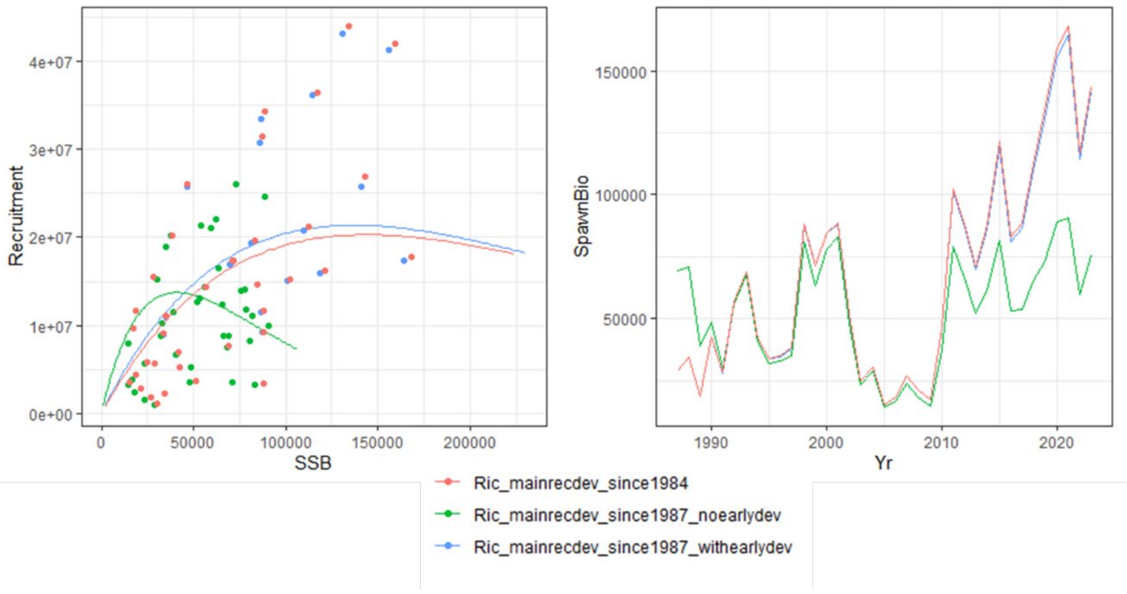

Figure 7: Fitted Ricker functions (left) and resulting SSB estimates (right) for three models: model including main recruitment deviations since 1984 (red), model including main recruitment deviations since 1987 and early deviation from 1984 to 1986 (blue) and model including main recruitment deviations since 1987 and no early recruitment deviations (green).

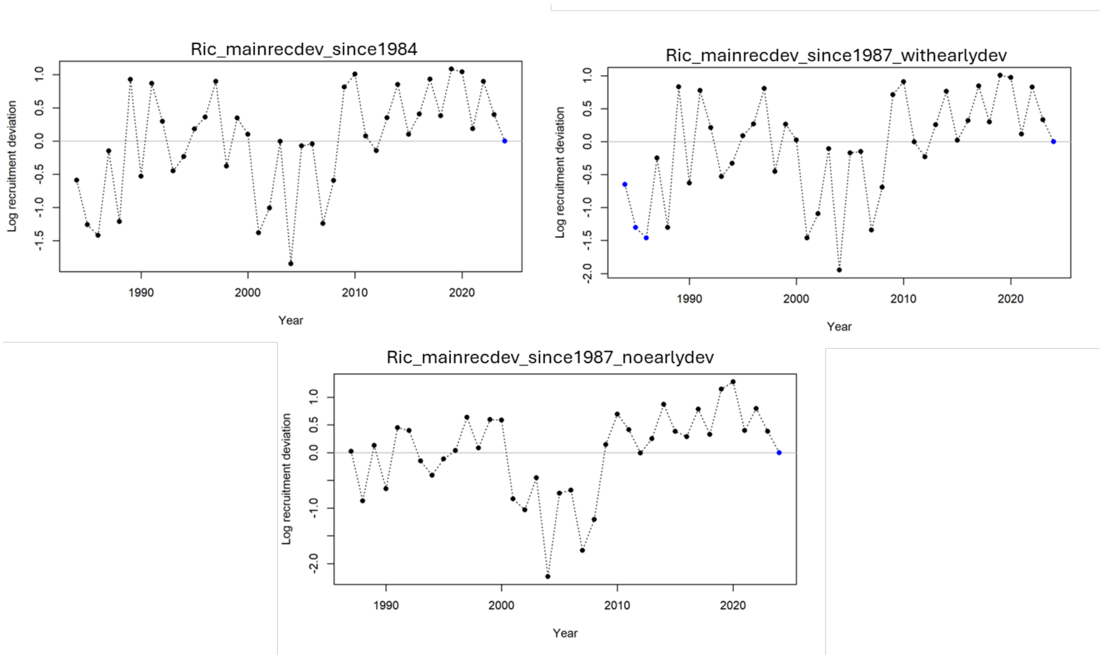

Figure 8: Recruitment deviations for three different models: model including main recruitment deviations since 1984 (left), model including main recruitment deviations since 1987 and early deviation from 1984 to 1986 (right) and model including main recruitment deviations since 1987 and no early recruitment deviations (bottom).

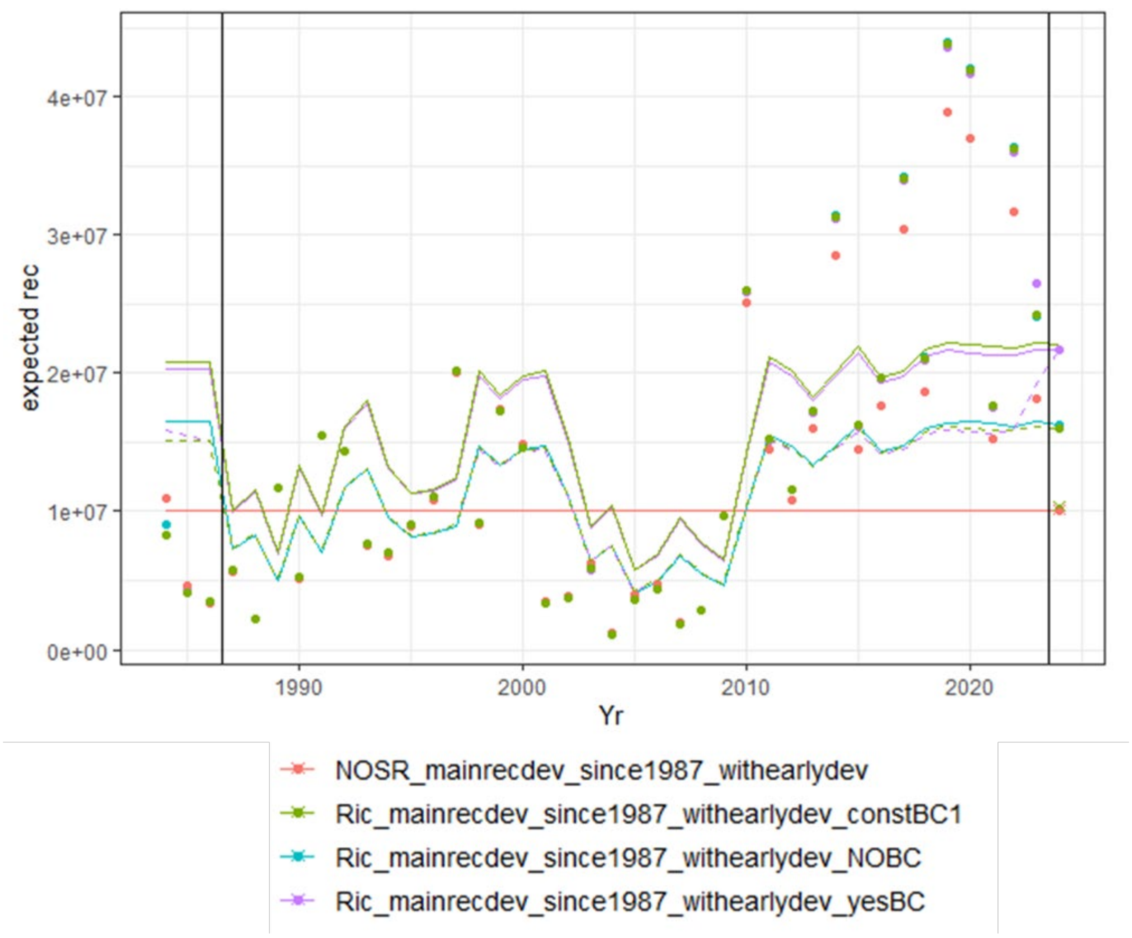

Figure 9: Expected recruitment (Ricker model) estimated by SS3 model (continuous line), for different bias correction options: model including main recruitment deviations since 1987 and early deviation from 1984 to

1986 with the suggested bias correction ramp by SS3 (purple), same model using a constant bias correction in time (no ramp) (green), same model with no bias correction (blue), same model with no fitted SR model (red). The dashed line represents the expected recruitment estimated by SS3 after the bias correction is applied. Points represent the predicted recruitments. Vertical lines represent the first data year (1987) and the last data year (2023). The last point is a forecast (2024) and "x" points represent geometric means for all historical series).

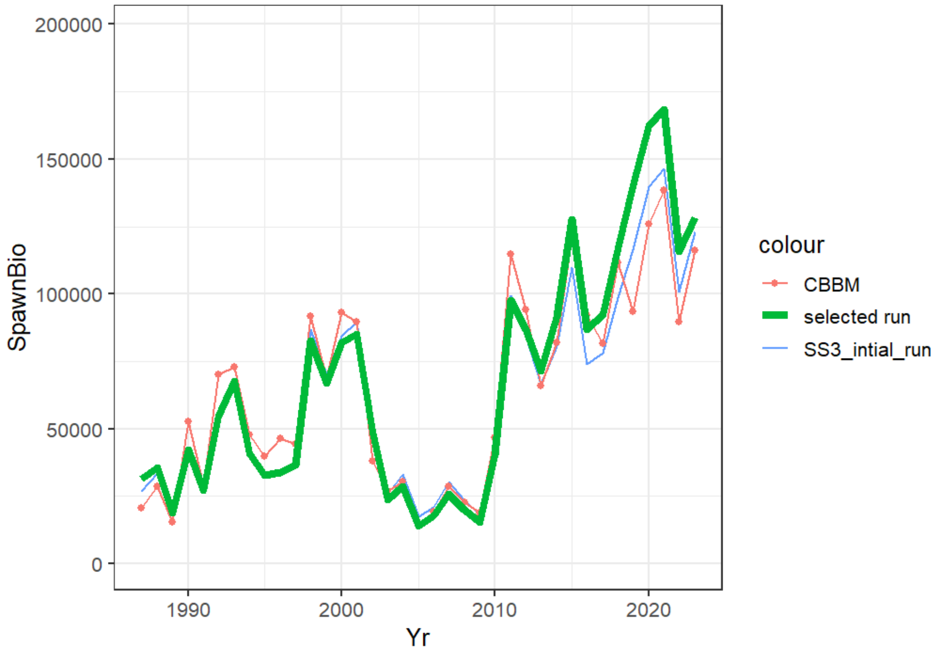

Figure 10: Resulting SSB from the selected model (2024/10/09) in comparison to the previous model (CBBM) output SSB and the SSB from the first proposed model (SS3_initial_run).

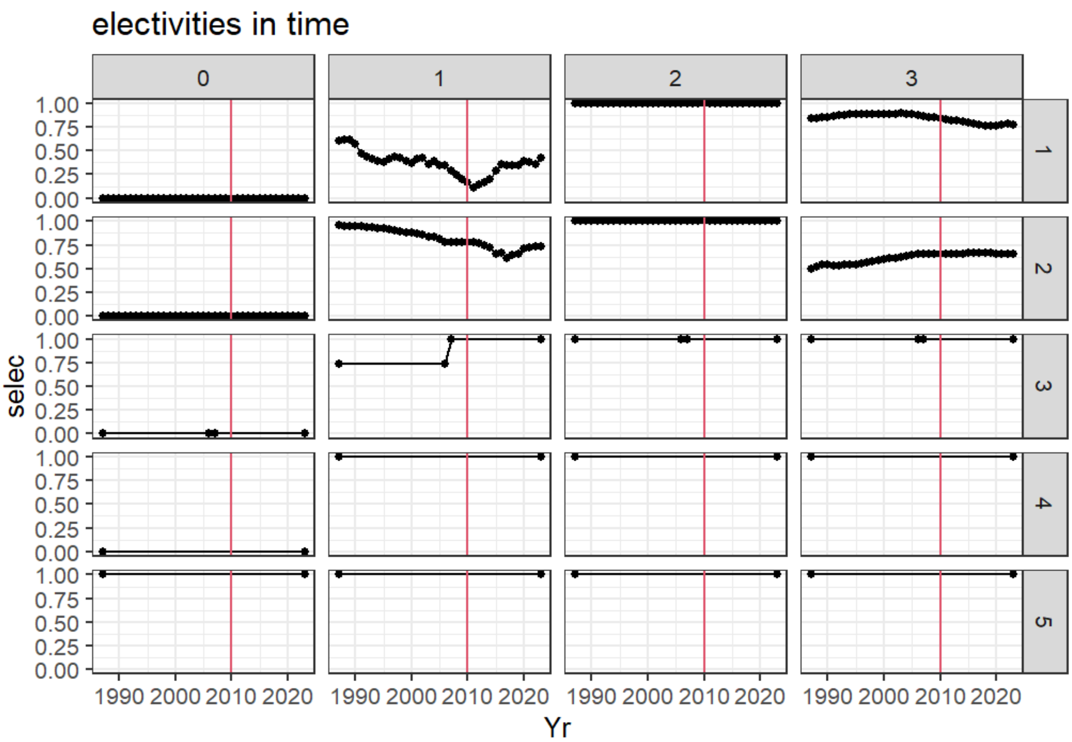

Figure 11: Estimated selectivities by fleet (rows) and ages (columns) for the selected model (2024/10/09). Fleet 1: fishery in the 1st semester, Fleet 2: fishery in the 2nd semester. Fleet 3: Acoustic survey. Fleet 4: DEPM survey. Fleet 5: Juvena recruitment survey (selectivity does not apply).

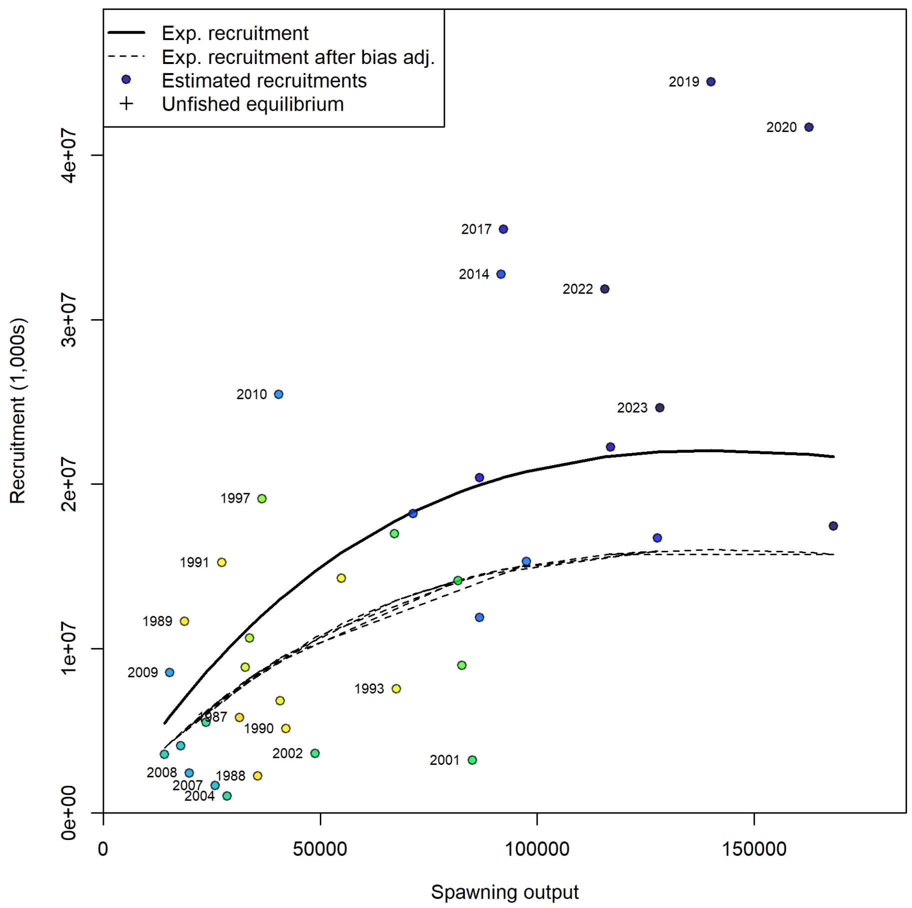

Figure 12: Fitted Ricker SR function within the selected model (2024/10/09) as estimated in SS.

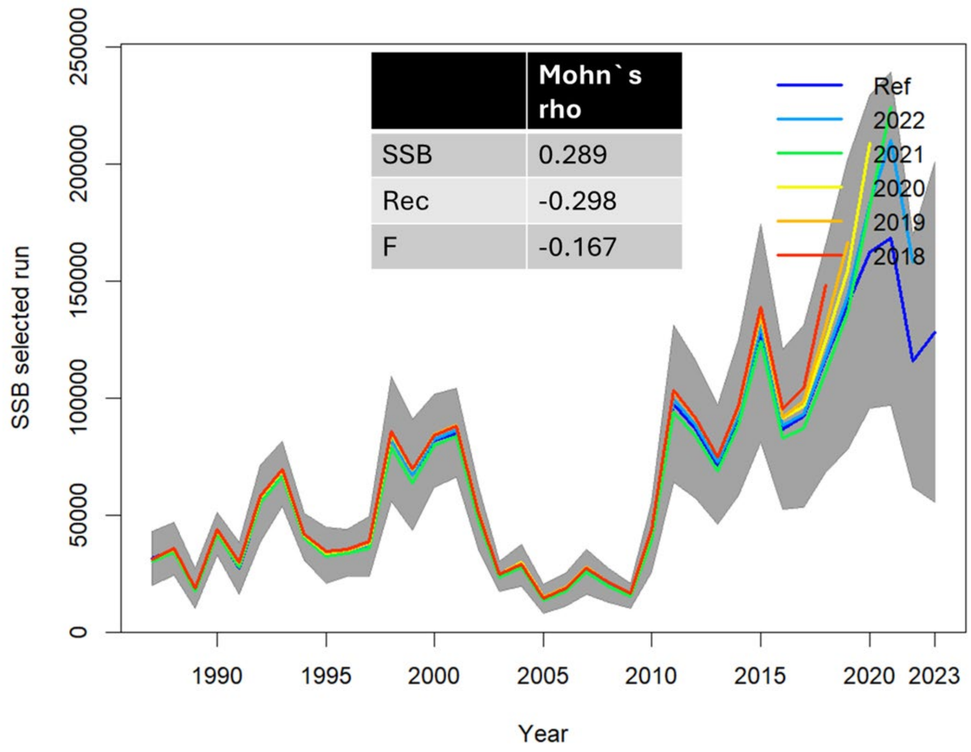

Figure 13: Retrospective SSB for the selected model (2024/10/09) and Mohn` s rho for SSB, recruitment and fishing mortality.

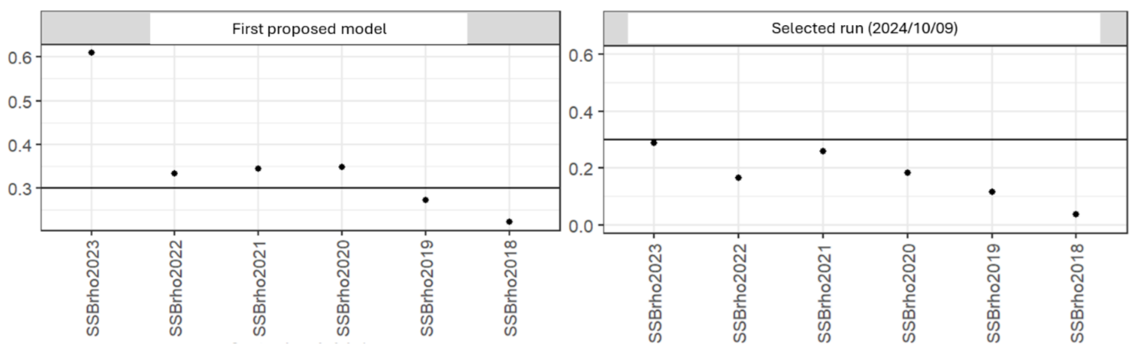

Figure 14: SSB Mohn` s rho values (y axis) for the first proposed model (left) and the selected model (2024/10/09) (right). The x axis represents the year for which the retros were computed, i.e., SSBrho2021 represents the SSB Mohn's rho obtained taking as reference the assessment model with 2021 as the final year and taking into account the retros for the previous 5 years (2020-2016).

Table 1: Used values for the new proposed model. Fleet 1: fishery in the 1st semester, Fleet 2: fishery in the 2nd semester. Fleet 3: Acoustic survey. Fleet 4: DEPM survey.

SR function	M3	Beta (Ricker)/ Steepness (B-H)	Sample size from Francis: Fleet1	Sample size from Francis: Fleet2	Sample size from Francis: Fleet3	Sample size from Francis: Fleet4
Ricker	2.263	1.296	39	23	25	54
B-H	2.283	0.547	39	23	25	54
Ricker selected model (2024/10/09)	2.2619	1.402	39	23	25	54

References

Maunder, M. N., & Thorson, J. T. (2019). Modeling temporal variation in recruitment in fisheries stock assessment: a review of theory and practice. Fisheries Research, 217, 71-86.

Punt, A. E. (2023). Those who fail to learn from history are condemned to repeat it: A perspective on current stock assessment good practices and the consequences of not following them. Fisheries Research, 261, 106642.