SPELMED

Evaluation of the population status and specific management alternatives for the small pelagic fish stocks in the Northwestern Mediterranean Sea

D3.2.
Report on stock status and reference points

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1. Executive summary (Managers)

1.1 Input data

- The status of the sardine and anchovy stocks in GSA 06 and GSA 07 were investigated using statistical catch-at-age (a4a) and two-stage biomass models.
- Life-history parameters of both species were reviewed and new estimates of the von Bertalanffy growth parameters (improving the value of t0) were used. The input data to the stock assessment model were updated, as required (including the natural mortality parameter, M). The new estimates for the growth parameters were for European sardine: Linf = 20.1 cm TL, k = 0.817 yr^{-1}, t0 = -0.246 yr, and for European anchovy: Linf = 18.0 cm TL, k = 0.984 yr^{-1}, t0 = -0.255 yr.
- Since 2002, the average annual catch of sardine in the combined GSA 06 and GSA 07 was 19949 tons. Catches have been declining along the time series with the highest value in 2006 (38528 tons) and lowest value in 2015 (6771 tons). Additionally, catches of sardine in GSA06 contributed on average 79% to the total catches obtained in both areas.
- Historically, catches of anchovy have represented two thirds of the catches of sardine in GSA 06 and GSA 07 (average of 13616 tons). Until 2008, the contribution of catches in each GSA was near 50%. However, since 2009 the catches in GSA 07 dropped to near 1000 tons $year^{-1}$ (2015 and 2016), while catches in GSA 06 have been increasing to reach around 19000 tons in recent years (2013-2016).
- The length structure of sardine landings indicate a reduction of the size of individuals landed of around 2 cm during the time series. Before 2010, most of the harvested length classes were 14.5-15 cm. Since 2010 the modal length of landed sardine was 12.5 cm.
- As for the sardine stock, the length structure of the anchovy landed in GSA 06 decreased from around 14 cm (before 2010) to 12 cm (since 2011). This same trend was observed in GSA 07 but showed higher variability in the length structure among years.
- Note that no changes in the fishing techniques or fishing practices that could affect selectivity are documented for these small pelagic fisheries in the study period.
- Because the value of the von Bertalanffy growth parameters (vGBP) have a strong influence on assessment results, different sets were considered in the analyses. A single set of vBGP for the entire time series or by period, or two sets according to apparent change in length at age (2004-2010 and 2011-2017), were used to transform catch-at-length data into the catch-at-age number ("slicing"). Additionally, the age-length keys (ALK), by year, merged by periods or merged for all periods were used to estimate the catch-at-age number.

1.2 Stock assessment

- Stock assessments using the catch-at-age a4a model for sardine and anchovy in GSA 06 and GSA 07 was either never performed in recent working groups of the STECF or GFCM, or tried but the assessment results not accepted. Here, following the ToR of the contract, a4a was used to assess these two species in GSA 06 and GSA 07. The performance of this method was affected by the availability and quality of data, finding the best results for sardine in GSA 06 and sardine GSA 06 and 07, according to the model diagnostics.
- Some of the slicing methods used to estimate the catch-at-age number produced acceptable stock assessment diagnostics. The assessment models that were set with catch-at-age data obtained from the slicing of a single vBGP for the whole period offered better diagnostics, more internal consistence (when achieved) as well as meeting the rationale of the species biology and fisheries.
- Sardine GSA 06 in 2017 was estimated as overexploited (SSB < Blim) and overfishing was occurring (E > 0.4, proxy Fmsy). The exploitation trend suggested that overexploitation has increased since 2002, and an incipient reduction in fishing mortality has occurred since 2014.
- Sardine GSA 07 in 2016 indicated a strong overexploitation, exhibiting a quite depleted SSB and E > 0.80. Despite the diagnostics of the a4a model (including residuals, data fitting and retrospective analysis) were acceptable, fishing mortality at age 1 after 2009 was outstandingly high.
- Given that the catches of sardine in GSA 06 contribute more than 90% to the catches of the combined GSAs, the stock assessment results of sardine GSA 06 and 07 was dominated by the trend and status of sardine in GSA 06. This means that a less pessimistic overexploitation scenario was perceived when both areas were combined (SSB 2014-2016 = 36% of Bpa, E=0.70) when compared with the single assessment of GSA 07 (SSB 2014-2016 = 3.41% of Bpa, E=0.83).
- Anchovy GSA 06 was overfished (SSB < Blim) and overfishing was occurring (E > E=0.4). Overexploitation in 2017 was higher than in 2004, meaning that fishing mortality have increased along the time series.
- The stock assessment of anchovy GSA 07 suggests that fishing mortality is very low in recent years, presumably, below E=0.4. However, poor model diagnostics and very high fishing mortality at age 2 preclude providing a reliable advice of the status of anchovy GSA 07.
- The stock assessment of the anchovy showed bigger challenges than in the case of sardine stocks. The final stock assessment of anchovy GSA 06 and 07 indicated a sustained status of overexploitation since 2004 (excluding 2005-2007). SSB was quite depleted and below Blim. Fishing mortality in recent years was twice the Fmsy proxy of E=0.4. Although the stock assessment results indicated that F is decreasing since 2014, the retrospective analysis

showed high instability depending on the final year data used to perform the stock assessment.

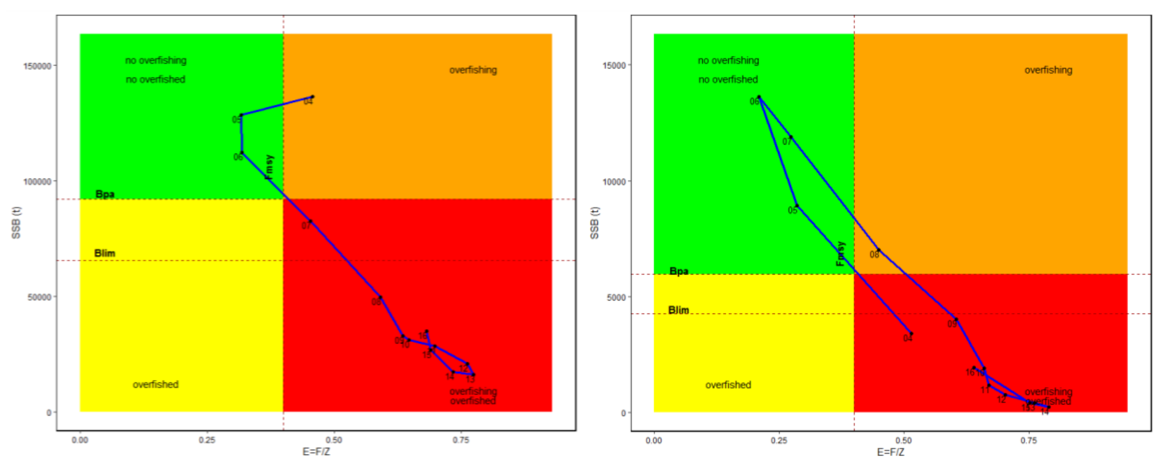
- Given that 1) fishery of sardine and anchovy are focused on ages 0 and 1, 2) both species reach sizes near asymptotic length in the first two years and 3) older ages are either poorly harvested or depleted, a two-stage biomass model was also tried. This model assumes a population structured in two stages: a recruit phase (age class 0 in our study) and an adult phase (age classes 1+).
- Results from the two-stage biomass model showed that a peak of exploitation rate larger than 70% in 2007 was observed for sardine in GSA 06 and GSA 07. These results suggested that the fishery took advantage of the high biomass available in early years of the time series to produce the largest catches, matching the results found by a4a. After dropping, the biomass did not recover in later years, even when exploitation rates remained below 20%. This would mean that stocks have not been capable to recover despite exploitation rates being low in recent years. This result would be consistent with the important decrease in fishing effort (number of vessels) reported for the last 10 years in the study areas.
- a4a indicated that fishing mortality on the sardine in GSA 06 and 07 was above the Fmsy proxy (E) for most of the years. Conversely, the two-stage biomass model suggested that exploitation rate has been most of the time below 40%.
- The two-stage biomass model indicated that anchovy in GSA 06 presented high exploitation rates in 2011 and 2017 (> 40 %), matching with large landings and depletion of the biomass for the adult fraction of the stock. Anchovy in GSA 07 also showed very low levels of adult biomass but exploitation rate since 2012 was below 40%. The assessment performed for anchovy for combined GSAs indicated an exploitation rate between 20% and 40%, suggesting that overfishing has not occurred since 2009 (excluding 2016). Conversely, a4a indicated strong overfishing as well as an overfished status since 2009.
- Considering previous results, it was not possible to achieve a consensus result on the status of sardine and anchovy in GSA 06, GSA 07 and 06 and 07 based on the two-stage biomass model and a4a. However, both models agreed in estimating the size of both stocks as very depleted.

1.3 Advice

- The very low catches of the two species in GSA 07 reported during recent years may induce high uncertainty in the stock status assessed with VPA methods. The most plausible explanation is stock depletion due to excessive removals (catches) in recent decades, leading to overfishing. The truncated age structure of the small pelagics populations and the low recruitment observed on recent years are consistent with this explanation.

- The two stock assessment methods did not provide the same message regarding the fisheries exploitation indicator, probably because of the different model assumptions underlying their application.
- According to our results, scientific advice for sardine and anchovy in GSA 06 can be done considering a single-management stock area (as currently occurs). However, a more reliable advice of the stocks in GSA 07 may be obtained when both areas are combined. The results of genetic analysis do not support separate stocks of sardine or anchovy between GSA06 and GSA07 (or in the Western Mediterranean, except the Alboran Sea in GSA 01).
- Sardine and anchovy stocks in GSA 06 and 07 are subject to overfishing (E > 0.4) and SSB is strongly depleted (SSB < Blim). Harvest rates of the two species has been slightly reduced since 2013, but this reduction has not been translated into recovering of SSB yet.

Kobe plot to the sardine (left) and anchovy (right) stocks in GSA 06 and 07.



1.4 Data gaps

- The catch-at-age stock assessments of anchovy and sardine in GSA 06 and 07 have been affected by a too negative t0. During this project we solved this gap, making it possible to obtain acceptable stock assessment outputs for providing advice to management these resources.
- Prodbiom was used as an indirect estimator of natural mortality because the M-at-age vector relies on the tradeoff between loss of biomass in younger ages and production of older ones. Thus, this estimator produced a reasonable vector of M and avoided too high values of M for ages 0 and 1 when t0 is near zero (if Gislason's estimator is used).
- The fishery-independent data series (acoustic surveys) showed problems to follow the trends in the fishery-dependent data (landings), among other reasons because each piece

of information holds different temporal information of the stock. Only data from the acoustic survey MEDIAS was used to fit the model, because stock assessment produced poor results if the acoustic survey ECOMED index was included.

- Official data on catch-at-age number and weight-at-age of sardine and anchovy in GSA 07 included several gaps as well as some incongruent information, which affected the performance of the stock assessment models. For instance, no information of catch-at-length number in 2011, unrealistic high catch-at-length number in 2013, no information on weight-at-age for some ages during several years, or there is confusing information on vessel number per year. All these gaps in raw data probably prevented a better performance of the catch-at-age model used.

2. Executive summary (Fishers)

- The sardine and anchovy are the two most caught small-pelagic species in the Spanish and French Mediterranean. In fact, 38528 tons of sardine were landed in 2006 by the fleets of both countries. Currently, landings of sardine are below 11000 tons, meaning that the catches of this species were reduced by 72%.
- The landings of anchovy in the French Mediterranean has been reducing along the time series from almost 8000 tons (2002) to near 1300 tons in recent years (2015-2016). Conversely, this species has been increasingly landed in the Spanish Mediterranean. Thus, the landings of anchovy in this area are eight times higher than in 2007.
- The above-mentioned landings mean that the landings of sardine fell to very low values while landings of anchovy have reached values comparable to those in 2002.
- The size of both species seems to be smaller in recent years. Taking into account that no changes in the fishing techniques or fishing practices that could affect selectivity are documented for these small pelagic fisheries since 2002, it seems that both species are now smaller than ten years ago.
- Using all available information derived from fisheries as well as scientific surveys, the scientists updated the growth, maturity and natural mortality. All this information was then used to determine what the status of both species is.
- The sardine and anchovy stocks look overexploited in both countries while the fishery is still producing too much harvesting pressure on the smaller sizes. The fishing effort should be reduced to allow that both species recover their stock size.

3. Introduction and objectives

Virtual Population analysis (VPA) is a powerful method of fisheries stock assessment and is the method of choice for data-rich stocks of long-lived species. The sardine and anchovy stocks in GSA 06 and GSA 07 either have never been assessed or the assessments are not been accepted by the stock-assessment working groups when catch-at-age statistical models have been used. Here we improve the biological input data that fed the model a4a Assessment for All (a4a) initiative, which is a non-linear catch-at-age model implemented in R. Therefore, different approaches to obtain the input data of the model (e.g. catch-at-number obtained from slicing or age-length keys) were used to improve the stock assessment of short-lived species.

However, in the context of short-lived species, such as cephalopods, or species where estimates of length-at-age are inaccurate (due to problems of aging, estimation of growth parameters, etc.) less data-demanding assessment models should be explored. One possibility is the two-stage biomass model originally proposed by Roel and Butterworth (2000) and recently used for stock assessment of small pelagics in GSA07 in GFCM working groups (2015, 2016). Basically, the model assumes that the exploited population is composed of two life stages only: recruits and fully recruited individuals. In the case of small pelagics in our study areas (GSA06 and GSA07), recruits would correspond to age 0 individuals and fully recruited would correspond to age 1+ individuals, which in our case can, additionally, be considered fully mature (i.e., for the model we assume an exploited population made of recruits “immature fish or juveniles” and fully recruited “adults”).

According to the above-mentioned framework, the main goals of this study were 1) to determine the stock status of sardine and anchovy in GSA 06, GSA 07 and combined areas using a robust catch-at-age model (a4a) and a data-limited model (two-stage biomass model) and 2) to elucidate the challenges and limitations of assessing these two species from the available data.

4. Material and Methods

4.1 Statistical catch-at-age model - a4a

4.1.1 Model basis

Assessment for All (a4a) is a non-linear catch-at-age model implemented in R that was developed to be applied rapidly to a wide range of situations (http://www.flr-project.org/). This stock assessment model is structured by submodels (F-at-age, catchability-at-age, recruitment model, observation variance of catch-at-age and abundance indices and model for the initial age structure).

Modelled catches *C* are based on natural mortality *M*, fishing mortality *F* and recruitment *R* , using the modified catch equation of Baranov:

$$C_{ay} = \frac{F_{ay}}{F_{ay} + M_{ay}} \left(1 - e^{-(F_{ay}+M_{ay})}\right) R_y e^{-\sum(F_{ay}+M_{ay})}$$

Where age (a) and year (y). Additionally, the modelled surveys *I* are also defined in terms of *M, F* and *R*, and additionally, catchability Q.

$$I_{ays} = Q_{ays} R_y e^{-\sum(F_{ay}+M_{ay})}$$

Where survey *s* or abundance indices may be used. Additionally, multiple surveys may be considered.

Larger details may be found in Jardim et al. (2017) and http://www.flr-project.org/

4.1.2 Model setting

Previously to run the stock assessment model, one stock object and at least one index object are required. These objects were created for the sardine and anchovy stocks for GSA 06, GSA 07 and combined GSA 06 and GSA 07. The stock object requires information of catch-at-length/age number, weight-at-age, growth information, M-at-age, maturity at age, total catches and proportion of mortality before spawning for all period that will be used to assess the stocks.

Catch-at-age matrix used to set the FLStock object was estimated from age-length keys or slicing under different treatments (using full time-series, by periods or by year) (Fig. 4.1.2.1). The two periods were defined according to some indications that growth of both species was higher in the first period (2002-2010) than the second period (2011-2017) (see deliverable 1.3.1.1, Report on age, growth and age-composition). The selected way to produce the catch-at-age matrix also was used to define the index-at-age matrix. At the same time, the M used to set the FLStock depended on the way used to estimate the catch-at-age information (Fig. 4.1.2.1). The result section indicates the data source and treatment applied to each piece of data required to set the stock object.

The stock assessment model requires setting the *F*, *Q* and *S-R* submodels and several diagnostics help to improve the model performance. However, a4a is quite sensitive to submodels settings requiring a good knowledge of the fisheries, because more than one model may be supported by good diagnostics. Several plus groups for age, indices (including combination between them) and submodels parameterizations were tested for each of the catch-at-age sources. Once the more reasonable stock assessment was defined by species and GSA, reference points (E=0.4, Blim and Bpa) were estimated and trajectory of stock was plotted using the Kobe plot.

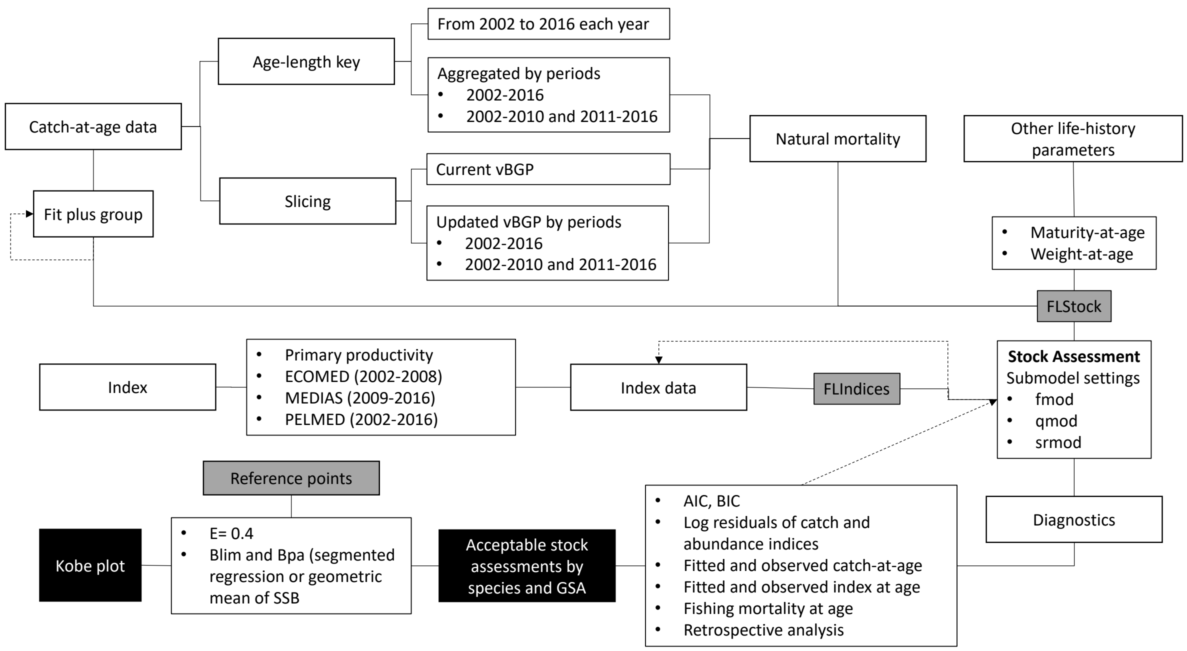


Fig. 4.1.2.1. Diagram of the process carried out to assess the stock status of the sardine and anchovy in GSA 06, GSA 07 and GSA 06 and GSA 07 combined.

4.2 Two-stage biomass model

Gras et al. (2014) summarized the relevant properties of the model: it allows to estimate accurately recruitment strength, it is consistent with VPA results and it can use one or more time-series of abundance[1] indices (e.g. survey index, commercial fishery index) to calibrate the landings.

The two-stage biomass model uses Pope (1972) simplification to mimic pulse fishing in the middle of the season. The dynamics of the biomass of adult fish (age 1+) is:

$$B_{A,y+1} = \left((B_{A,y}+B_{J,y})e^{-\varphi g} - C_y\right)e^{-\varphi g}$$

Where B_A and B_J are the biomasses of adults and juveniles (or recruits) at time y, respectively, C are the landings, φ is the timing of the fishing pulse along the year and *g* is the net growth (in biomass) of the population. Fisheries independent biomass indices can be used to calibrate the biomasses over time. In GSA06 data from the ECOMED winter survey were available for the period 2003-2009,

[1] Properly speaking, the model uses indices based on biomass only.

while data from the MEDIAS summer survey were available from 2009 to 2017. In GSA07 the former PELMED and the current MEDIAS surveys are carried out in summer and the data were available from 2002 to 2016. The biomass indices (S) used take into account whether the annual survey was carried out in winter (Survey1, ECOMED) or in summer (Survey 2, PELMED and MEDIAS). Survey1 coincides with the recruitment of the population of sardine, while Survey2 coincides with the recruitment of the population of anchovy:

$$S_{J,y} = k_J B_{J,y} e^{-\chi g} e^{\xi 1}$$

and

$$S_{A,y} = k_A B_{A,y} e^{-\chi g} e^{\xi 2}$$

Where k_J and k_A are the "catchabilities" of the acoustic survey, for juveniles and adults, respectively, χ is the timing of the survey in relation to the fish life cycle (0 for sardine, 0.5 for anchovy) and $\xi 1$ and $\xi 2$ are observation errors. The indices were scaled to zero mean and unit variance to facilitate computation of the model.

The net growth of the population was estimated as the difference between G (adult growth rate) and M (natural mortality): g = G – M, following Gras et al. (2014). The von Bertalanffy growth parameters used in this calculation were the updated parameters (see above).

The two-stage model was fitted in R v. 3.5.0 with the script kindly provided by Claire Saraux (IFREMER, Sète), based on the model implementation of Nicola D. Walker (CEFAS, February 2015). It was used to assess the vulnerable biomass and exploitation rate of sardine and anchovy in GSA06 and GSA07 (separately and combined).

5. Results and discussion

5.1 Statistical catch-at-age model - a4a

5.1.1 European sardine (Sardina pilchardus)

5.1.1.1 Sardine GSA 06

5.1.1.1.1 Input data

The length structure of the sardine harvested by the purse seine fleet in GSA 06 included individuals from 5.5 cm to 23 cm. Most of the caught individuals were between 11 and 17 cm. Before 2009, from 14.5 cm to 17 cm were the most harvested sizes. Since 2010, individuals from 11.5 cm to 15 cm were the most represented sizes in landings. (Table 5.1.1.1).

Table 5.1.1.1. Length structure of the stock of sardine harvested by the purse seine fleet in GSA 06. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
5.5	0	0	0	0	0	0	0	0	40	0	0	0	0	0
6	0	0	0	0	0	0	0	0	63	0	0	0	0	0
6.5	48	0	0	0	0	0	0	0	70	0	0	0	0	0
7	145	0	0	0	0	0	0	0	64	0	0	0	0	0
7.5	145	0	0	0	0	0	0	308	41	0	0	0	0	0
8	918	0	0	0	0	0	0	619	54	0	0	8	62	41
8.5	2088	0	0	0	0	0	152	1089	142	26	158	275	1242	111
9	3410	23	84	0	1	203	163	336	521	373	951	679	1673	130
9.5	4959	1877	332	94	256	754	876	664	2446	966	3245	2741	5832	252
10	8387	8134	1811	277	420	1950	2182	3212	6349	4189	7205	6468	12651	2249
10.5	10122	17600	6105	364	6478	6359	6804	11310	12554	10642	11142	12401	24512	6706
11	23068	19850	7001	1272	7798	16670	10292	27919	22703	21576	22040	15917	31197	10190
11.5	41405	21916	8099	5281	25145	35129	20728	41227	34092	36113	27330	27776	61747	14595
12	64155	23672	9732	15524	36191	48709	28399	46988	48094	43954	48226	44921	92205	37686
12.5	67895	29173	9494	21964	35352	54077	33686	48892	46697	57003	65163	52839	93057	60861
13	73782	44694	15428	26871	38981	55774	35234	58853	52834	65065	79915	59337	85050	58500
13.5	64128	51030	22913	22895	37182	52425	37803	69060	46892	66418	68759	55036	72027	52435
14	70171	72370	44045	29447	33034	54277	39209	78180	44717	56156	63980	41092	57289	39906
14.5	76589	78297	68155	44078	47646	41752	35199	62759	34784	44171	48187	24239	37759	26732
15	89921	84131	102200	66215	61022	27556	34953	51231	33131	39133	38932	15521	25372	21012
15.5	77726	77684	118740	72193	55473	19483	36127	32509	26222	24306	19700	7646	13302	16308
16	66133	71290	110856	75909	54687	14561	28845	23190	21784	19851	12252	5887	6988	11909
16.5	49153	55279	95804	61314	45476	9120	16072	15472	15297	10930	4960	2363	2851	7802
17	33974	42581	74919	56123	38660	6910	12718	12195	10688	6156	4052	1436	1181	6290
17.5	17349	21909	40414	40718	26324	4668	5129	6577	4976	2428	1455	616	568	3128
18	10676	11321	27827	37504	17015	3624	3285	4380	2440	1538	628	469	215	1513
18.5	6882	5295	14178	28558	12718	2566	1410	2033	1388	624	508	255	168	423
19	5066	3377	9139	19739	7706	1346	422	797	510	389	481	176	108	204
19.5	2887	1046	4437	8161	4133	811	519	243	86	168	312	57	108	57
20	2224	657	2533	3895	2173	600	1063	181	54	98	86	34	46	0
20.5	787	353	748	1371	608	311	548	39	10	11	0	4	1	0
21	536	172	252	530	79	156	340	11	16	4	126	3	3	0
21.5	232	38	290	17	25	66	99	10	9	0	0	0	0	0
22	60	36	55	36	1	18	29	2	0	0	0	0	0	0
22.5	18	13	13	4	0	0	11	0	0	0	0	0	0	0
23	0	0	0	0	0	0	2	0	0	0	0	0	0	0

Length structure observed in the ECOMED surveys carried out in winter (2004-2009) and coinciding with recruitment of sardine included individuals from 7.5 cm to 23 cm. The most recorded individuals belonged to sizes between 10. 5 cm and 13 cm (Table 5.1.1.2). Since 2009, the length structure observed by the Medias surveys which were carried out in summer, coinciding with recruitment of anchovy, indicated more abundance of smaller sizes (7 cm to 11 cm) (Table 5.1.1.3).

Table 5.1.1.2. Length structure of sardine recorded during the ECOMED survey program in GSA 06. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2004	2005	2006	2007	2008	2009
7.5	2451	0	0	0	0	0
8	8243	8	5762	0	0	0
8.5	13642	1033	13405	0	0	0
9	18250	9417	25700	0	0	458
9.5	43401	23969	39530	0	0	6688
10	113900	51843	75082	0	7821	19229
10.5	200870	97104	117856	1279	40872	40097
11	261979	147829	167935	35258	82467	83972
11.5	348113	182156	115612	57566	116192	109199
12	302171	306201	128796	98169	79108	123237
12.5	224614	232014	111532	92233	40453	82698
13	137199	220668	90293	103666	15625	78513
13.5	94210	134238	74139	67951	18720	51525
14	107397	126602	60221	29891	4939	39640
14.5	82209	84547	52631	23603	1935	24068
15	74938	77215	63324	35636	2314	25584
15.5	58299	64819	90365	29645	4017	15790
16	29298	67507	101195	33792	3280	17293
16.5	19185	41725	100584	28715	6707	6713
17	10685	44405	126375	28375	4210	8580
17.5	8985	40228	109475	27294	6465	5763
18	4009	24783	115048	21649	6603	8631
18.5	4120	12034	82886	16311	6480	3884
19	2137	6688	64911	10877	5012	3379
19.5	3117	5758	30212	4392	2859	3131
20	1747	1805	14377	3120	1499	1030
20.5	1131	1078	7401	303	1214	699
21	442	632	4831	616	287	1130
21.5	361	719	2658	120	14	362
22	41	855	2450	0	0	66
22.5	27	715	393	0	0	0
23	0	0	393	0	88	13

Table 5.1.1.3. Length structure of sardine recorded during the MEDIAS survey program in GSA 06. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2009	2010	2011	2012	2013	2014	2015	2016	2017
5.5	0	0	0	0	0	0	306	0	
6	3114	0	0	0	16888	0	1225	0	0
6.5	4566	0	494	2697	111974	1987	22041	55	
7	7835	0	4300	34224	224938	15311	82484	45532	212864
7.5	21826	1208	2486	107978	458516	45223	171926	416603	
8	132062	30220	97772	334491	579523	90624	455582	786921	387162
8.5	473956	104664	334018	831078	1325791	112807	417192	621466	
9	592134	331335	650302	1188613	1193368	134082	440014	245694	831411
9.5	790704	440721	675764	1297455	833785	86200	346366	282825	
10	650040	349783	825862	765176	599762	47913	415473	242962	844553
10.5	443750	360829	534244	478037	519886	26480	410440	253265	
11	304518	185596	332145	317985	296043	12163	358599	203909	347290
11.5	136442	108167	154664	120876	131640	10752	112541	227774	
12	41486	26923	108228	129114	56776	52338	41246	198895	432175
12.5	19144	26603	71032	120532	39950	47868	103424	143284	
13	4401	18035	69061	76605	84312	46987	87777	119740	336058
13.5	9606	35897	69319	33725	72667	25070	89090	78051	
14	14829	39195	87570	34798	44824	17303	40288	58895	212934
14.5	11219	46057	66482	24568	17637	6094	25814	47363	
15	11735	26443	67905	18443	14348	7544	18159	36256	84231
15.5	7665	25609	42767	10873	17832	2195	9835	18339	
16	6743	11739	61956	8156	8190	200	4226	3776	14511
16.5	3626	6311	36623	4908	461	154	1794	2308	
17	2180	2729	15935	2660	1643	0	808	1230	1437
17.5	1836	611	11756	703	86	0	67	0	
18	389	986	1851	612	0	0	1692	0	0
18.5	275	155	170	0	0	0	0	547	
19	200	0	249	0	0	0	0	0	0
19.5	38	0	0	0	0	0	0	0	
20	0	0	58	0	61	0	0	0	
20.5	38	0	0	293	0	0	0	0	
21	0	348	0	0	0	0	0	0	

The Spanish Institute of Oceanography (IEO) has a large data set of otolith readings of sardine in GSA 06 harvested by fisheries since 2004 (n=12839). Additionally, there are some otolith readings of larvae of this species from 1983 to 2007. The otolith readings obtained through several research projects; ARECES in 1983 (n= 30), ARO in 2000 (n= 163), CAIMAN in 1996 (n=50), SAVOR in 2003 (n= 109), JUVALION in 2007 (n=29) and PELMED, (n=2007) were shared by Dr. Isabel Palomera from the Marine Science Institute of Barcelona (ICM-CSIC). Additionally, Dr. Alberto Garcia of the IEO Malaga shared 193 otolith readings of sardine obtained in 2000. All these sources of information on growth were used to update the estimates of the von Bertalanffy growth parameters of sardine. In order to merge the available information on growth, only were used those otolith readings derived from fisheries for the spawning peak of sardine (December-February, n=2111). The updated estimates of the von Bertalanffy growth parameters were calculated by the Bayesian Von Bertalanffy Growth Model - B-VBGM (Catalan, 2018) (Table 5.1.1.4).

Table 5.1.1.4. von Bertalanffy growth parameters estimated by the B-VBGM - Bayesian Von Bertalanffy Growth Model (Catalan et al., 2018) as indicated in the deliverable 1.3.1.1.

Linf	K	t0	n	period	method
20.1	0.817	-0.246	3336	1983-2003 (larvae) 2005-2017 (adults)	B-BVGM

The deliverable 1.3.2.1 (Report on gonadosomatic index, size at firs maturity and reproductive parameters) explored and updated the percentage of mature individuals at age. This information was used to set the maturity vector of the sardine stock (Table 5.1.1.5). The fecundity of the species has presumably decreased because individuals are smaller than before 2010, the percentage of maturity at age zero was precautionary set in 0.5.

Table 5.1.1.5. Maturity vector used to set the maturity-at-age of sardine in GSA 06.

Age	0	1	2	3
Maturity	0.5	1	1	1

The natural mortality usually used in the stock assessment of sardine is usually estimated using the Gislason's first equation, among other reasons, because produces an M-at-age vector with values around 1. However, this vector is produced when the vBGP hold a t0 very negative (< -1.5). The updated vBGP obtained in this study to sardine in GSA 06 hold a t0 near zero (> -0.3). Consequently, the Gislason's estimator produces M-at-age for the most fished ages (0 and 1) with too high values (between 4.5 and 1) (see deliverable D.1.4.1), promoting that the stock is perceived as lower overexploited or even underexploited.

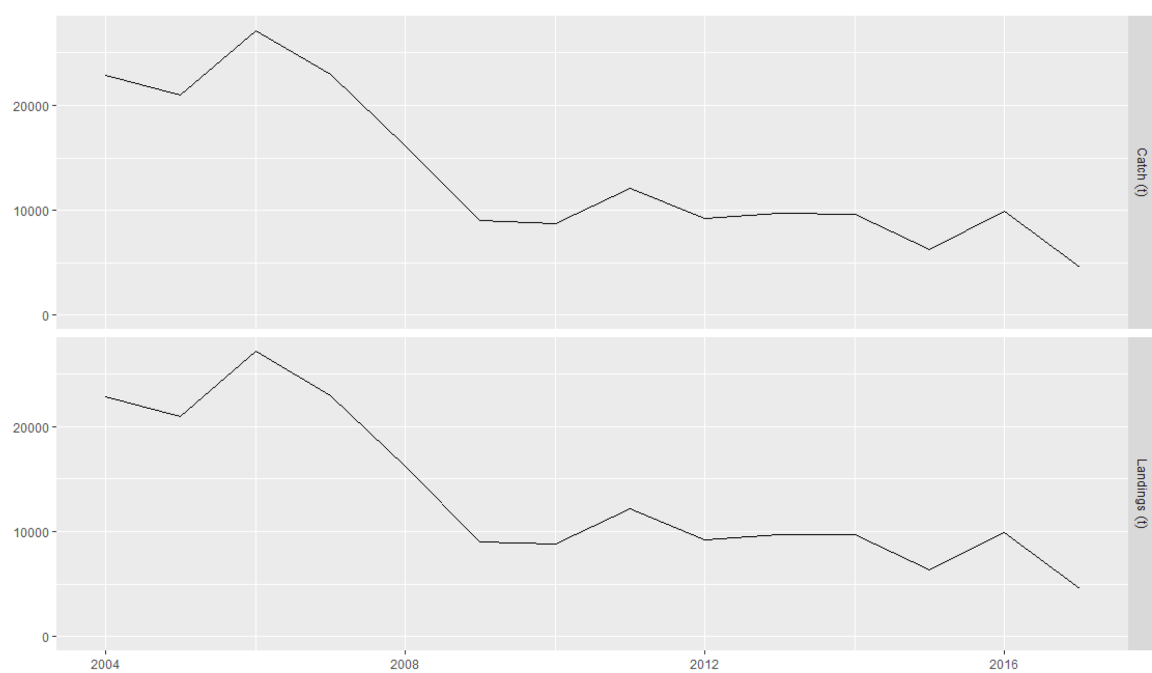
The updated vBGP of sardine meets the biology rationale of a short-lived species, growing fast during the first year to follow a very low increase of size-at-age after this point. Thus, the t0 near zero makes sense to this species. In order to avoid too high values of M for younger individuals, it was preferred to use the Prodbiom estimator of natural mortality (Abella et al., 1997) (Table 5.1.1.6). This estimator relies on the fact that losses of biomass associated to natural mortality are compensated by production (growth). Therefore, this estimator may be reasonable used to estimate the M of species where there is indications of changes of mortality with age, as small pelagic species.

Table 5.1.1.6. Natural mortality at age (M-at-age) of sardine in GSA 06 estimated by Prodbiom

Age	0	1	2	3
M	1.18	0.72	0.5	0.42

The reported catches of sardine in GSA 06 have decreased since 2004 (Table 5.1.1.7). The highest value was reported in 2006 (27800 tons) and the lowest catch was obtained in 2015 (6450 tons). These results mean that catches of sardine in recent years (after 2009) represent 43% of catches of early years of the time series (before 2009). Due to there is not reliable temporal information of discards and values are absent or very low for most of the available period of catches, the discards were assumed as zero.

Table 5.1.1.7. Catches of sardine in GSA 06. Discards are assumed as zero tons, meaning that catches correspond to the reported landings.



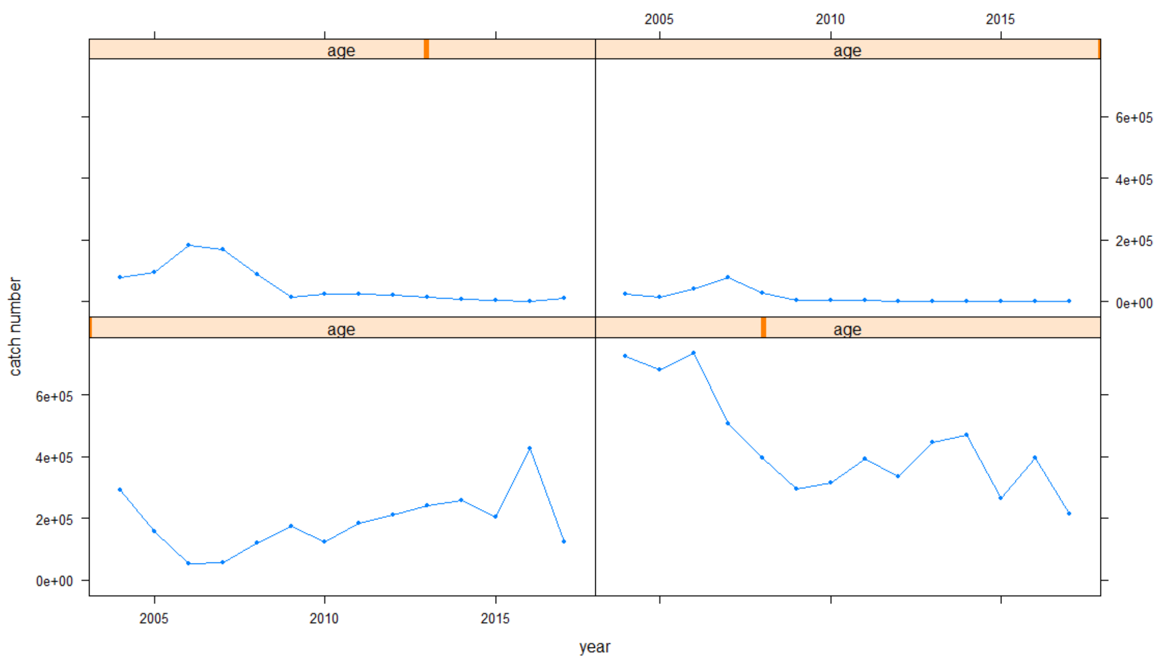
Weight at age used to estimate the total catches at age of sardine in GSA 06. Data was provided by the IEO (Table 5.1.1.8).

Table 5.1.1.8. Weight at age of sardine in GSA 06. Data obtained from the Spanish Institute of Oceanography

Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0	0.013	0.014	0.015	0.015	0.015	0.014	0.013	0.012	0.011	0.011	0.009	0.011	0.012	0.011
1	0.021	0.022	0.025	0.024	0.023	0.019	0.019	0.023	0.018	0.015	0.015	0.015	0.012	0.014
2	0.031	0.032	0.032	0.033	0.04	0.035	0.032	0.032	0.032	0.022	0.022	0.022	0.019	0.02
3	0.041	0.042	0.041	0.045	0.05	0.05	0.053	0.051	0.046	0.028	0.031	0.039	0.024	0.032
4	0.056	0.051	0.051	0.05	0.057	0.06	0.064	0.059	0.055	0.031	0.051	0.051	0.049	0.05
5	0.073	0.06	0.067	0.068	0.079	0.079	0.078	0.064	0.078	0.078	0.078	0.078	0.078	0.078

The fishery of sardine in GSA 06 mainly harvest individuals of ages 0 and 1, while those individuals of ages two and three are only represented before 2009 (Fig. 5.1.1.1). Higher representation of individuals of age 0 in recent years (after 2010) was followed of lower abundances in age 1.

Fig. 5.1.1.1. Number at age of sardine individuals in GSA 06 after slicing using the updated vBGP above shown. Plus group has been set for age 3.



5.1.1.1.2 Stock assessment

The sardine stock was assessed using different source of data as showed in the Fig. 4.1.2.1. The catch-at-age matrix obtained from ALK per year (and *M* estimated by Gislason) suggested that *F* has tended to decrease since 2004. However, there is not an identified measure that could be responsible for this *F* trend. The catch-at-age matrix obtained from ALK by periods (2004-2010 and 2011-2017), and *M* estimated by Gislason, showed an increasing of *F* along the time series, suggesting that a high harvesting has prevented the stock recovery. The catch-at-age matrix derived from slicing using the current vBGP (too negative t0 and *M* estimated by Gislason) suggested increasing of *F* along time series, starting from a very low *F* (<0.5) in early years. The catch-at-age matrix obtained from the updated vBGP (and *M* estimated by Prodbiom) showed similar results than “ALK_2periods” (Fig. 5.1.1.2). These is the main reason because both stock assessments were accepted in the last assessment session in GFCM. The stock assessment that we finally selected to describe the stock status of the sardine in GSA 06 relies in catch-at-age matrix derived from the updated vBGP because better stock assessment diagnostics were found and life-history parameters had better reflect the nature of this small-pelagic species. Hereafter, the stock assessment based on the vBGP is explained.

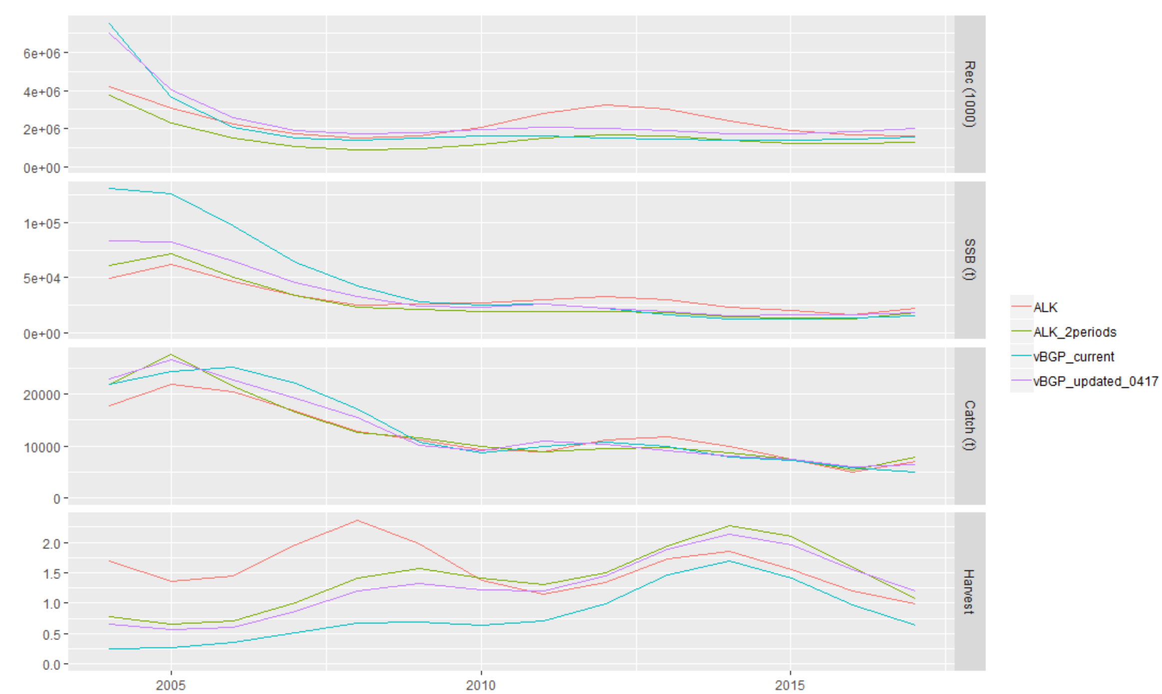


Fig. 5.1.1.2. Results of the stock assessment when catch-at-age matrix was obtained from ALK data per year (ALK), aggregated in two periods (2004-2010 and 2011-2017) (ALK_2periods), sliced using the current vBGP and sliced using the updated vBGP.

The stock assessment model set the fishing mortality submodel (fmodel) using a separable model in which age and year effects are modelled as (unpenalised) thin plate spline (Table 5.1.1.9). It was assumed that ages older than two hold the same F than age two because the gear is capable to entirely select all ages older than this age. We model the change in F through time as a smoother with 7 degrees of freedom. The catchability submodel (qmod) was only related to the Medias index (since 2009), because the stock assessment diagnostics were worse when the Ecomed index was included. It was considered that catchability at a specific age to be dependent on catchability on the other ages. Finally, the stock-recruitment submodel used a smooth model with 6 degrees of freedom (Table 5.1.1.9).

Table 5.1.1.9. Submodels setting of the the sca method

fmod= ~s(replace(age, age>2,2), k=3)+s(year,k=7)
qmod=list(~s(age,k=4))
srmod=~s(year,k=6)
fit <-   sca(stk, medias, fmodel=fmod,qmodel=qmod,srmodel=srmod)

The stock assessment of sardine GSA 06 produced low residuals (most of them below 1.5) and did not show trend for most of ages (excluding catch number of age 3) (Fig. 5.1.1.3). The fitted and observed catch-at-age were comparable for most of years, showing worse fit in the last two years (2016 and 2017) (Fig. 5.1.1.4). The fitted and observed index at age was good for most of years, excluding 2013 and 2014 where the fitted number at age zero was lower and higher, respectively (Fig. 5.1.1.5). Fishing mortality was a little high for age 1 from 2012 to 2016, meaning that Fbar (0-2) could be slightly affected (Fig. 5.1.1.6). Simulation of submodel settings produce low uncertainty (Fig. 5.1.1.7) and retrospective analysis showed, in general, good consistence when one or more years were excluded of the analysis (Fig. 5.1.1.8). Accordingly, fishing mortality is tending to decrease since 2014 but the stock size did not indicate a clear recovery yet.

Fig. 5.1.1.3. Log residuals of catch and abundance indices obtained in the stock assessment of the sardine in GSA 06.

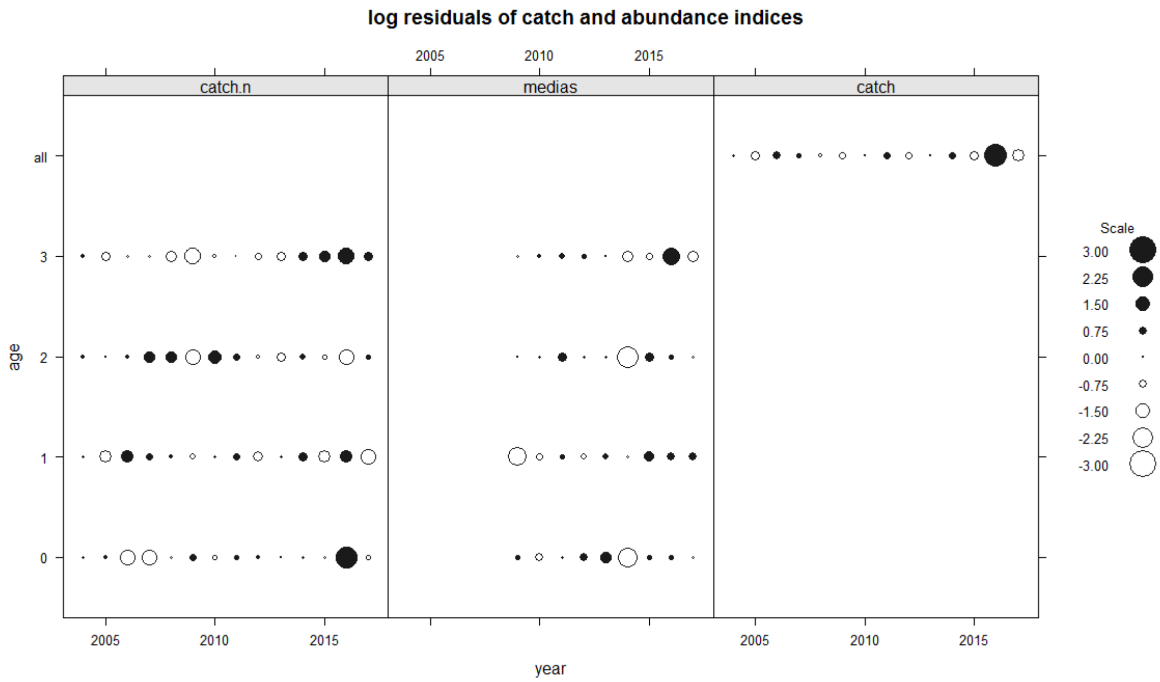


Fig. 5.1.1.4. Fitted and observed catch-at-age obtained in the stock assessment of the sardine in GSA 06.

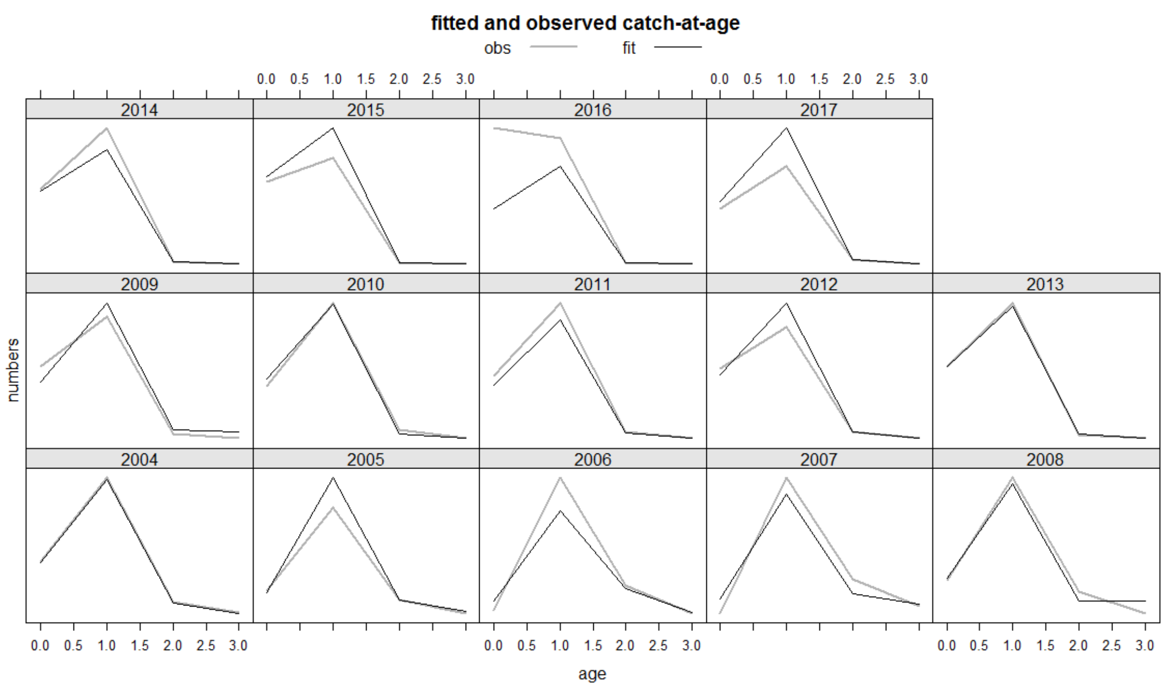


Fig. 5.1.1.5. Fitted and observed index at age obtained in the stock assessment of the sardine in GSA 06.

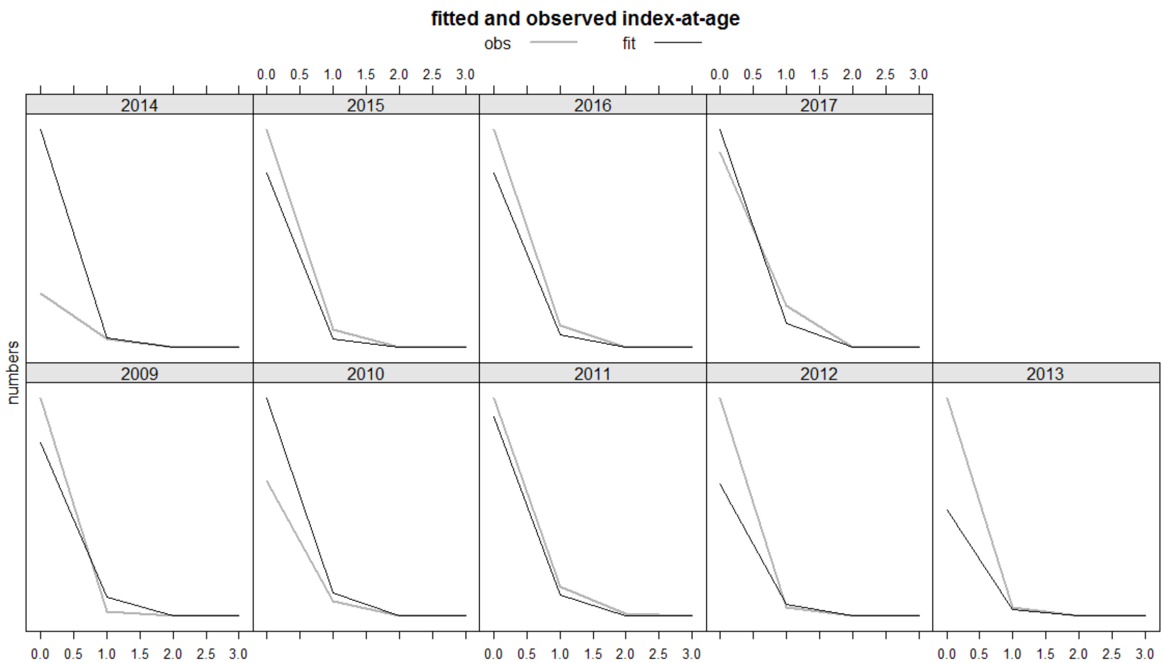


Fig. 5.1.1.6. Fishing mortality at age and year obtained in the stock assessment of the sardine in GSA 06.

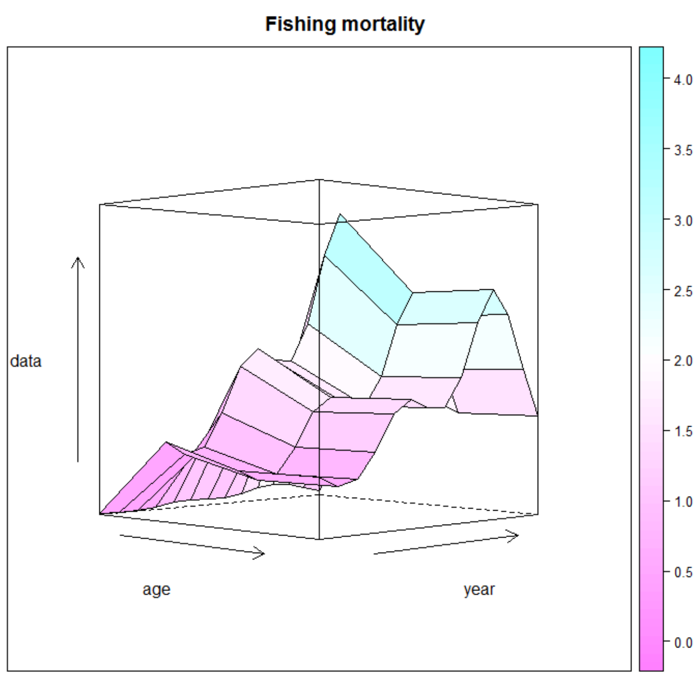


Fig. 5.1.1.7. Simulation of the fitted object that holds the stock assessment results of sardine in GSA 06.

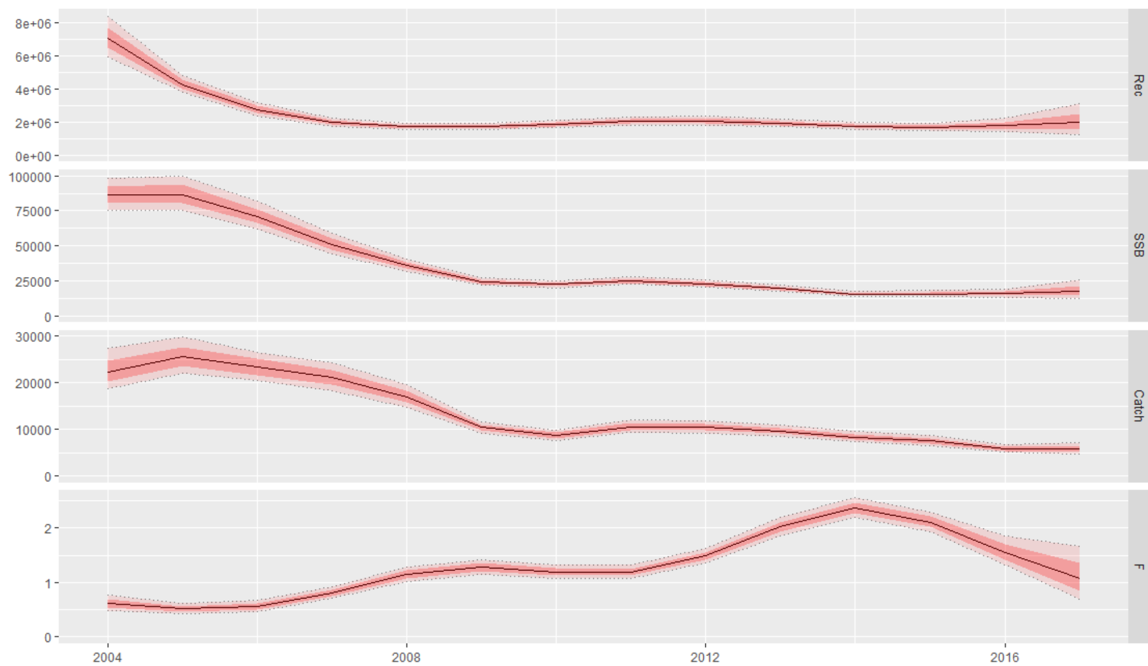
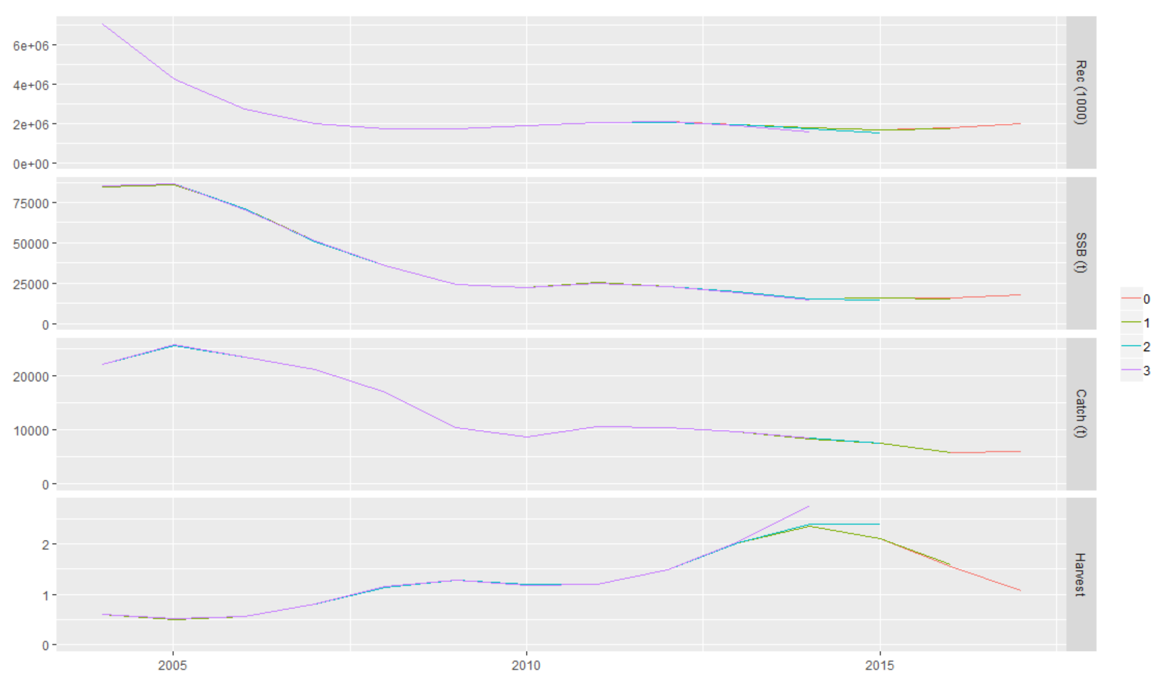


Fig. 5.1.1.8. Retrospective analysis of the stock assessment results of sardine in GSA 06 when the last three, two or one years are omitted of the analysis.



5.1.1.1.3 Reference points

To estimate Blim (ICES, 2017) for sardine in GSA 06, was used a segmented regression stock recruitment relationship (

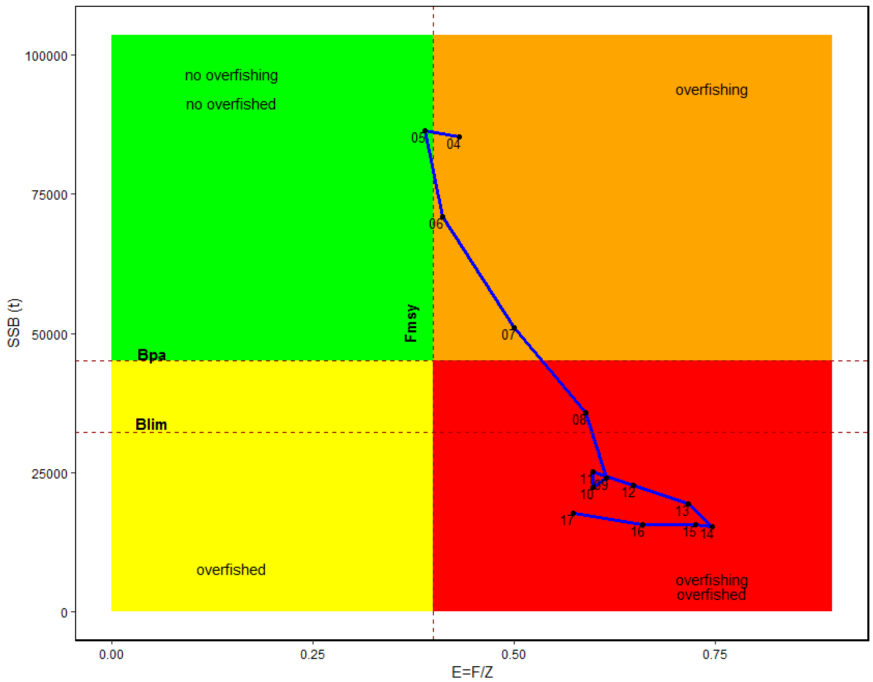
Fig. 5.1.1.9). Blim was used to estimate Bpa. $Bpa = Blim * \exp(1.645 * \sigma)$, where σ was set equal to 0.2 (ICES, 2013). Thus, Bpa was estimated as 45087 tons. Fmsy was calculated as that value of fishing motality that produces an exploitation rate (E=F/Z) equal to 0.4.

Fig. 5.1.1.9. Segmented regression performed with the R package msy ("ices-tools-prod/msy") used to estimate Blim of the sardine in GSA 06.

5.1.1.1.4 Kobe plot

The stock of sardine in GSA 06 is highly overexploited (SSB below Blim) and overfishing is occurring since 2006 (Fig. 5.1.1.10). From 2014 to 2017, the fishing mortality is decreasing but at levels that do not promote that overfishing stops nor the stock size overcome Bpa.

Fig. 5.1.1.10. Kobe plot for the sardine stock in GSA 06 using Blim, Bpa and E of Patterson as reference points.



5.1.1.1.5 Summary

		Bpa								Fmsy
		45087								0.4
Year	recruits	ssb	f0	f1	f2	f3	harvest (f0-2)	Observed catch	model catch	E
2004	7086048	85186	0.07	1.02	0.74	0.74	0.61	22833	22115	0.43
2005	4284187	86317	0.06	0.85	0.62	0.62	0.51	20983	25562	0.39
2006	2751795	70915	0.06	0.93	0.67	0.67	0.56	27145	23384	0.41
2007	2000424	50934	0.09	1.34	0.97	0.97	0.80	22911	21090	0.50
2008	1712954	35752	0.13	1.92	1.39	1.39	1.14	16186	16922	0.59
2009	1712055	24127	0.15	2.14	1.55	1.55	1.28	8997	10392	0.62
2010	1873697	22275	0.14	1.99	1.44	1.44	1.19	8762	8703	0.60
2011	2046478	25108	0.14	1.99	1.44	1.44	1.19	12135	10595	0.60
2012	2075532	22672	0.17	2.47	1.79	1.79	1.48	9193	10434	0.65
2013	1937377	19407	0.23	3.37	2.44	2.44	2.02	9734	9717	0.72
2014	1762062	15291	0.27	3.95	2.86	2.86	2.36	9659	8426	0.75
2015	1689668	15610	0.24	3.53	2.55	2.55	2.11	6309	7565	0.72
2016	1778298	15687	0.18	2.60	1.88	1.88	1.55	9934	5860	0.66
2017	2000143	17728	0.12	1.80	1.30	1.30	1.07	4590	5912	0.57

5.1.1.2 Sardine GSA 07

5.1.1.2.1 Input data

The length structure of the sardine harvested by the purse seine fleet in GSA 07 included individuals from 6 cm to 21 cm. Most of the caught individuals were between 14 and 17 cm. Before 2009, from 14.5 cm to 17 cm were the most harvested sizes. Since 2010, individuals from 12 cm to 14 cm were the most represented sizes in landings. (Table 5.1.1.10). The catch-at-length number derived from the DCF in 2012 included negative values. Additionally, the catch-at-length number in 2013 indicated very high values compared to previous and late years. Therefore, the DCF included doubt data of sardine in GSA 06.

Table 5.1.1.10. Length structure of the stock of sardine harvested by the purse seine fleet in GSA 07. Number of individuals by length represent the total catch each year. Source: DCF. Length is expressed in centimeters.

Length (cm)	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
6								69							
7								43			-3				
8								284			222				
9			192	167				754			372				
10	352		871	354		122	2199	1561	1263		372	58118		136	83
11	1920	171	2153	804			8776	1918	4188		833	1369855	519	700	
12	6190	2746	6551	4692	881	839	4059	20320	18312		3350	6747354	11124	1965	12245
13	8402	10875	15614	21159	5348	1967	5040	35887	31043		15184	12181506	14061	3378	
14	34252	46759	81589	68371	18966	10492	10427	44502	19695		10877	7879356	4835	696	7059
15	91824	58719	92433	110237	84965	81996	49492	71222	10946		1245	1893406	1208	60	
16	91027	45853	43096	66555	114602	137946	83803	74031	4355		531	262155	250	6	260
17	41942	15444	14392	18209	44089	105700	48022	38444	1330		59				
18	9140	3360	3317	2553	10124	33010	12055	7717	61		5				
19	1491	503	537	587	971	4817	2531	875			1				
20				80	260	639	79	254							
21						172									

Length structure observed in the PELMED surveys (2004-2009) included individuals from 5 cm to 21 cm. The length structure varied among years (Table 5.1.1.11). Since 2009, the length structure observed indicated more abundance of smaller sizes (9 cm to 12 cm) (Table 5.1.1.12).

Table 5.1.1.11. Length structure of sardine recorded during the PELMED survey program in GSA 07. Number of individuals by length represent the total catch each year. Source: DCF. Length is expressed in centimeters.

Length	2002	2003	2004	2005	2006	2007	2008
5			2440				
6	6334		39038				
7	64696	6801	130623				6171
8	396392	133900	1079312	193993			277650
9	547851	770490	2488184	1746034	1911		2668251
10	579216	1028834	1136132	1540565	6203		3749864
11	320488	416162	38363	470468	20115	344	1350806
12	75917	149154	147585	375886	33229	3008	202780
13	178792	736227	1075895	1229300	29761		31977
14	841156	1375512	1959388	1736783	408524	25377	165726
15	879920	1193861	1755828	2022955	1310015	593202	469454
16	1166186	641353	1267866	2174909	874013	968976	392127
17	624990	299843	462160	759362	448954	684424	225892
18	138779	79559	129669	138145	99323	268260	63584
19	8840			57243	15659	60535	17807
20					3898	10583	892
21							265

Table 5.1.1.12. Length structure of sardine recorded during the PELMED survey program in GSA 07. Number of individuals by length represent the total catch each year. Source: DCF. Length is expressed in centimeters.

Length	2009	2010	2011	2012	2013	2014	2015	2016
5								
6				352				
7		116472	127897	30327			58083	41896
8	1589277	934920	182305	454969	330515	42166	623088	922134
9	3100078	3356134	1324413	2518439	1508309	239286	1385116	2877988
10	972702	2227156	1764843	2924410	1331572	834368	1235901	910040
11	583564	728508	1262712	1158300	3279511	2246835	1640894	1979202
12	805378	200100	563430	1293123	1166728	1570177	1690864	1093795
13	224881	334628	326363	823667	238294	498119	383542	249123
14	83201	115514	57125	153697	61873	151956	61666	44121
15	41013	11772	20482	7137	11060	25397	17322	3376
16	36387	37301	6733	4263		3657	1706	
17	90805			2153		219		
18	30714							
19	1805							
20								
21								

Given that raw data in otolith readings were not available to update the von Bertalanffy growth parameters of sardine in GSA 07, the available information of otoliths readings in GSA 06 was borrowed to estimate the vBGP that were later used to estimate catch-at-age number in GSA 07 by slicing. The data and process used to estimate the vBGP of sardine in GSA 06 are explained below. The Spanish Institute of Oceanography (IEO) has a large data set of otolith readings of sardine harvested by fisheries in GSA 06 since 2004 (n=12839). Additionally, there are some otolith readings of larvae of this species from 1983 to 2007. The otolith readings obtained through several research projects; ARECES in 1983 (n= 30), ARO in 2000 (n= 163), CAIMAN in 1996 (n=50), SAVOR in 2003 (n= 109), JUVALION in 2007 (n=29) and PELMED, (n=2007) were contributed by Dr. Isabel Palomera (Marine Science Institute of Barcelona, ICM-CSIC). Additionally, Dr. Alberto Garcia of the IEO Malaga contributed 193 otolith readings of sardine obtained in 2000. All these sources of information on growth were used to update the estimates of the von Bertalanffy growth parameters of sardine. In order to merge the available information on growth, only those otolith readings derived from fisheries for the spawning peak of sardine were used (December-February, n=2111). The updated estimates of the von Bertalanffy growth parameters were calculated by the Bayesian Von Bertalanffy Growth Model - B-VBGM (Catalan, 2018) (Table 5.1.1.13).

Table 5.1.1.13. von Bertalanffy growth parameters estimated by the B-VBGM - Bayesian Von Bertalanffy Growth Model (Catalan et al., 2018) as indicated in the deliverable 1.3.1.1. The vBGP were estimated using otolith readings from GSA6, and borrowed to slice data of GSA 07.

Linf	K	t0	n	period	method
20.1	0.817	-0.246	3336	1983-2003 (larvae) 2005-2017 (adults)	Bayesian analysis

The deliverable 1.3.2.1 (Report on gonadosomatic index, size at firs maturity and reproductive parameters) explored and updated the percentage of mature individuals at age. This information was used to set the maturity vector of the sardine stock (Table 5.1.1.14). The fecundity of the species has presumably decreased because individuals are smaller than before 2010, the percentage of maturity at age zero was precautionary set in 0.5.

Table 5.1.1.14. Maturity vector used to set the maturity-at-age of sardine in GSA 07.

Age	0	1	2	3
Maturity	0.5	1	1	1

The natural mortality used in recent stock assessment of sardine by GFCM or STECF working groups is based on Gislason's first equation, among other reasons, because it produces an M-at-age vector with values around 1. However, this vector is produced when the vBGP has a very negative t0 (< -1.5). The updated vBGP obtained in this study to sardine in GSA 06 and borrowed to sardine in GSA 07 has a t0 near zero (> -0.3). Consequently, the Gislason's estimator produces M-at-age for the most fished ages (0 and 1) with too high values (between 1 and 4.5) (see deliverable D.1.4.1), resulting in the stock being perceived as slightly overexploited or even underexploited.

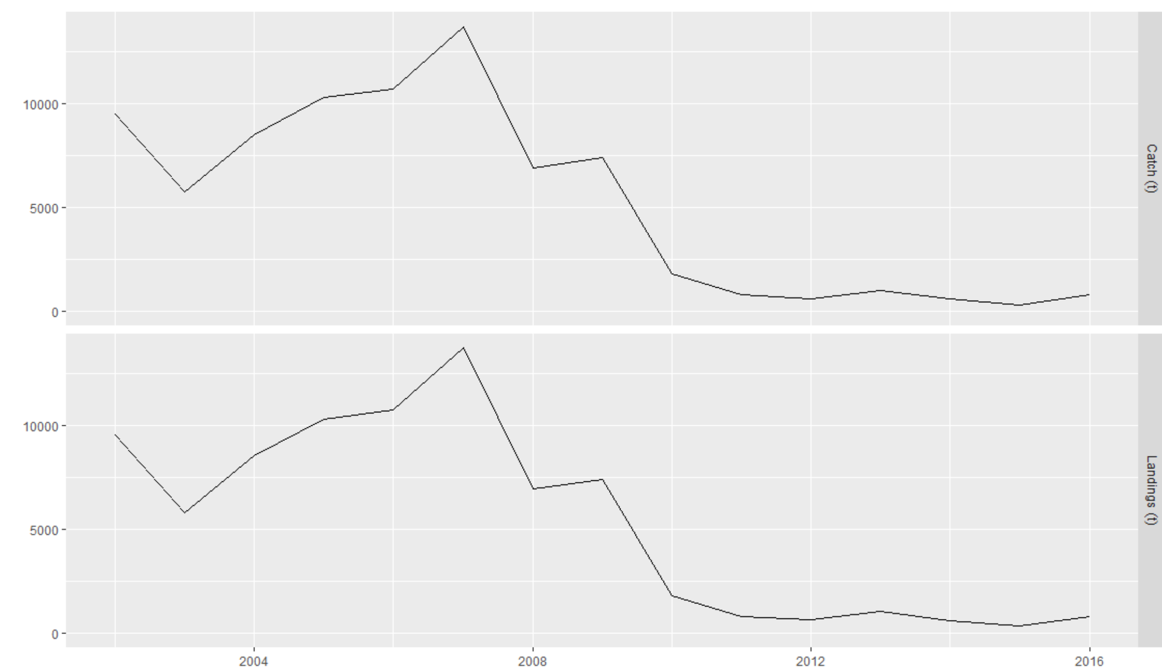
The updated vBGP of sardine meets the biology rationale of a short-lived species, growing fast during the first year to follow a very low increase of size-at-age after this point. Thus, the t0 near zero makes sense to this species. In order to avoid too high values of M for younger individuals, it was preferred to use the Prodbiom estimator of natural mortality (Abella et al., 1997) (Table 5.1.1.15). This estimator relies on the fact that losses of biomass associated to natural mortality are compensated by production (growth). Therefore, this estimator may be reasonable used to estimate the M of species where there is indication of changes of mortality with age, as small pelagic species.

Table 5.1.1.15. Natural mortality at age (M-at-age) of sardine in GSA 07 estimated by Prodbiom

Age	0	1	2	3
M	1.18	0.72	0.5	0.42

The reported catches of sardine in GSA 07 have decreased since 2002. The highest value was reported in 2007 (13713 tons) and the lowest catch was obtained in 2015 (321 tons) (Table 5.1.1.16). These results mean that catches of sardine in recent years (after 2009) represent 9% of catches of early years of the time series (before 2009). Due to there is not reliable temporal information of discards and values are absent or very low for most of the available period of catches, the discards were assumed as zero.

Table 5.1.1.16. Catches of sardine in GSA 06. Discards are assumed as zero tons, meaning that catches correspond to the reported landings.



Weight at age used to estimate the total catches at age of sardine in GSA 07. Data was obtained from the Data call framework DCF (Table 5.1.1.17).

Table 5.1.1.17. Weight at age of sardine in GSA 07. Data obtained from the Spanish Institute of Oceanography

Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0	0.013	0.014	0.015	0.015	0.015	0.014	0.013	0.012	0.011	0.011	0.009	0.011	0.012	0.011
1	0.021	0.022	0.025	0.024	0.023	0.019	0.019	0.023	0.018	0.015	0.015	0.015	0.012	0.014
2	0.031	0.032	0.032	0.033	0.04	0.035	0.032	0.032	0.032	0.022	0.022	0.022	0.019	0.02
3	0.041	0.042	0.041	0.045	0.05	0.05	0.053	0.051	0.046	0.028	0.031	0.039	0.024	0.032
4	0.056	0.051	0.051	0.05	0.057	0.06	0.064	0.059	0.055	0.031	0.051	0.051	0.049	0.05
5	0.073	0.06	0.067	0.068	0.079	0.079	0.078	0.064	0.078	0.078	0.078	0.078	0.078	0.078

The fishery of sardine in GSA 07 mainly harvest individuals of ages 1 and 2, while those individuals of ages zero and three are scarce represented (Fig. 5.1.1.11). Lower representation of individuals of age 1 in recent years (after 2011) was not compensated by higher abundances in age two.

Fig. 5.1.1.11. Number at age of sardine individuals in GSA 07 after slicing using the updated vBGP above shown. Plus group has been set for age 3.

5.1.1.2.2 Stock assessment

The sardine stock was assessed using different source of data as explained in the Fig. 4.1.2.1. The catch-at-age matrix obtained from ALK per year (and *M* estimated by Gislason) suggested that the recent *F* is as low as that observed in early years (~0.5). However, it is striking to observe that despite the fishing mortality being very low since 2002 the size of the stock has not recovered. These low values of *F* also may be affected by higher values of *M* for ages 1-3 when the Gislason's estimator is used to estimate natural mortality. The catch-at-age matrix obtained from the updated vBGP (and stock assessment uses *M* estimated by Prodbiom) produce higher *F* in recent years in comparison with early years (Fig. 5.1.1.12). High *F* led to very low size of the stock, while larger stock was observed when *F* was below 1.0 (before 2007). Additionally, better diagnostics for the stock assessment model were found when slicing than ALK were used to define the catch-at-age matrix used to model the stock.

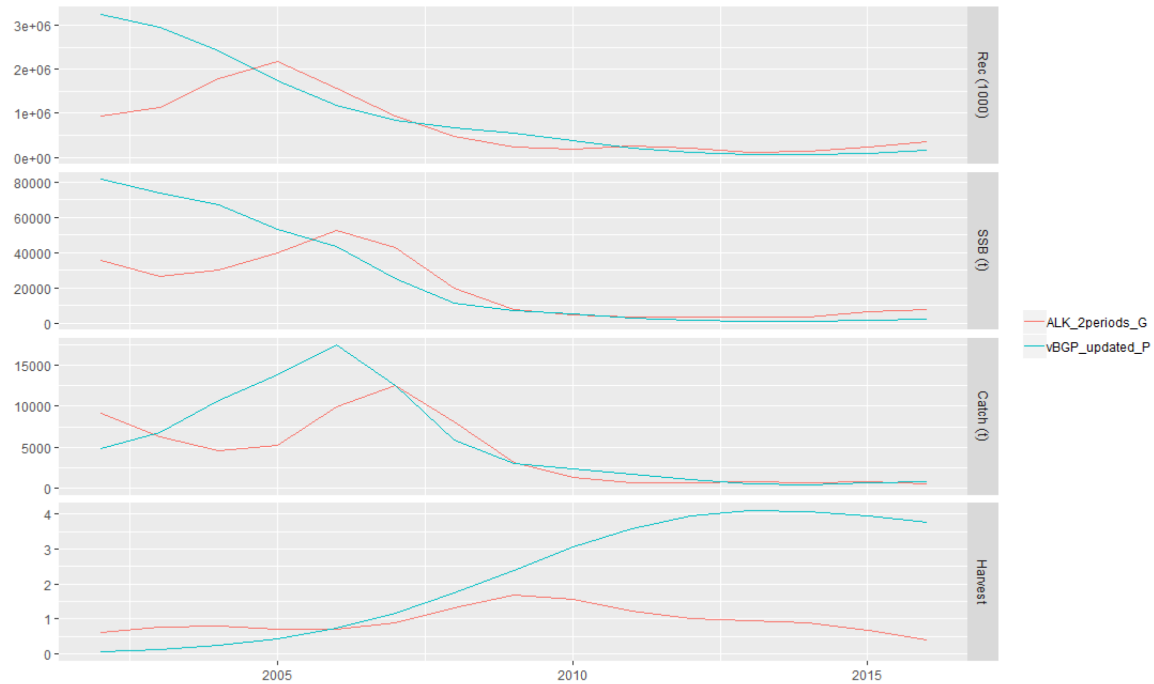


Fig. 5.1.1.12. Results of the stock assessment when catch-at-age matrix was obtained from ALK data per period (2004-2010 and 2011-2017) and sliced using the updated vBGP. The stock assessment based on ALK and slicing used M estimated by Gislason and Prodbiom, respectively.

The stock assessment model set the fishing mortality submodel (fmodel) using a separable model in which age and year effects are modelled as (unpenalised) thin plate spline (Table 5.1.1.18). It was assumed that ages older than two hold the same F than age two because the gear is capable to entirely select all ages older than this age. We model the change in F through time as a smoother with 3 degrees of freedom. The catchability submodel (qmod) was only related to the Medias index (since 2009), because the stock assessment diagnostics were worse when the Ecomed index was included. It was considered that catchability at a specific age to be dependent on catchability on the other ages. Finally, the stock-recruitment submodel used a smooth model with 6 degrees of freedom (Table 5.1.1.18).

Table 5.1.1.18. Submodels setting of the the sca method

fmod= ~s(replace(age, age>2,2), k=3)+s(year,k=3)
qmod=list(~s(age,k=3))
srmod=~s(year,k=6)
fit <- sca(stk, medias, fmodel=fmod,qmodel=qmod,srmodel=srmod)

The stock assessment of sardine GSA 07 produced low residuals (most of them below 1.5) but did show some residual trends for all ages (Fig. 5.1.1.13). The fitted and observed catch-at-age were not comparable for all years, suggesting that catch-at-age number varied a lot among years (Fig. 5.1.1.15). The fitted and observed index at age were also more or less comparable depending on the year. Better fits were found since 2013 (Fig. 5.1.1.16). Since 2010, fishing mortality was too high, meaning that Fbar (0-2) could be overestimated (Fig. 5.1.1.16). Simulation of submodel settings produce a higher uncertainty than observed in GSA 06 (Fig. 5.1.1.17) but retrospective analysis showed good consistence when one or more years were excluded of the analysis (Fig. 5.1.1.18). Accordingly, fishing mortality is increasing since 2002 and the stock size is very low.

Fig. 5.1.1.13. Log residuals of catch and abundance indices obtained in the stock assessment of the sardine in GSA 07.

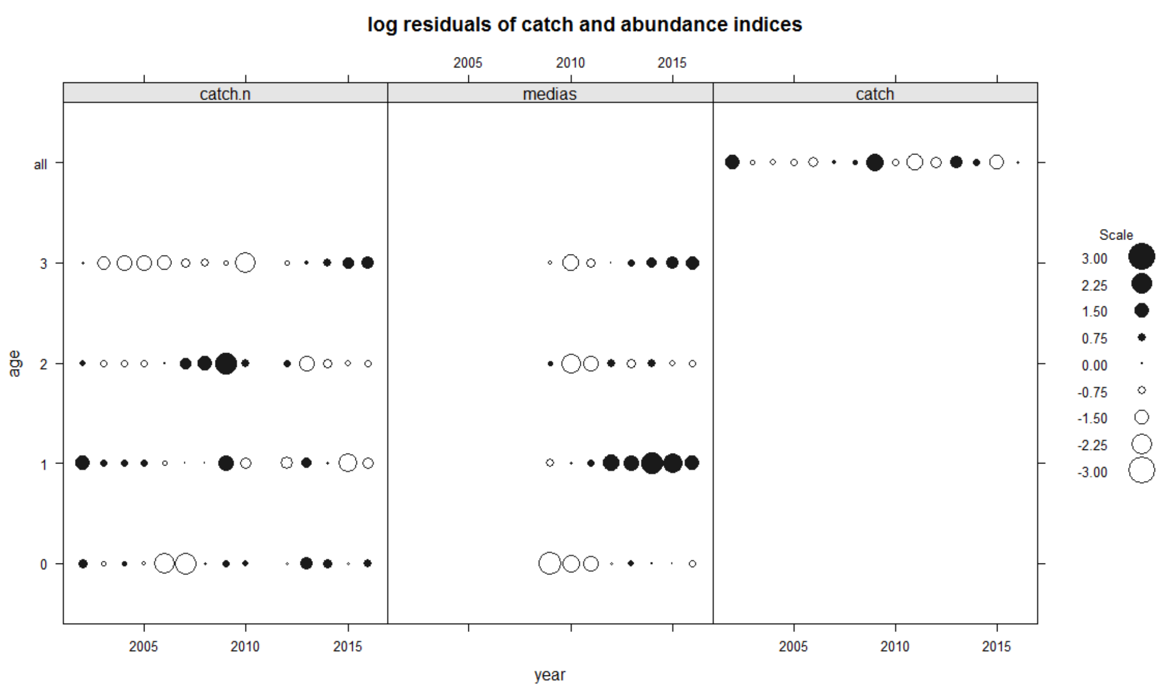


Fig. 5.1.1.14. Fitted and observed catch-at-age obtained in the stock assessment of the sardine in GSA 07.

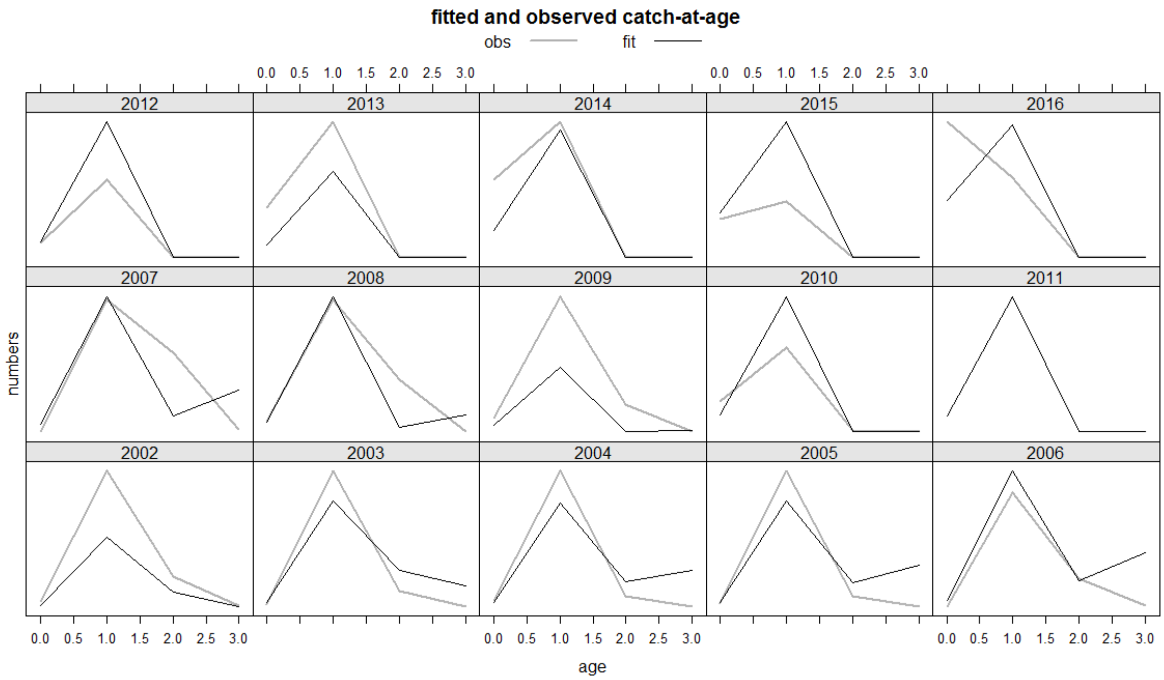


Fig. 5.1.1.15. Fitted and observed index at age obtained in the stock assessment of the sardine in GSA 07.

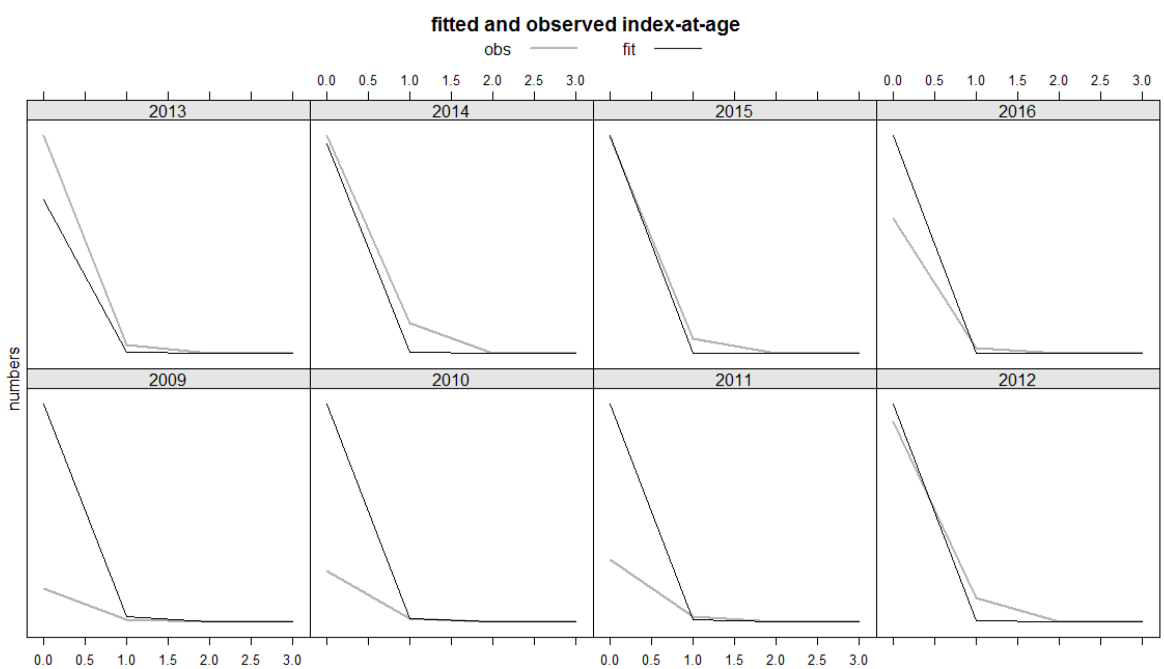


Fig. 5.1.1.16. Fishing mortality at age and year obtained in the stock assessment of the sardine in GSA 07.

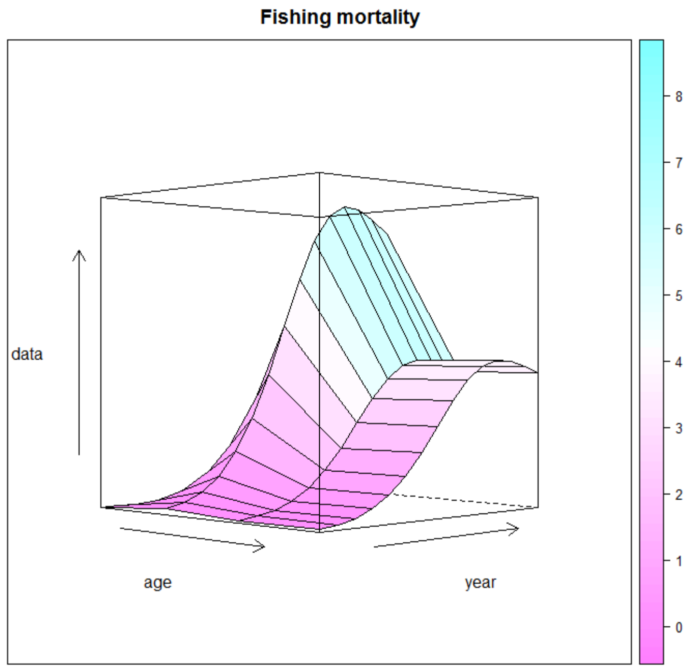


Fig. 5.1.1.17. Simulation of the fitted object that holds the stock assessment results of sardine in GSA 07.

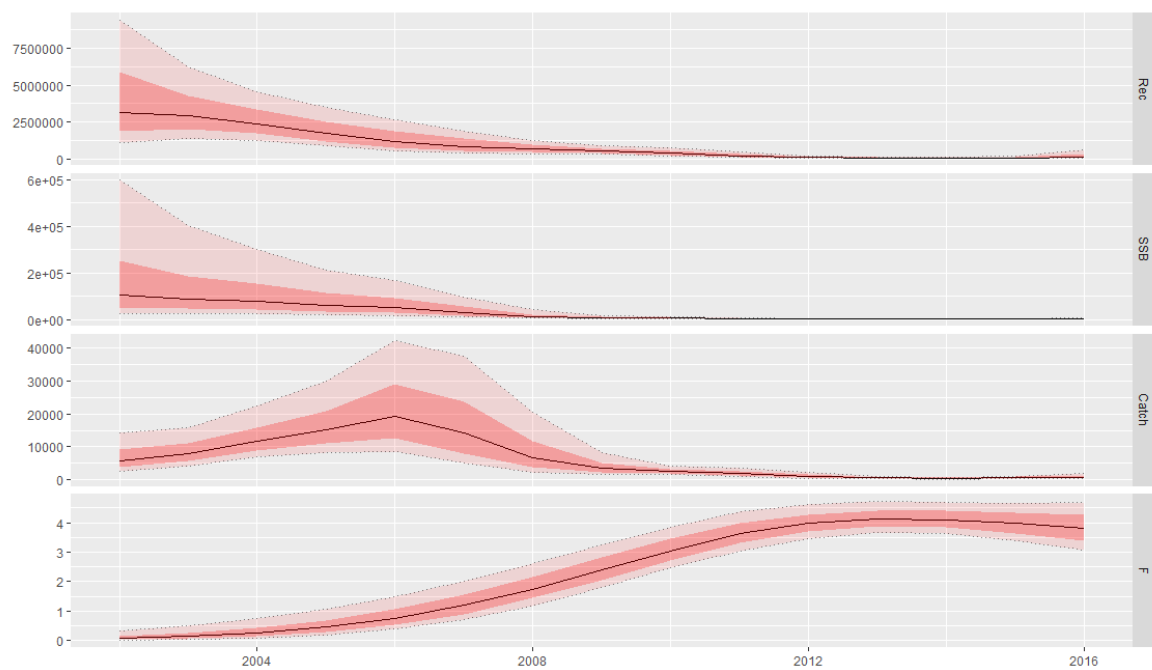
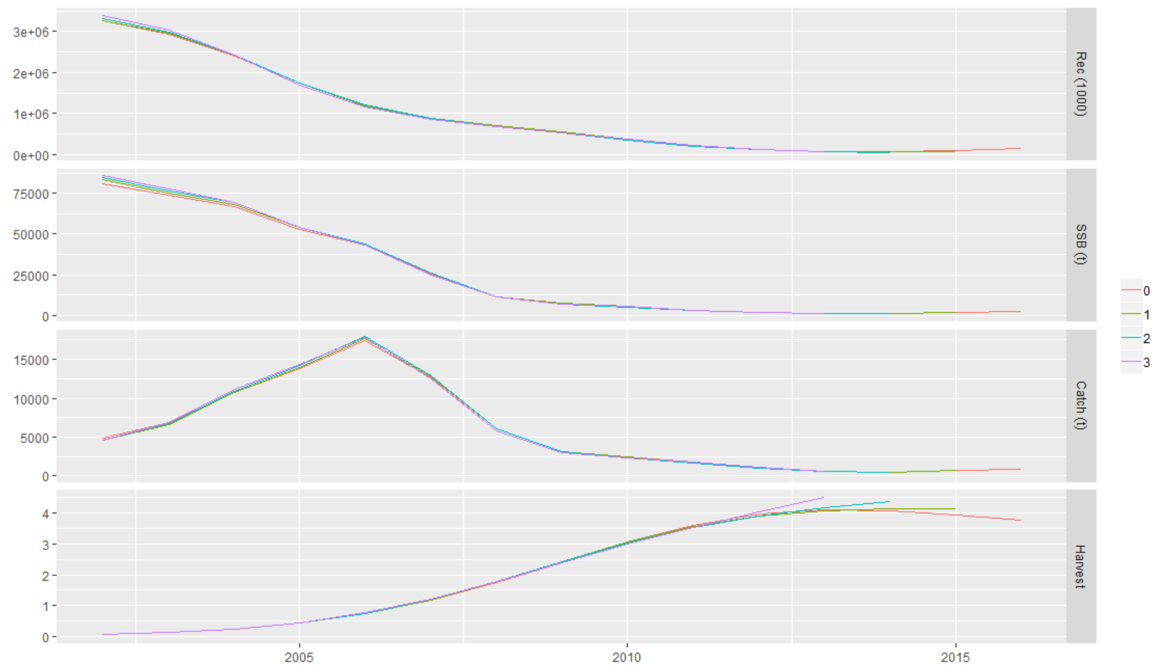


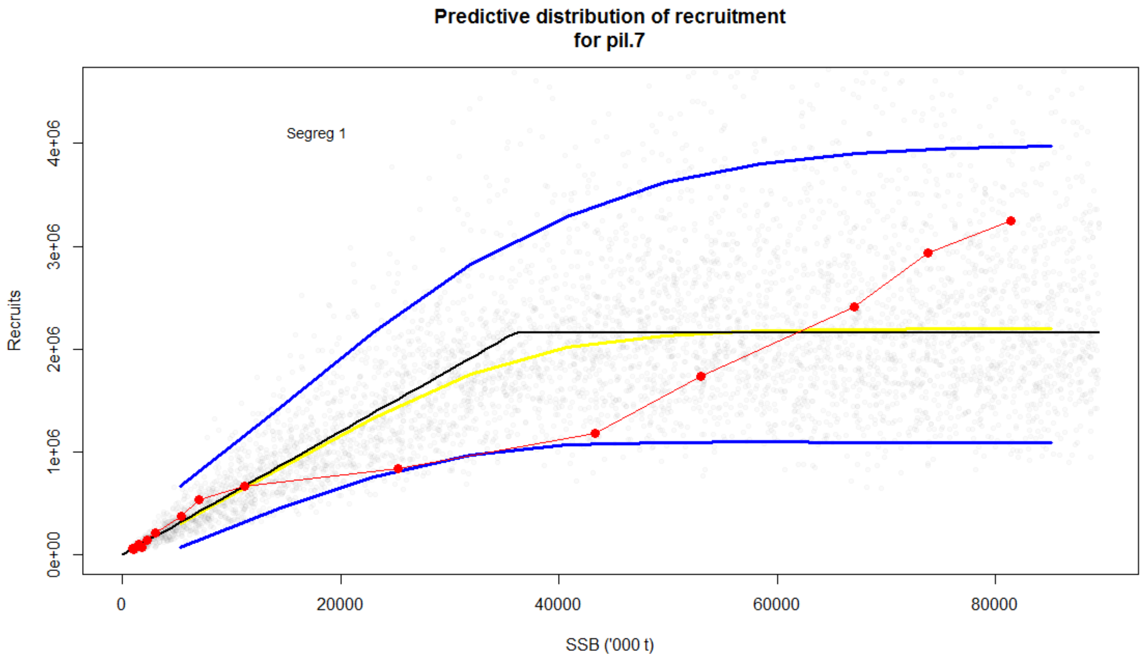
Fig. 5.1.1.18. Retrospective analysis of the stock assessment results of sardine in GSA 07 when the last three, two or one years are omitted of the analysis.



5.1.1.2.3 Reference points

To estimate Blim (ICES, 2017) for sardine in GSA 07, was used a segmented regression stock recruitment relationship (Fig. 5.1.1.19). Blim was used to estimate Bpa. $Bpa = Blim * \exp(1.645 * \sigma)$, where σ was set equal to 0.2 (ICES, 2013). Thus, Bpa was estimated as 50448 tons. Fmsy was calculated as that value of fishing motality that produces an exploitation rate (E=F/Z) equal to 0.4.

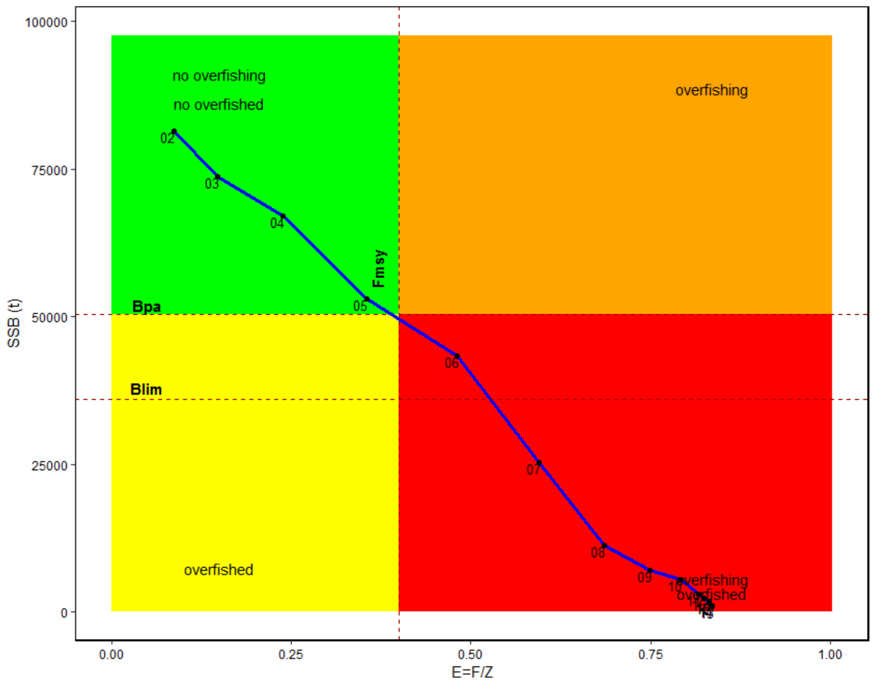
Fig. 5.1.1.19. Segmented regression performed with the R package msy ("ices-tools-prod/msy") used to estimate Blim of the sardine in GSA 07.



5.1.1.2.4 Kobe plot

The stock of sardine in GSA 07 is highly overexploited (SSB below Blim) and overfishing is occurring since 2006 (Fig. 5.1.1.20). Remember that diagnostics of the stock assessment model were poor and fishing mortality was probably estimated above the current values. However, the kobe plot may be used to obtain information on the general trend of the stock size and fishing mortality. The stock looks in very bad condition while there are no signals of stock size recovery.

Fig. 5.1.1.20. Kobe plot for the sardine stock in GSA 07 using Blim, Bpa and E of Patterson as reference points.



5.1.1.2.5 Summary

		Bpa								Fmsy
		50448								0.4
Year	recruits	ssb	f0	f1	f2	f3	harvest (f0-2)	Observed catch	model catch	E
2002	3252812	81364	0.00	0.15	0.07	0.07	0.08	9535	4810	0.09
2003	2938515	73759	0.00	0.28	0.13	0.13	0.14	5788	6823	0.15
2004	2412689	67048	0.01	0.51	0.24	0.24	0.25	8541	10772	0.24
2005	1738665	52993	0.01	0.89	0.42	0.42	0.44	10306	13800	0.36
2006	1178894	43324	0.02	1.50	0.71	0.71	0.74	10737	17435	0.48
2007	844705	25231	0.03	2.37	1.13	1.13	1.18	13739	12555	0.60
2008	670217	11171	0.05	3.52	1.67	1.67	1.75	6934	5838	0.69
2009	541192	7020	0.06	4.84	2.29	2.29	2.40	7418	3058	0.75
2010	380961	5418	0.08	6.14	2.91	2.91	3.05	1826	2402	0.79
2011	215819	3025	0.10	7.23	3.43	3.43	3.59	819	NA	0.82
2012	109351	1527	0.11	7.95	3.77	3.77	3.94	642	1095	0.83
2013	64438	927	0.11	8.25	3.91	3.91	4.09	1036	596	0.84
2014	56933	1052	0.11	8.20	3.89	3.89	4.07	633	468	0.84
2015	80169	1798.4	0.11	7.93	3.76	3.76	3.93	348	690	0.83
2016	150568	2321	0.10	7.58	3.60	3.60	3.76	820	796	0.82

5.1.1.3 Sardine GSA 06 and GSA 07

5.1.1.3.1 Input data

The length structure of the sardine harvested by the purse seine fleet in GSA 06 included individuals from 5.5 cm to 23 cm. Most of the caught individuals were between 11 and 17 cm. The differences between length structures that were already observed in single GSA were also present when both GSAs were combined. Then, smaller individuals were caught since 2010 (Table 5.1.1.19).

Table 5.1.1.19. Length structure of the stock of sardine harvested by the mid water trawl and purse seine fleets in GSA 06 and 07. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography and DCF. Length is expressed in centimeters.

Length	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
5.5	0	0	0	0	0	0	0	0	40	0	0	0	0
6	0	0	0	0	0	69	0	0	63	0	0	0	69
6.5	48	0	0	0	0	0	0	0	70	0	0	0	0
7	145	0	0	0	0	43	0	0	64	0	0	0	43
7.5	145	0	0	0	0	0	0	308	41	0	0	0	0
8	918	0	0	0	0	284	0	619	280	0	0	8	346
8.5	2088	0	0	0	0	0	152	1089	142	26	158	275	1242
9	3602	190	84	0	1	957	163	336	897	373	951	679	2785
9.5	4959	1877	332	94	256	754	876	664	2446	966	3245	2741	5832
10	9258	8488	1811	399	2619	3511	3445	3212	6725	62311	7205	6618	19375
10.5	10122	17600	6105	364	6478	6359	6804	11310	12554	10642	11142	12401	24512
11	25221	20654	7001	1272	16574	18588	14480	27919	23536	1391431	22557	16611	55146
11.5	41405	21916	8099	5281	25145	35129	20728	41227	34092	36113	27330	27776	61747
12	70706	28364	10613	16363	40250	69029	46711	46988	51438	6791308	59316	46836	162416
12.5	67895	29173	9494	21964	35352	54077	33686	48892	46697	57003	65163	52839	93057
13	89396	65853	20776	28838	44021	91651	66272	58853	67996	12246571	93931	62638	226479
13.5	64128	51030	22913	22895	37182	52425	37803	69060	46892	66418	68759	55036	72027
14	151760	140741	63011	39939	43461	98734	58884	78180	55562	7935512	68801	41766	396803
14.5	76589	78297	68155	44078	47646	41752	35199	62759	34784	44171	48187	24239	37759
15	182354	194368	187165	148211	110514	98689	45880	51231	34366	1932539	40135	15574	681769
15.5	77726	77684	118740	72193	55473	19483	36127	32509	26222	24306	19700	7646	13302
16	109229	137845	225458	213855	138490	88480	33112	23190	22310	282006	12500	5897	668830
16.5	49153	55279	95804	61314	45476	9120	16072	15472	15297	10930	4960	2363	2851
17	48366	60790	119008	161823	86682	45248	14030	12195	10748	6156	4052	1440	328693
17.5	17349	21909	40414	40718	26324	4668	5129	6577	4976	2428	1455	616	568
18	13993	13874	37951	70514	29070	11302	3344	4380	2444	1538	628	469	81514
18.5	6882	5295	14178	28558	12718	2566	1410	2033	1388	624	508	255	168
19	5603	3964	10110	24556	10237	2220	422	797	512	389	481	178	12423
19.5	2887	1046	4437	8161	4133	811	519	243	86	168	312	57	108
20	2224	737	2793	4534	2252	854	1063	181	54	98	86	34	1358
20.5	787	353	748	1371	608	311	548	39	10	11	0	4	1
21	536	172	252	702	79	156	340	11	16	4	126	3	175
21.5	232	38	290	17	25	66	99	10	9	0	0	0	0
22	60	36	55	36	1	18	29	2	0	0	0	0	0
22.5	18	13	13	4	0	0	11	0	0	0	0	0	0
23	0	0	0	0	0	0	2	0	0	0	0	0	0

Length structure observed in surveys carried out from 2004 to 2009 included individuals from 5 cm to 23 cm. However, the length structure varied along years (Table 5.1.1.20). Since 2009, the length structure observed by the surveys indicated more abundance of sizes from 8 cm to 11 cm (Table 5.1.1.21).

Table 5.1.1.20. Length structure of sardine recorded during the PELMED survey program in GSA 06 and 07. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography and DCF. Length is expressed in centimeters.

Length	2004	2005	2006	2007	2008
5	2440	0	0	0	0
5.5	0	0	0	0	0
6	39038	0	0	0	0
6.5	0	0	0	0	0
7	130623	0	0	0	6171
7.5	2451	0	0	0	0
8	1087555	194000	5762	0	277650
8.5	13642	1033	13405	0	0
9	2506434	1755451	27611	0	2668251
9.5	43401	23969	39530	0	0
10	1250031	1592408	81285	0	3757685
10.5	200870	97104	117856	1279	40872
11	300342	618297	188050	35601	1433272
11.5	348113	182156	115612	57566	116192
12	449756	682087	162025	101177	281888
12.5	224614	232014	111532	92233	40453
13	1213094	1449968	120054	103666	47602
13.5	94210	134238	74139	67951	18720
14	2066785	1863384	468746	55268	170664
14.5	82209	84547	52631	23603	1935
15	1830766	2100170	1373340	628838	471768
15.5	58299	64819	90365	29645	4017
16	1297164	2242416	975208	1002769	395406
16.5	19185	41725	100584	28715	6707
17	472845	803767	575329	712800	230103
17.5	8985	40228	109475	27294	6465
18	133677	162927	214371	289909	70187
18.5	4120	12034	82886	16311	6480
19	2137	63931	80570	71412	22820
19.5	3117	5758	30212	4392	2859
20	1747	1805	18276	13703	2390
20.5	1131	1078	7401	303	1214

21	442	632	4831	616	551
21.5	361	719	2658	120	14
22	41	855	2450	0	0
22.5	27	715	393	0	0
23	0	0	393	0	88

Table 5.1.1.21. Length structure of sardine recorded during the PELMED survey program in GSA 06 and 07. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography and DCF. Length is expressed in centimeters.

Length	2009	2010	2011	2012	2013	2014	2015	2016
5.5	0	0	0	0	0	0	306	0
6	3114	0	0	351.56	16888	0	1225	0
6.5	4566	0	494	2697	111974	1987	22041	55
7	7835	116472.28	132197.09	64551.23	224938	15311	140567.48	87427.87
7.5	21826	1208	2486	107978	458516	45223	171926	416603
8	1721339.32	965139.99	280076.51	789459.6	910037.63	132789.87	1078670.26	1709054.71
8.5	473956	104664	334018	831078	1325791	112807	417192	621466
9	3692211.72	3687469.12	1974715.2	3707052.01	2701677.48	373368.05	1825129.93	3123682.42
9.5	790704	440721	675764	1297455	833785	86200	346366	282825
10	1622742.2	2576938.93	2590704.6	3689586.05	1931333.59	882281.47	1651374.44	1153001.91
10.5	443750	360829	534244	478037	519886	26480	410440	253265
11	888082	914103.58	1594857.34	1476284.52	3575553.63	2258997.5	1999493.4	2183110.63
11.5	136442	108167	154664	120876	131640	10752	112541	227774
12	846864.22	227022.61	671658.2	1422237.02	1223504	1622515.39	1732110.32	1292689.95
12.5	19144	26603	71032	120532	39950	47868	103424	143284
13	229282.23	352662.68	395424.37	900271.91	322606.39	545105.52	471318.55	368862.77
13.5	9606	35897	69319	33725	72667	25070	89090	78051
14	98029.89	154709.38	144694.57	188494.57	106696.97	169259.49	101954.08	103016.24
14.5	11219	46057	66482	24568	17637	6094	25814	47363
15	52747.5	38214.94	88387.36	25580.42	25407.54	32941.46	35480.95	39632.29
15.5	7665	25609	42767	10873	17832	2195	9835	18339
16	43130.06	49039.77	68689.23	12418.64	8190	3857.04	5931.71	3776
16.5	3626	6311	36623	4908	461	154	1794	2308
17	92985.25	2729	15935	4813.27	1643	219.27	808	1230
17.5	1836	611	11756	703	86	0	67	0
18	31103.29	986	1851	612	0	0	1692	0
18.5	275	155	170	0	0	0	0	547
19	2004.97	0	249	0	0	0	0	0
19.5	38	0	0	0	0	0	0	0
20	0	0	58	0	61	0	0	0
20.5	38	0	0	293	0	0	0	0
21	0	348	0	0	0	0	0	0

Given that raw data in otolith readings were not available to update the von Bertalanffy growth parameters of sardine in GSA 07, the available information of otoliths readings in GSA 06 was borrowed to estimate the vBGP that were later used to estimate catch-at-age number by slicing in GSA 06 and 07 combined. The data and process used to estimate the vBGP of sardine in GSA 06 are below explained. The Spanish Institute of Oceanography (IEO) has a large data set of otolith readings of sardine in GSA 06 harvested by fisheries since 2004 (n=12839). Additionally, there are some otolith readings of larvae of this species from 1983 to 2007. The otolith readings obtained through several research projects; ARECES in 1983 (n= 30), ARO in 2000 (n= 163), CAIMAN in 1996 (n=50), SAVOR in 2003 (n= 109), JUVALION in 2007 (n=29) and PELMED, (n=2007) were contributed by Dr. Isabel Palomera from the Marine Science Institute of Barcelona (ICM-CSIC). Additionally, Dr. Alberto Garcia of the IEO Malaga contributed 193 otolith readings of sardine obtained in 2000. All these sources of information on growth were used to update the estimates of the von Bertalanffy growth parameters of sardine. In order to merge the available information on growth, only those otolith readings derived from fisheries for the spawning peak of sardine were used (December-February, n=2111). The updated estimates of the von Bertalanffy growth parameters were calculated by the Bayesian Von Bertalanffy Growth Model - B-VBGM (Catalan, 2018) (Table 5.1.1.22).

Table 5.1.1.22. von Bertalanffy growth parameters estimated by the B-VBGM - Bayesian Von Bertalanffy Growth Model (Catalan et al., 2018) as indicated in the deliverable 1.3.1.1. The vBGP were estimated using otolith readings from GSA6.

Linf	K	t0	n	period	method
20.1	0.817	-0.246	3336	1983-2003 (larvae) 2005-2017 (adults)	Bayesian analysis

The deliverable 1.3.2.1 (Report on gonadosomatic index, size at first maturity and reproductive parameters) explored and updated the percentage of mature individuals at age. This information was used to set the maturity vector of the sardine stock (Table 5.1.1.23). The fecundity of the species has presumably decreased because individuals are smaller than before 2010, the percentage of maturity at age zero was precautionary set in 0.5.

Table 5.1.1.23. Maturity vector used to set the maturity-at-age of sardine in GSA 06 07.

Age	0	1	2	3
Maturity	0.5	1	1	1

The natural mortality used in recent stock assessment of sardine by GFCM or STECF working groups is based on Gislason's first equation, among other reasons, because it produces an M-at-age vector with values around 1. However, this vector is produced when the vBGP has a very negative t0 (< -1.5). The updated vBGP obtained in this study to sardine in GSA 06 and borrowed to sardine in GSA 06 and GSA 07 combined has a t0 near zero (> -0.3). Consequently, the Gislason's estimator produces M-at-age for the most fished ages (0 and 1) with too high values (between 4.5 and 1) (see deliverable D.1.4.1), resulting in the stock being perceived as slightly overexploited or even underexploited.

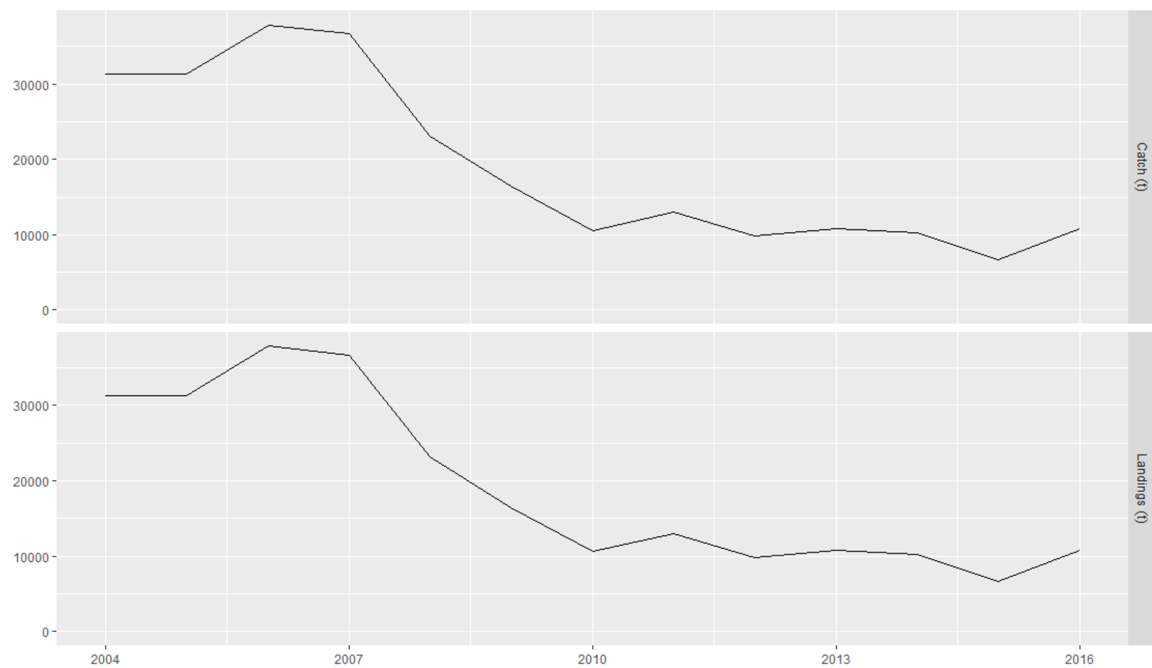
The updated vBGP of sardine meets the biology rationale of a short-lived species, growing fast during the first year to follow a very low increase of size-at-age after this point. Thus, the t0 near zero makes sense to this species. In order to avoid too high values of M for younger individuals, it was preferred to use the Prodbiom estimator of natural mortality (Abella et al., 1997) (Table 5.1.1.24). This estimator relies on the fact that losses of biomass associated to natural mortality are compensated by production (growth). Therefore, this estimator may be reasonable used to estimate the M of species where there is indications of changes of mortality with age, as small pelagic species.

Table 5.1.1.24. Natural mortality at age (M-at-age) of sardine in GSA 06 and 07estimated by Prodbiom

Age	0	1	2	3
M	1.18	0.72	0.5	0.42

The reported catches of sardine in GSA 06 and 07 combined have decreased since 2002 (Table 5.1.1.25). The highest value was reported in 2006 (38528 tons) and the lowest catch was obtained in 2015 (6771 tons). These results mean that catches of sardine in recent years (after 2009) represent 39% of catches of early years of the time series (before 2009). Due to there is not reliable temporal information of discards and values are absent or very low for most of the available period of catches, the discards were assumed as zero.

Table 5.1.1.25. Catches of sardine in GSA 06 and 07. Discards are assumed as zero tons, meaning that catches correspond to the reported landings.



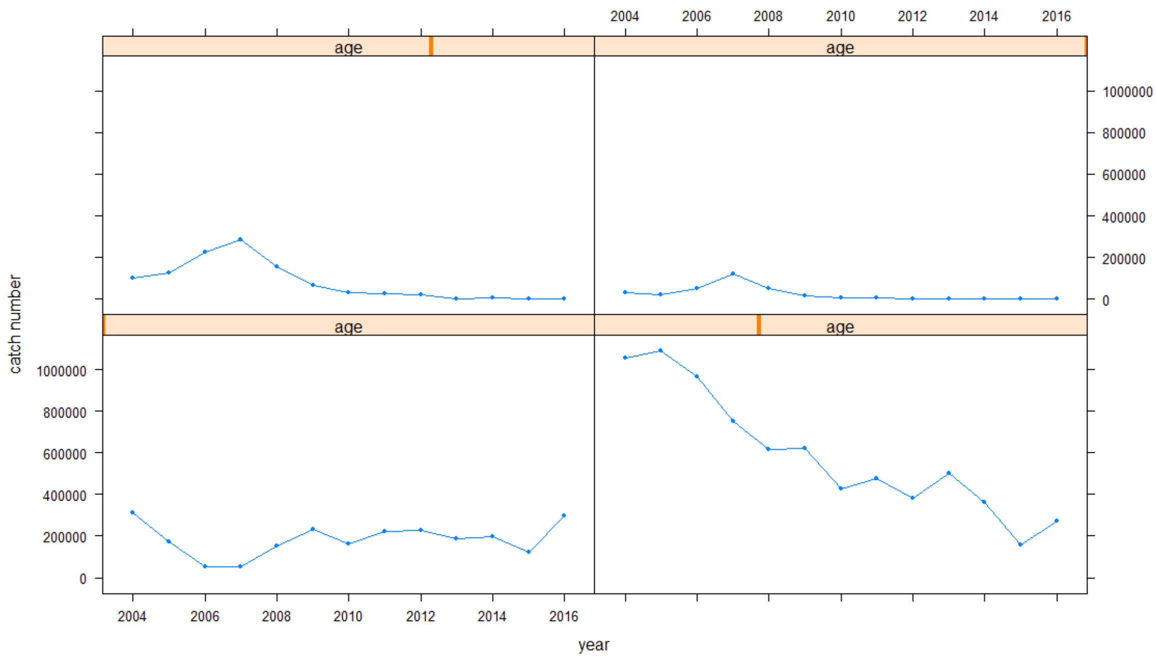
Weight at age used to estimate the total catches at age of sardine in GSA 06 and GSA 07 as combined stocks. Data was obtained as average of the weight at age by year in GSA 06 and GSA 07 (Table 5.1.1.26).

Table 5.1.1.26. Weight at age of sardine in GSA 06 and 07. Data obtained from the Spanish Institute of Oceanography

Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0	0.0145	0.015	0.0155	0.0155	0.0135	0.014	0.0145	0.0115	0.009	0.0105	0.0155	0.0205	0.017
1	0.0215	0.022	0.028	0.0275	0.022	0.017	0.017	0.02	0.0185	0.0175	0.0195	0.0265	0.021
2	0.0295	0.0305	0.0345	0.035	0.0345	0.0275	0.0255	0.026	0.0265	0.021	0.0235	0.035	0.0305
3	0.0365	0.0375	0.04	0.042	0.0415	0.039	0.038	0.037	0.035	0.024	0.0295	0.0445	0.0345
4	0.0455	0.043	0.0465	0.0435	0.046	0.0465	0.0465	0.0445	0.0425	0.0305	0.0395	0.0535	0.0495

The fishery of sardine in GSA 06 and GSA 07 as combined stocks mainly harvest individuals of ages 0 and 1, while those individuals of ages two and three are only represented before 2009 (Fig. 5.1.1.21). Lower representation of individuals of age 1 in recent years (after 2010) was not compensated by higher abundances in age 2.

Fig. 5.1.1.21. Number at age of sardine individuals in GSA 06 and 07 after slicing using the updated vBGP above shown. Plus group has been set for age 3.



5.1.1.3.2 Stock assessment

The sardine combined stocks (GSA 06 and GSA 07) were assessed using different source of data as explained in the Fig. 4.1.2.1. The catch-at-age matrix obtained from ALK per periods (2004-2010 and 2011-2016) (and *M* estimated by Gislason) suggested that the recent *F* is as low as observed in early years (~0.5). However, it looks little feasible that despite since 2004 the fishing mortality is very low the size of the stock has been not recovered. The catch-at-age matrix obtained from the updated vBGP (and stock assessment uses *M* estimated by Prodbiom) produced higher *F* in recent years in comparison with early years (Fig. 5.1.1.22). Both catch-at-age source showed comparable trends in *R* and *SSB*, as well as indicated equally low values of *F* until 2009. Since, 2014, the *F* indicated by the stock assessment based on slicing suggests that fishing mortality is declining but it remains too high. This result for both stocks combined seems to describe an unsustainable fishery and very low stock size. Better diagnostics for the stock assessment model were found when slicing than ALK were used to define the catch-at-age matrix used to model the stock.

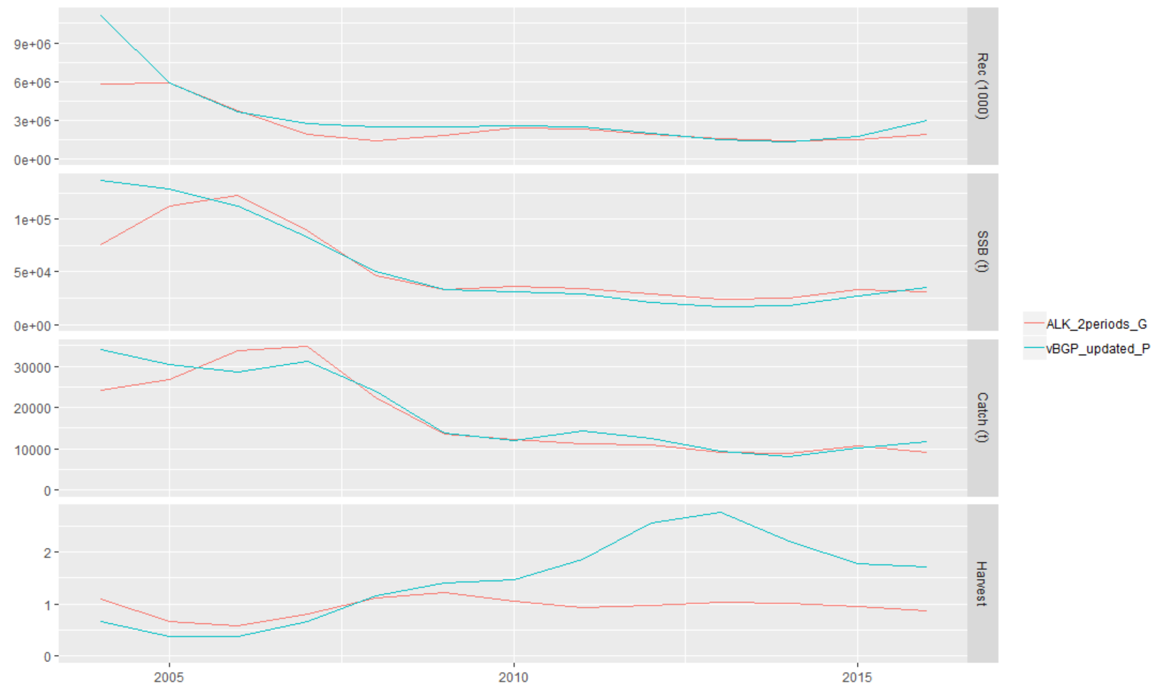


Fig. 5.1.1.22. Results of the stock assessment of the sardine GSA 06 and GSA 07 combined stocks when catch-at-age matrix was obtained from ALK data per period (2004-2010 and 2011-2017) and sliced using the updated vBGP. The stock assessment based on ALK and slicing used M estimated by Gislason and Prodbiom, respectively.

The stock assessment model set the fishing mortality submodel (fmodel) using a separable model in which age and year effects are modelled as (unpenalised) thin plate spline (Table 5.1.1.27). It was assumed that ages older than two hold the same F than age two because the gear is capable to entirely select all ages older than this age. We model the change in F through time as a smoother with 7 degrees of freedom. The catchability submodel (qmod) was only related to the Medias index (since 2009), because the stock assessment diagnostics were worse when the Ecomed index was included. It was considered that catchability at a specific age to be dependent on catchability on the other ages. Finally, the stock-recruitment submodel used a smooth model with 7 degrees of freedom (Table 5.1.1.27).

Table 5.1.1.27. Submodels setting of the the sca method

fmod= ~s(replace(age, age>2,2), k=3)+s(year,k=7)
qmod=list(~s(age,k=4))
srmod=~s(year,k=7)
fit <-   sca(stk, medias, fmodel=fmod,qmodel=qmod,srmodel=srmod)

The stock assessment of sardine GSA 06 and GSA 07 as combined stocks produced low residuals (most of them below 1.5) and did not show trend for most of ages (excluding catch number of age 3) (Fig. 5.1.1.23). The fitted and observed catch-at-age were comparable for most of years. However, given that fishery data of GSA 07 showed worse diagnostics when was modeled as isolated stock, more years (2006, 2007, 2012, 2014, 2015 and 2016) showed worse fit (Fig. 5.1.1.24). Conversely, the fitted and observed index at age was better for most of years than when single stocks were considered (Fig. 5.1.1.25). Fishing mortality was a little high for age 1 during 2012 and 2013, meaning that Fbar (0-2) could be slightly affected (Fig. 5.1.1.26). Simulation of submodel settings produce a reasonable uncertainty for the stock size indicators but harvesting in the last two years was high (Fig. 5.1.1.27). Retrospective analysis showed, in general, good consistence in stock size indicators when one or more years were excluded of the analysis (Fig. 5.1.1.28). However, the fishing mortality trend changed when one or more years were excluded. Accordingly, fishing mortality is tending to decrease since 2014 but the level at which is declining not clear enough.

Fig. 5.1.1.23. Log residuals of catch and abundance indices obtained in the stock assessment of the sardine in GSA 06 and 07.

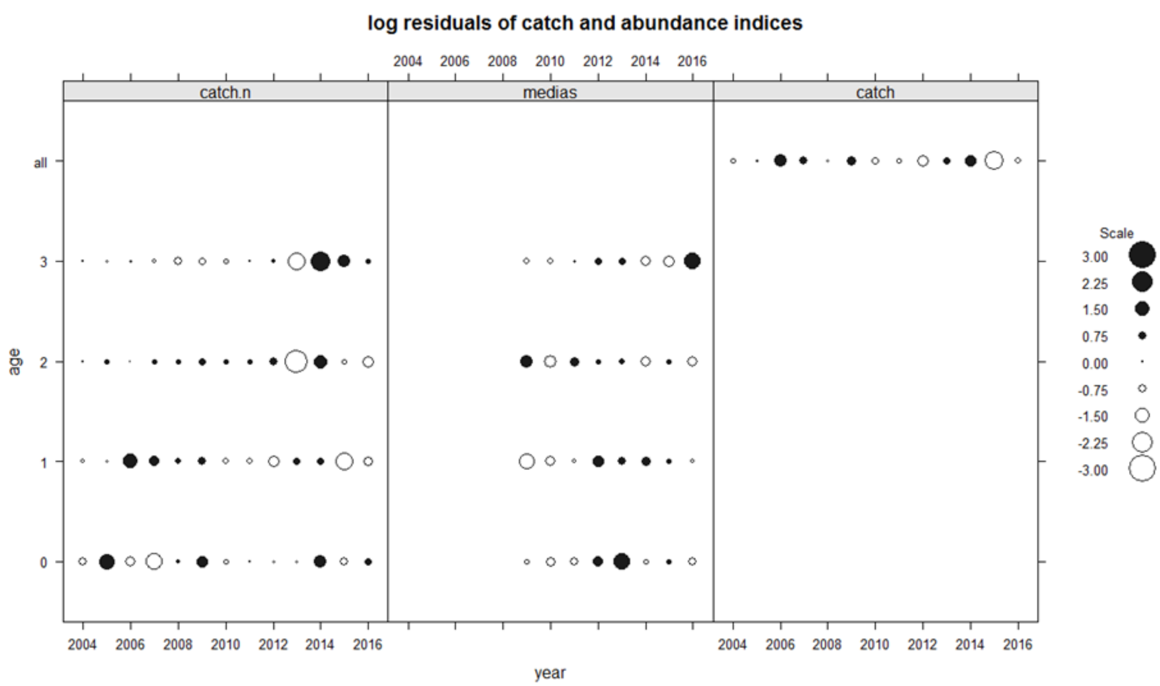


Fig. 5.1.1.24. Fitted and observed catch-at-age obtained in the stock assessment of the sardine in GSA 06 and 07.

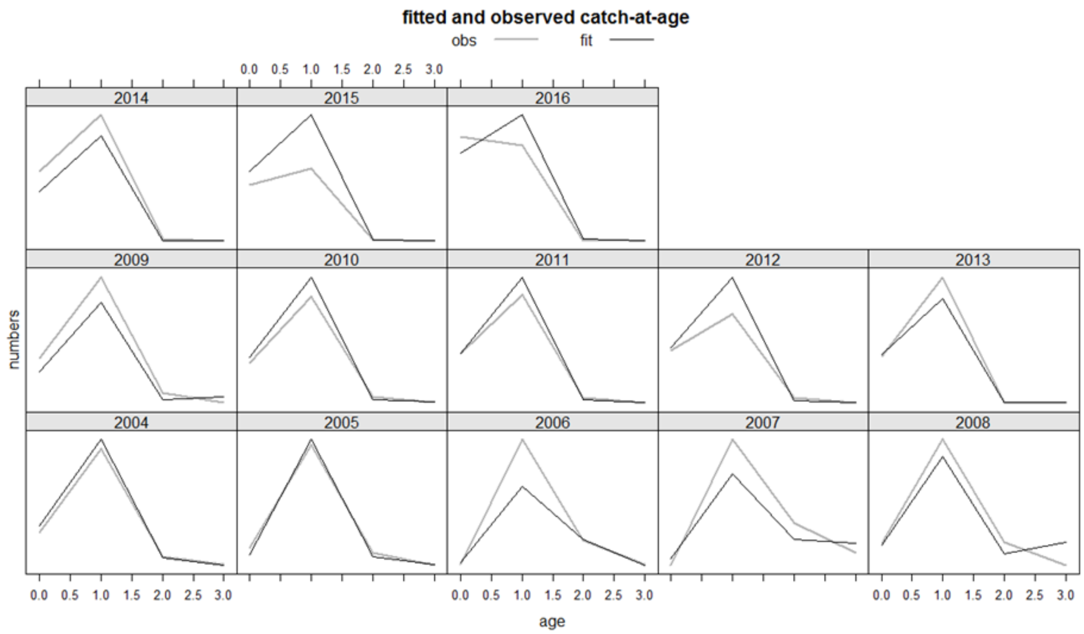


Fig. 5.1.1.25. Fitted and observed index at age obtained in the stock assessment of the sardine in GSA 06 and 07.

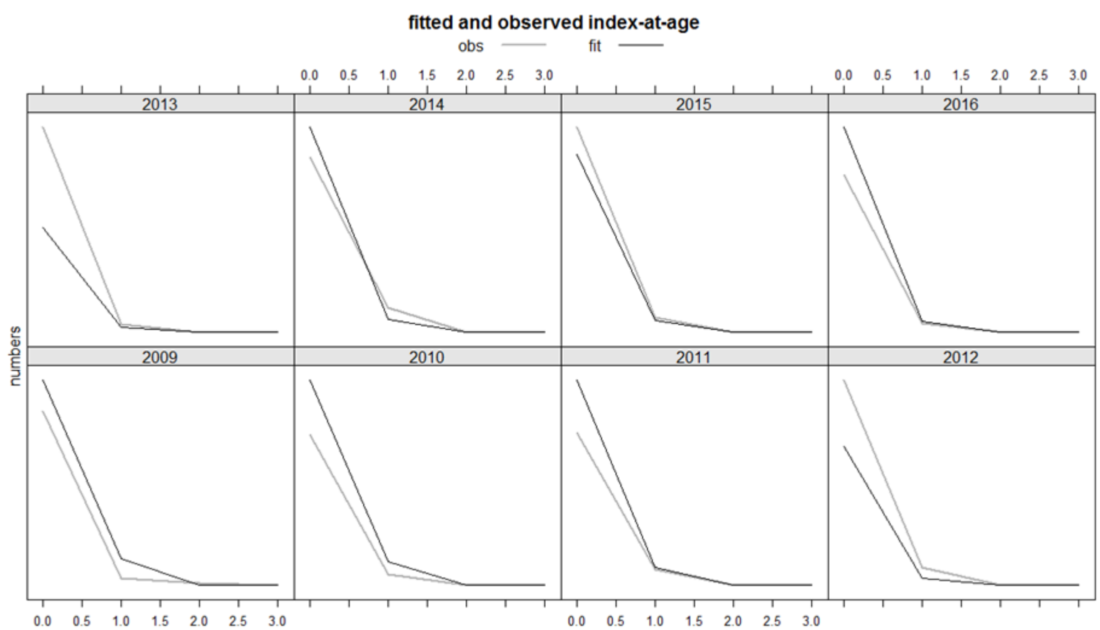


Fig. 5.1.1.26. Fishing mortality at age and year obtained in the stock assessment of the sardine in GSA 06 and 07.

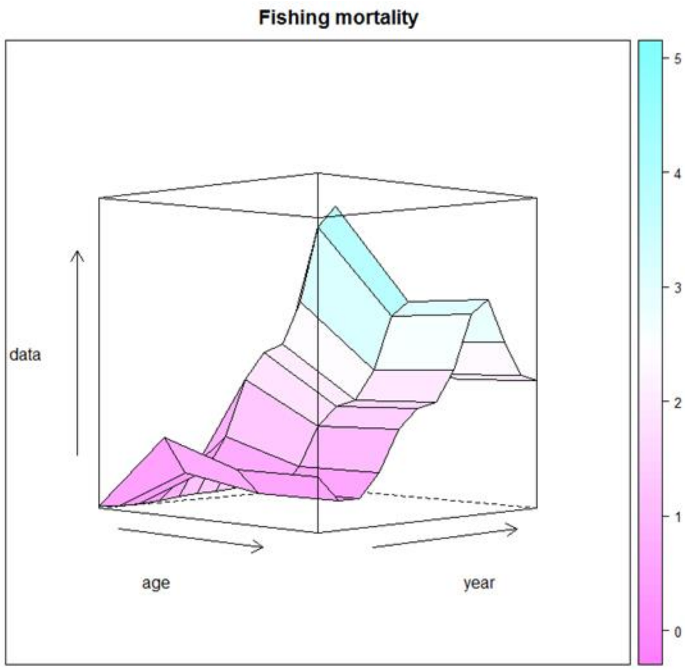


Fig. 5.1.1.27. Simulation of the fitted object that holds the stock assessment results of sardine in GSA 06 and 07.

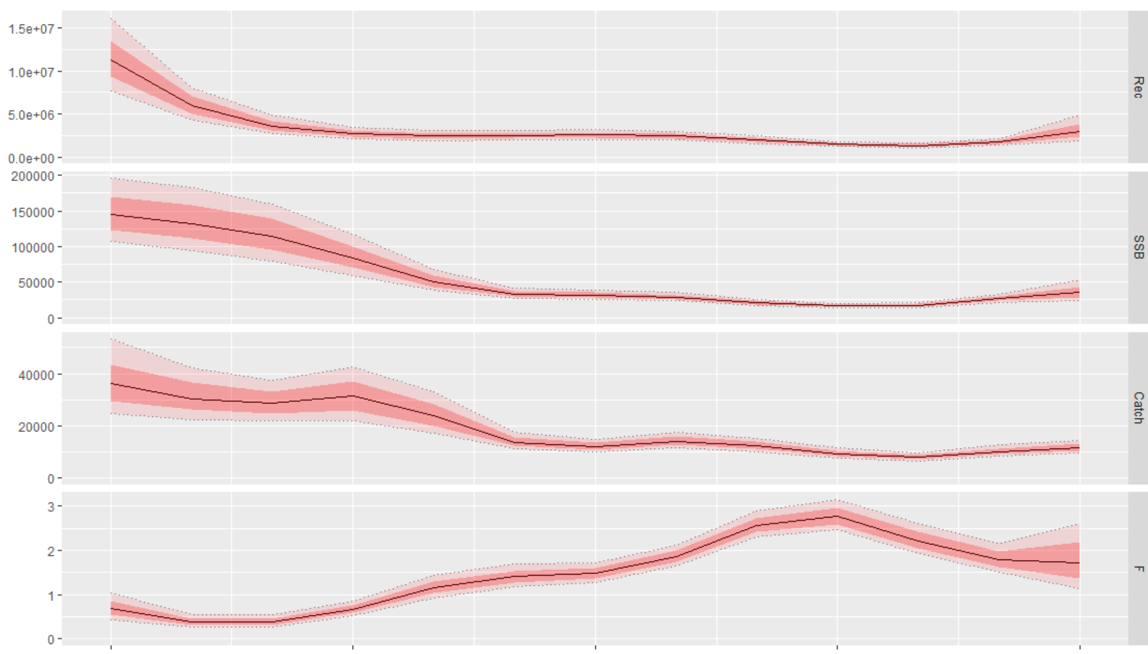
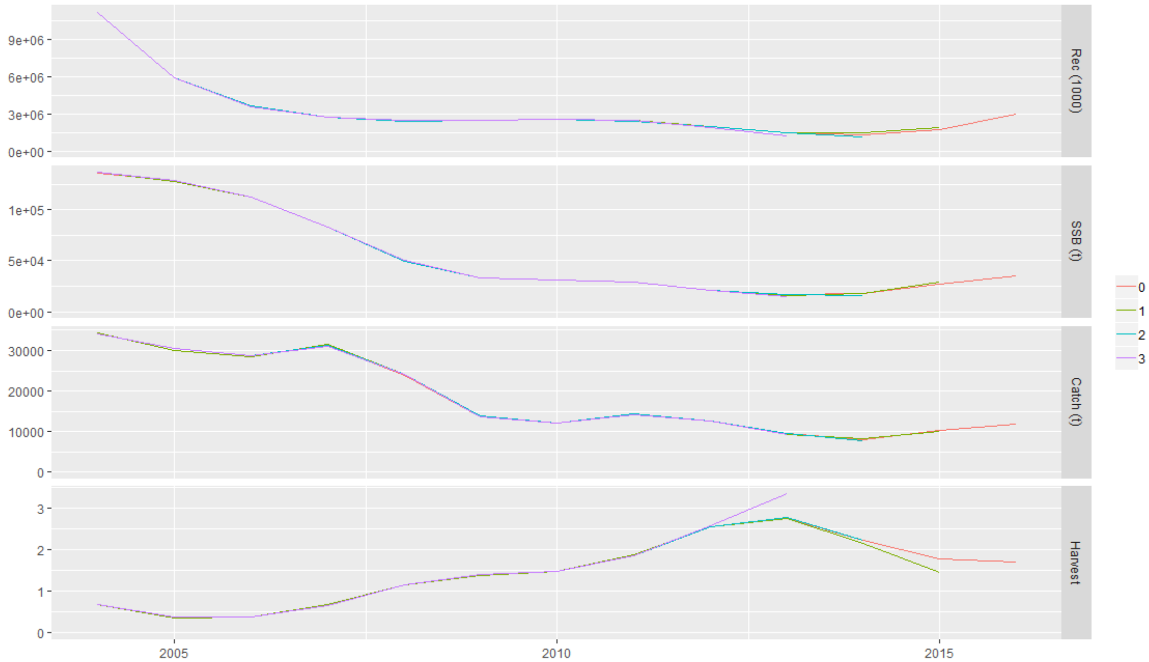


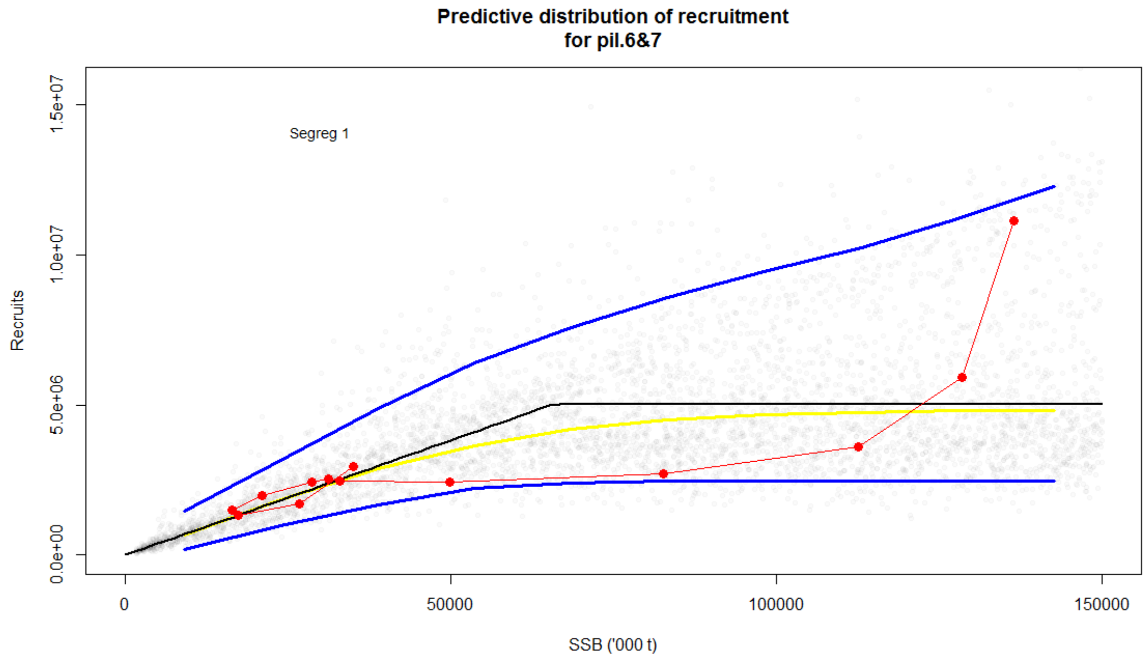
Fig. 5.1.1.28. Retrospective analysis of the stock assessment results of sardine in GSA 06 and 07 when the last three, two or one years are omitted of the analysis.



5.1.1.3.3 Reference points

To estimate Blim (ICES, 2017) for sardine in GSA 07, was used a segmented regression stock recruitment relationship (Fig. 5.1.1.29). Blim was used to estimate Bpa. $Bpa = Blim * \exp(1.645 * \sigma)$, where σ was set equal to 0.2 (ICES, 2013). Thus, Bpa was estimated as 92070 tons. Fmsy was calculated as that value of fishing mortality that produces an exploitation rate (E=F/Z) equal to 0.4.

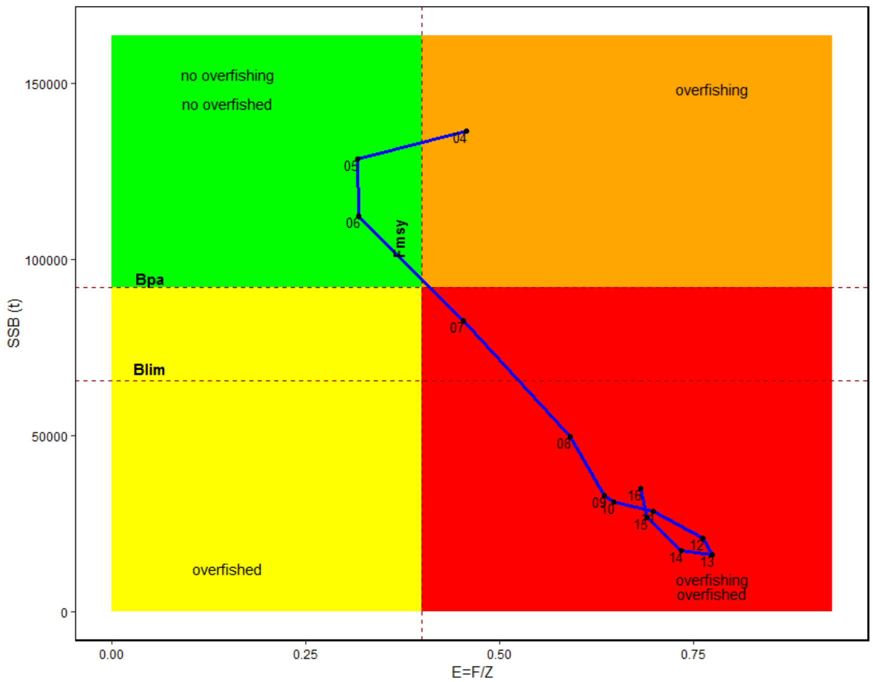
Fig. 5.1.1.29. Segmented regression performed with the R package msy ("ices-tools-prod/msy") used to estimate Blim of the sardine in GSA 6&7.



5.1.1.3.4 Kobe plot

The combined stocks of sardine in GSA 06 and GSA 07 are highly overexploited (SSB below Blim) and overfishing is occurring since 2007 (Fig. 5.1.1.30). From 2013 to 2016, the fishing mortality is decreasing but at levels that do not promote that overfishing stops nor the stock size overcome Bpa.

Fig. 5.1.1.30. Kobe plot for the sardine stock in GSA 6&7 using Blim, Bpa and E of Patterson as reference points.



5.1.1.3.5 Summary

		Bpa								Fmsy
		92070								0.4
Year	recruits	ssb	f0	f1	f2	f3	harvest (f0-2)	Observed catch	model catch	E
2004	11163370	136473	0.06	1.17	0.79	0.79	0.67	31374	34036	0.46
2005	5913316	128571	0.03	0.65	0.43	0.43	0.37	31289	30507	0.32
2006	3604721	112570	0.03	0.65	0.44	0.44	0.37	37882	28664	0.32
2007	2700060	82711	0.06	1.16	0.77	0.77	0.66	36650	31170	0.45
2008	2428005	49897	0.10	2.02	1.35	1.35	1.16	23120	23954	0.59
2009	2456508	32918	0.12	2.44	1.63	1.63	1.40	16415	13766	0.64
2010	2554435	31214	0.13	2.57	1.72	1.72	1.47	10588	12139	0.65
2011	2430011	28615	0.16	3.24	2.17	2.17	1.86	12954	14223	0.70
2012	1969859	21029	0.22	4.47	2.99	2.99	2.56	9835	12550	0.76
2013	1488742	16362	0.24	4.81	3.23	3.23	2.76	10770	9426	0.78
2014	1337467	17413	0.19	3.87	2.59	2.59	2.22	10292	8073	0.73
2015	1725745	26785	0.16	3.11	2.09	2.09	1.78	6657	10279	0.69
2016	2969974	35001	0.15	2.99	2.00	2.00	1.71	10754	11859	0.68

5.1.2 European anchovy (Engraulis encrasicolus)

5.1.2.1 Anchovy GSA 06

5.1.2.1.1 Input data

The length structure of the anchovy harvested by the purse seine fleet in GSA 07 included individuals from 5 cm to 18 cm. Before 2009, individuals from 12 cm to 15 cm were the most harvested sizes. Since 2010, individuals from 11 cm to 14 cm were the most represented sizes in landings. (Table 5.1.2.1).

Table 5.1.2.1. Length structure of the stock of anchovy harvested by the purse seine fleet in GSA 06. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
5									25		0	0		
5.5											40	0		
6					6			24			253	69		
6.5								353	121		432	126	0	50
7					34		55	673	605	107	869	336	98	361
7.5	3	7		2	303	157	4	771	1639	343	1942	782	551	1105
8	243	0		4	421	945	161	3475	4064	2703	3160	2134	1104	3033
8.5	1573	14		7	877	2029	181	17130	9515	5534	6076	4641	2065	10039
9	6859	41		24	2359	4249	465	28706	22099	12975	11473	16978	4902	24066
9.5	10403	149		59	4816	10515	4197	28511	42052	22274	34478	32803	14171	46450
10	10642	1033	199	71	9458	13716	10887	25575	67503	51055	84750	80560	38471	64969
10.5	11219	2496	991	89	12997	18524	15857	39368	74597	78029	116482	146784	59732	105564
11	14659	3997	3140	66	18762	24832	23466	40914	81515	127407	147678	210362	72132	160542
11.5	20896	8800	4596	134	20196	23420	33451	41748	77149	153102	167833	239961	136822	186316
12	34585	10727	6657	920	20764	28923	50011	52209	74722	191802	185319	225046	194644	180668
12.5	48070	17215	10107	2168	18216	40564	82783	68176	68806	187290	162943	173256	168839	152032
13	65079	20137	14287	3865	23293	74514	109602	83385	79363	176354	157842	151626	149817	155260
13.5	58705	22746	15265	7561	22806	94030	109675	80071	70140	125859	114969	97168	134105	137226
14	51641	33685	19659	11000	22976	108097	84168	73659	67538	92936	90011	51798	128439	129484
14.5	30214	40886	14656	12329	16803	94433	53896	48570	51361	47668	45384	17582	76380	57982
15	17405	43064	13143	13635	12094	72273	30298	28778	40724	27195	22788	6263	45166	23114
15.5	7760	29704	8492	11650	5618	42715	12064	16307	20717	11550	6717	1169	12071	5223
16	2834	17010	5583	8786	2123	16378	3838	3908	11357	3596	1855	51	4013	1620
16.5	320	8166	3001	4651	646	5730	735	1139	3063	43	449		514	804
17	0	2440	1372	1666	102	954	253	90	832	94	74			476
17.5		428	371	199	31									215
18		14	119	3	99									134
18.5			4		16									54

Length structure observed in the ECOMED surveys carried out in winter (2004-2009) and coinciding with recruitment of sardine included individuals from 5 cm to 18 cm. The most recorded individuals belonged to sizes between 8 cm and 11.5 cm (Table 5.1.2.2). Since 2009, the length structure observed by the Medias surveys which were carried out in summer, coinciding with recruitment of anchovy, indicated more abundance of individuals from 10 cm to 12 cm (Table 5.1.2.3).

Table 5.1.2.2. Length structure of anchovy recorded during the PELMED survey program in GSA 06. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2003	2004	2005	2006	2007	2008	2009
5	0	0	0	0	1744	0	0
5.5	557	2107	0	0	934	0	0
6	371	2447	236	0	4535	0	971
6.5	1484	12074	236	0	9665	9921	3487
7	2412	27250	236	0	27962	240158	11315
7.5	35111	65745	3517	746	60516	405636	54279
8	187129	91633	4768	5077	119142	716241	265812
8.5	445742	151145	15439	28504	150633	751598	673279
9	606363	241957	84448	112145	150480	801389	732154
9.5	590844	204337	87859	278520	176357	947786	514982
10	633615	227252	85803	181543	112959	928761	502418
10.5	521470	212324	71921	171197	61143	607392	479891
11	357516	176523	79070	219322	41279	332390	460899
11.5	208110	111171	78473	203762	10609	108242	337666
12	128387	82649	55133	118024	10902	81011	179180
12.5	33426	58962	42321	64815	5859	9712	84868
13	18081	40613	41034	40365	3816	16121	46699
13.5	29406	33404	29102	9769	1503	15136	24810
14	11310	48439	21175	11565	3189	0	4763
14.5	16060	32385	16671	10988	3679	0	2060
15	4750	27726	8495	14417	6737	0	516
15.5	4750	10491	7180	10832	5259	0	47
16	0	6341	4992	9288	1092	0	9
16.5	0	1974	2383	2088	742	0	0
17	0	0	270	6586	0	0	0
17.5	0	0		1544	0	0	0
18	0	0		338	0	0	0

Table 5.1.2.3. Length structure of anchovy recorded during the PELMED survey program in GSA 06. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2009	2010	2011	2012	2013	2014	2015	2016	2017
5	0	0	1661	0	0	0	0	0	0
5.5	330	0	1775	0	0	5211	0	0	
6	0	0	4779	0	56	7135	0	0	11776
6.5	0	0	8205	0	0	2882	216	0	
7	5773	0	7183	0	0	7250	1617	0	17657
7.5	29577	0	1664	0	1826	24042	863	0	
8	90990	0	1980	0	64826	90161	20939	0	123052
8.5	134951	3009	9106	33244	268860	160254	49531	9756	
9	108160	11868	68049	192847	642142	368022	99462	6065	247029
9.5	156028	40812	87265	502911	780615	537076	321212	52701	
10	242246	93009	85252	1029017	802935	916448	828197	247266	913504
10.5	308815	204892	112195	2568621	898879	1100840	1511908	531169	
11	401962	249977	183374	2108324	931277	1306484	2532960	1300870	2247014
11.5	381553	200585	173683	1193542	680579	879224	2266685	1648102	
12	278716	135517	185777	423325	473841	520347	1332944	1186451	1556782
12.5	284931	124242	132679	208554	217729	362552	759801	670078	
13	174213	105699	130434	83925	112355	454968	394338	349112	792267
13.5	138742	147375	124649	38075	47297	338336	132178	256868	
14	52454	146788	118127	18732	9589	205151	48936	86562	584485
14.5	41701	130447	76337	4047	3506	86638	7915	49637	
15	15006	91870	43494		3099	39708	1408	12660	93554
15.5	2253	33653	23768		451	9574	1408	5188	
16	953	16149	3420			5537		1592	2076
16.5	74	2167							
17	74								

The Spanish Institute of Oceanography (IEO) has a large data set of otolith readings of anchovy in GSA 06 harvested by fisheries since 2005 (n=8054). Additionally, there are some otolith readings of larvae of this species from 1995 to 2003. The otolith readings obtained through two research projects; FIL in 1988 and 1989 (n= 179) and JUVALION in 2009 (n=58) were contributed by Dr. Isabel Palomera from the Marine Science Institute of Barcelona (ICM-CSIC). Additionally, Dr. Alberto Garcia of the IEO Malaga contributed several otolith readings of anchovy obtained from 1995 to 2003 (117 in 1995, 138 in 1997, 305 in 1998, 121 in 2000, 189 in 2001 and 118 in 2003. All these sources of information on growth were used to update the estimates of the von Bertalanffy growth parameters of anchovy. In order to merge the available information on growth, only were used those otolith readings derived from fisheries for the spawning peak of anchovy (June-August, n=2901). The updated estimates of the von Bertalanffy growth parameters were calculated by the Bayesian Von Bertalanffy Growth Model - B-VBGM (Catalan, 2018) (Table 5.1.2.4).

Table 5.1.2.4. von Bertalanffy growth parameters estimated by the B-VBGM - Bayesian Von Bertalanffy Growth Model (Catalan et al., 2018) as indicated in the deliverable 1.3.1.1. The vBGP were estimated using otolith readings from GSA6.

Linf	K	t0	n	period	method
18	0.984	-0.255	3510	1995-2003 (larvae) 2005-2017 (adults)	B-BVGM

The deliverable 1.3.2.1 (Report on gonadosomatic index, size at first maturity and reproductive parameters) explored and updated the percentage of mature individuals at age. This information was used to set the maturity vector of the anchovy stock (Table 5.1.2.5). The fecundity of the species has presumably decreased because individuals are smaller than before 2010, the percentage of maturity at age zero was precautionary set in 0.0.

Table 5.1.2.5. Maturity vector used to set the maturity-at-age of anchovy in GSA 06.

Age	0	1	2	3
Maturity	0	0.98	0.99	1

The natural mortality used in recent stock assessment of sardine by GFCM or STECF working groups is based on Gislason's first equation, among other reasons, because it produces an M-at-age vector with values around 1. However, this vector is produced when the vBGP has a very negative t0 (< -1.5). The updated vBGP obtained in this study to anchovy in GSA 06 has a t0 near zero (> -0.3). Consequently, the Gislason's estimator produces M-at-age for the most fished ages (0 and 1) with too high values (between 1 and 3.5) (see deliverable D.1.4.1), resultin in the stock being perceived as slightly overexploited or even underexploited.

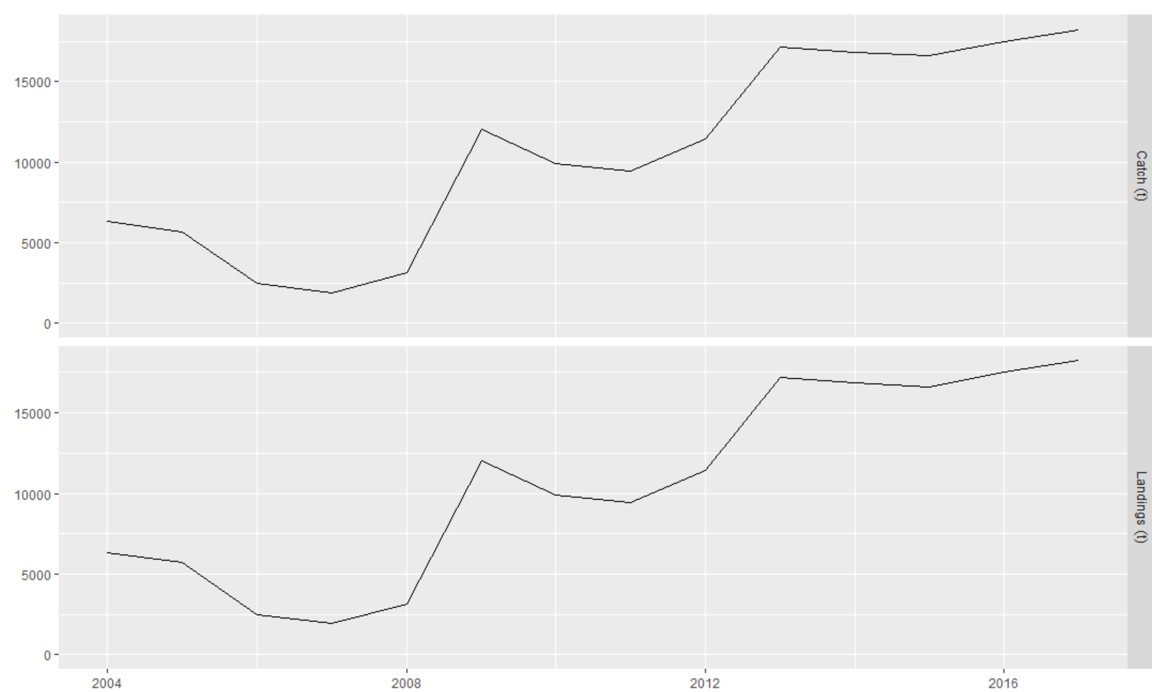
The updated vBGP of anchovy meets the biology rationale of a short-lived species, growing fast during the first year to follow a very low increase of size-at-age after this point. Thus, the t0 near zero makes sense to this species. In order to avoid too high values of M for younger individuals, it was preferred to use the Prodbiom estimator of natural mortality (Abella et al., 1997) (Table 5.1.2.6). This estimator relies on the fact that losses of biomass associated to natural mortality are compensated by production (growth). Therefore, this estimator may be appropriate to estimate the M of species where there is indications of changes of mortality with age, as small pelagic species.

Table 5.1.2.6. Natural mortality at age (M-at-age) of anchovy in GSA 06 estimated by Prodbiom

Age	0	1	2	3
M	1.23	0.75	0.51	0.43

The reported catches of anchovy in GSA 06 decreased from 2004 to 2008. Since 2009, the catches of this species has been increasing until reaching the highest value in 2013 (17397 tons). These results mean that catches of sardine in recent years (after 2009) represent 235% of catches of early years of the time series (before 2009). In the absence of reliable temporal information of discards and values are absent or very low for most of the available period of catches, the discards were assumed as zero.

Table 5.1.2.7. Catches of anchovy in GSA 06. Discards are assumed as zero tons, meaning that catches correspond to the reported landings.



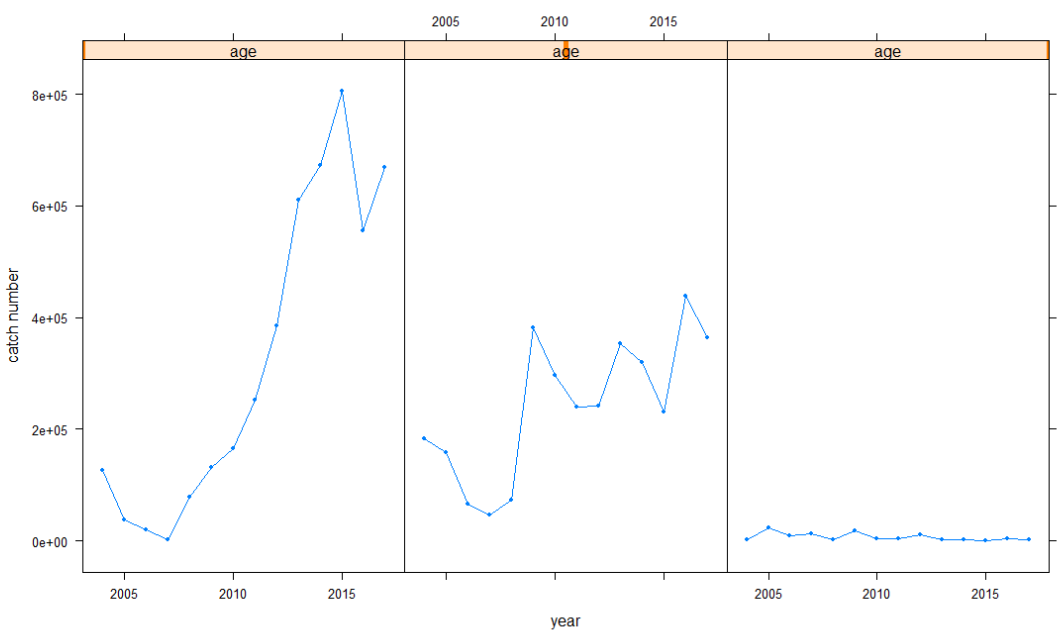
Weight at age used to estimate the total catches at age of anchovy in GSA 06. Data was provided by the IEO (Table 5.1.2.8).

Table 5.1.2.8. Weight at age of anchovy in GSA 06. Data obtained from the Spanish Institute of Oceanography

Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0	0.006	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.006	0.006	0.006	0.007	0.007	0.006
1	0.012	0.012	0.012	0.013	0.011	0.012	0.012	0.012	0.011	0.011	0.011	0.011	0.011	0.011
2	0.016	0.017	0.017	0.017	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
3	0.021	0.023	0.023	0.024	0.022	0.022	0.021	0.021	0.022	0.021	0.021	0.02	0.021	0.021

The fishery of anchovy in GSA 06 mainly harvest individuals of ages 0 and 1, while those individuals of ages two are scarce represented (Fig. 5.1.2.1). Higher number of individuals were reported after 2009.

Fig. 5.1.2.1. Number at age of anchovy individuals in GSA 06 after slicing using the updated vBGP above shown. Plus group has been set for age 2.



5.1.2.1.2 Stock assessment

The anchovy stock was assessed using different source of data as showed in the Fig. 4.1.2.1. The catch-at-age matrix obtained from ALK (and *M* estimated by Gislason) suggested that *F* has tended to oscillate since 2004, meaning that an absolute decrease is not observed. A drastic change on *R* since 2010 may imply that the ALK data could promote two very different catch-at-age structures between periods. The catch-at-age matrix derived from slicing using the current vBGP (too negative t0 and *M* estimated by Gislason) suggested a very low *F* along time series. According to this low *F*, the stock size is increasing since 2010. However, according to this stock assessment model *R* number is even higher than 2004 because *F* is very low. This result looks little feasible because catches have been increasing along the time series (Fig. 5.1.2.2). The updated vBGP (2+) showed the best diagnostics among the different tested models. This stock assessment indicates that the anchovy stock in GSA 06 have been harvested with high fishing mortalities since 2007. Therefore, the stock size is very low, exhibiting some signals of recovering since 2015.

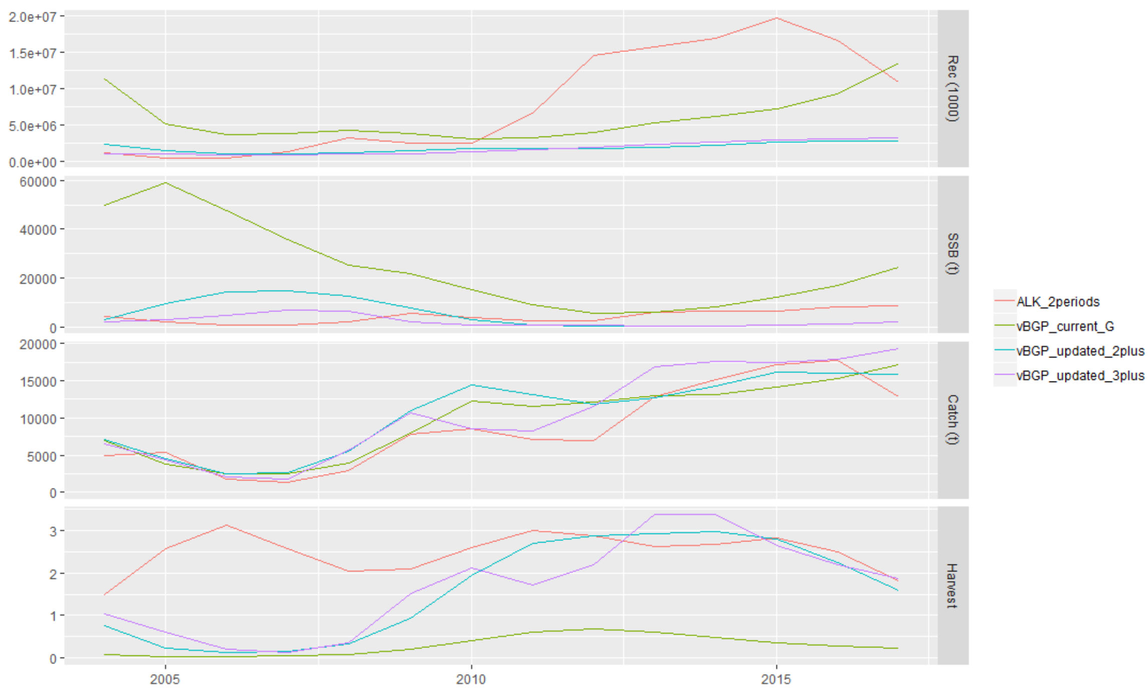


Fig. 5.1.2.2. Results of the stock assessment of the anchovy GSA 06 when catch-at-age matrix is obtained from ALK data aggregated in two periods (2004-2010 and 2011-2017) (ALK_2periods), sliced using the current vBGP (vBGP_current_G) and sliced using the updated vBGP for 2+ and 3+ age groups.

The stock assessment model set the fishing mortality submodel (fmodel) using a separable model in which age is modeled as dummy variable and year effects are modelled as (unpenalised) thin plate spline (Table 5.1.2.9). It should be assumed, as occurred in sardine, that ages older than one have the same F than age one because the gear can entirely select all ages older than one. However, the stock assessment model produced poor diagnostics when this setting was used. Then, it was accepted that older ages might have lower F than the most fished ages. However, as Fbar (the most fished ages) exclude ages older than 1, the perceived harvesting rate was not affected. The catchability submodel (qmod) was only related to the Medias index (since 2009), because the stock assessment diagnostics were worse when the Ecomed index was included. It was considered that catchability at a specific age to be dependent on catchability on the other ages. It was also explored the trend in catchability with time because the Medias index did not properly fit the catch data. Finally, the stock-recruitment submodel used a smooth model with 6 degrees of freedom (Table 5.1.2.9).

Table 5.1.2.9. Submodels setting of the the sca method

fmod = ~factor(age) + s(year, k = 6)
qmod =list(~ s(age, k=3) + year)
srmod =~s(year, k = 6)
fit <- sca(stk, medias, fmodel=fmod,qmodel=qmod,srmodel=srmod)

The stock assessment of anchovy GSA 06 produced low residuals (most of them below 1.5) but some trend in residuals were found (Fig. 5.1.2.3). The fitted and observed catch-at-age were different among years, showing good fit since 2004 to 2007 but bad fits from 2008 to 2011 (Fig. 5.1.2.4). The fitted and observed index at age was very variable among years, in general, showing poor results (Fig. 5.1.2.5). These two previous results suggest that the two sources of information on the anchovy stock did not provide consistent information. Fishing mortality was a little high for age 1 from 2011 to 2016, meaning that Fbar (0-1) could be considerable affected (Fig. 5.1.2.6). Simulation of submodel settings produce very high uncertainty in comparison with that obtained for the sardine stock (Fig. 5.1.2.7), indicating that the stock size and fishing mortality may go up, down or remain stable. The retrospective analysis suggest that the stock size is increasing while fishing mortality tends to decrease (Fig. 5.1.2.8). The stock status of anchovy GSA 06 offers higher uncertainty than found to sardine in the same area.

Fig. 5.1.2.3. Log residuals of catch and abundance indices obtained in the stock assessment of the anchovy in GSA 06.

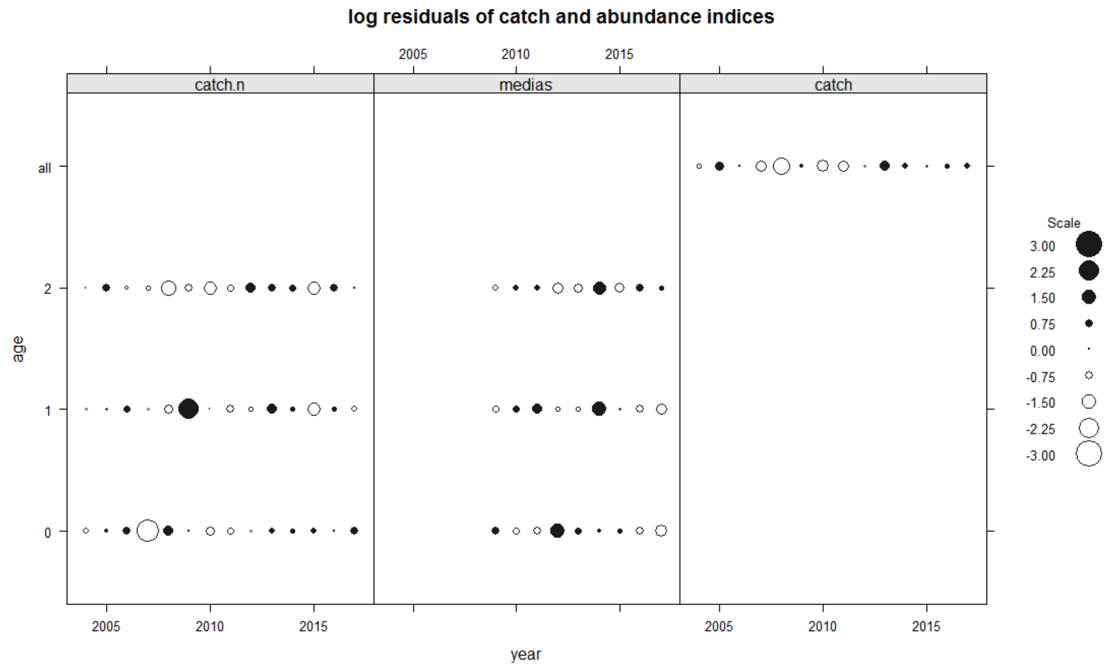


Fig. 5.1.2.4. Fitted and observed catch-at-age obtained in the stock assessment of the anchovy in GSA 06.

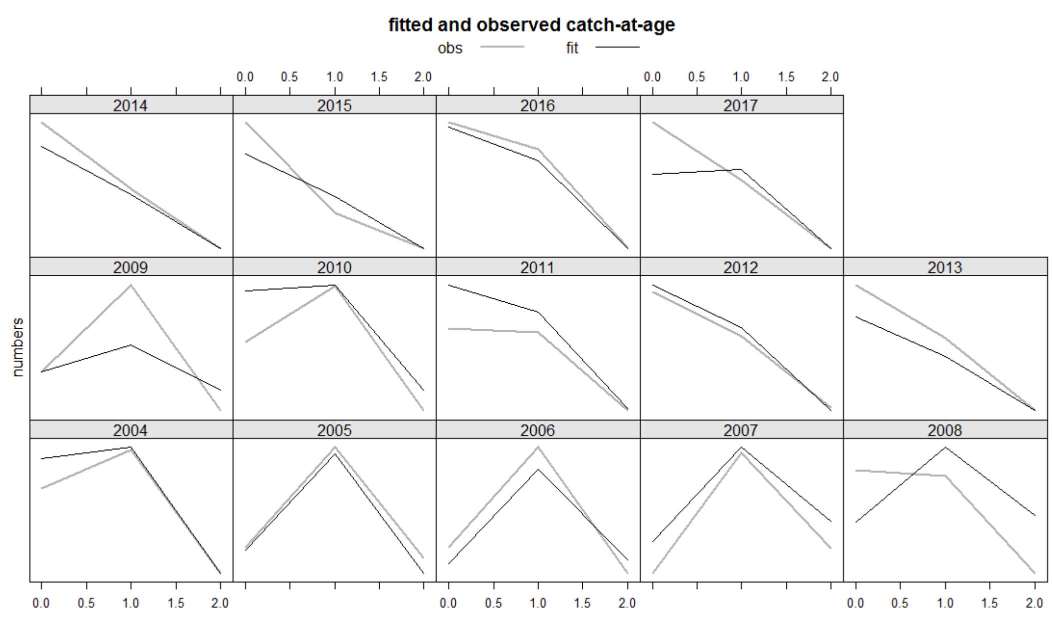


Fig. 5.1.2.5. Fitted and observed index at age obtained in the stock assessment of the anchovy in GSA 06.

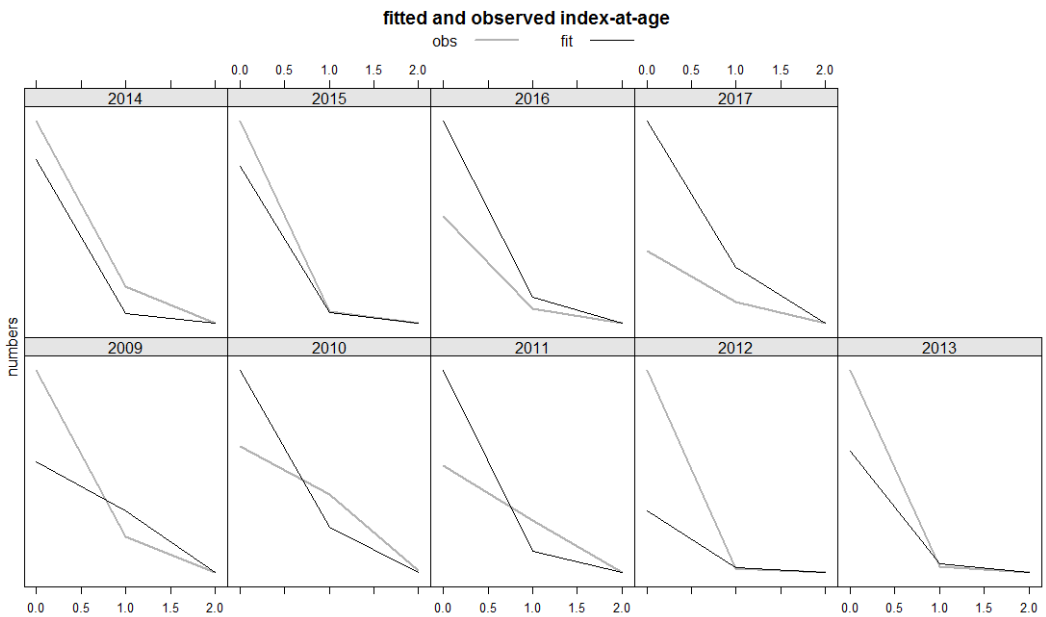


Fig. 5.1.2.6. Fishing mortality at age and year obtained in the stock assessment of the anchovy in GSA 06.

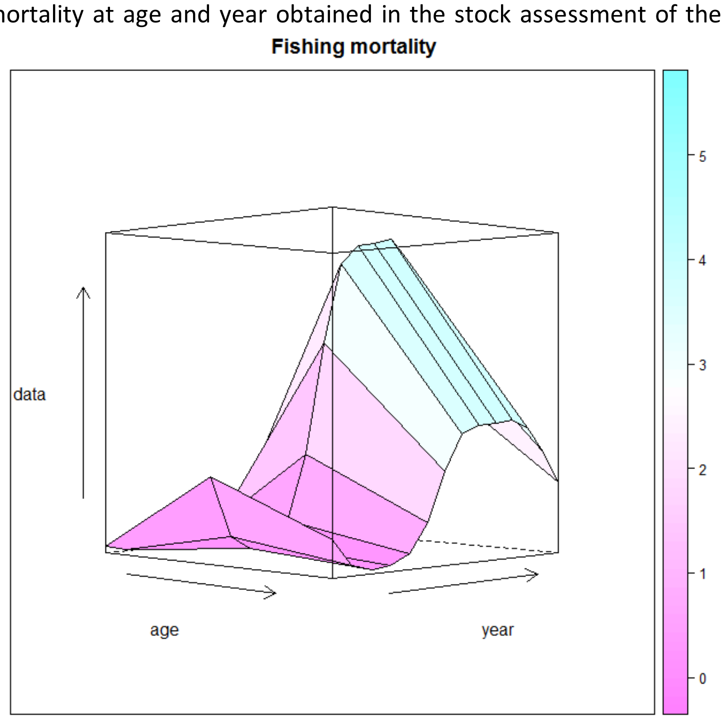


Fig. 5.1.2.7. Simulation of the fitted object that holds the stock assessment results of anchovy in GSA 06.

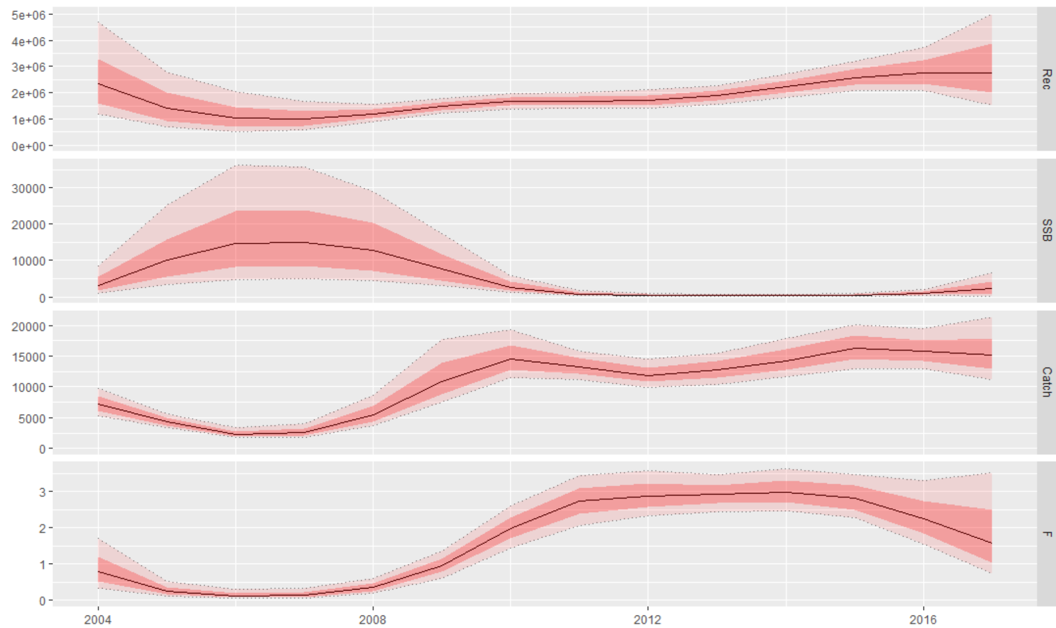
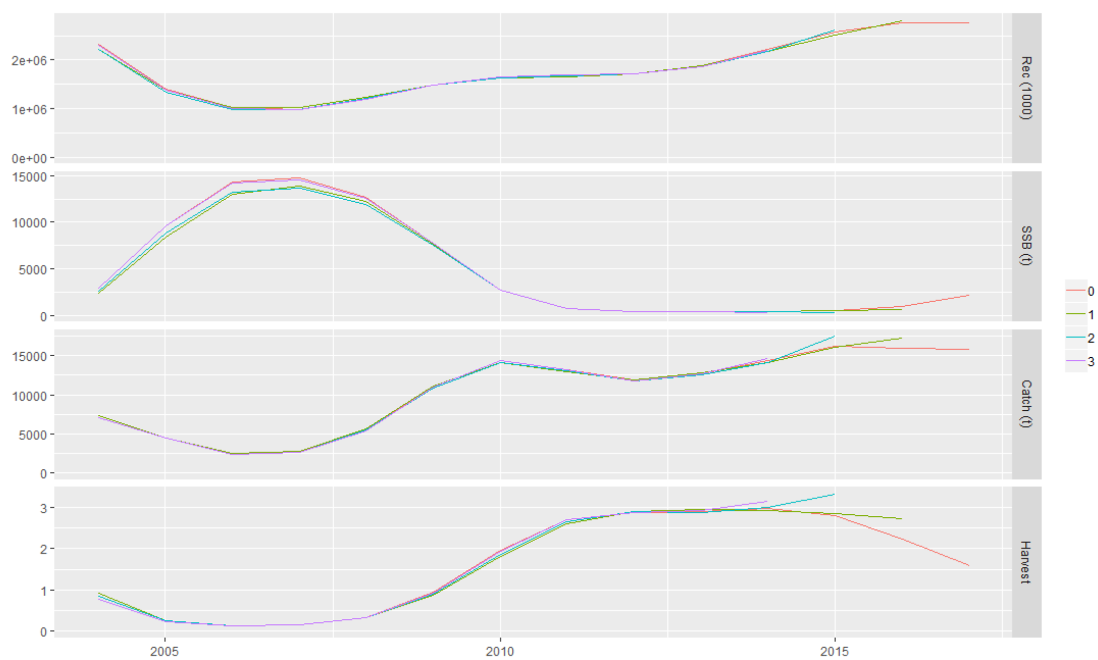


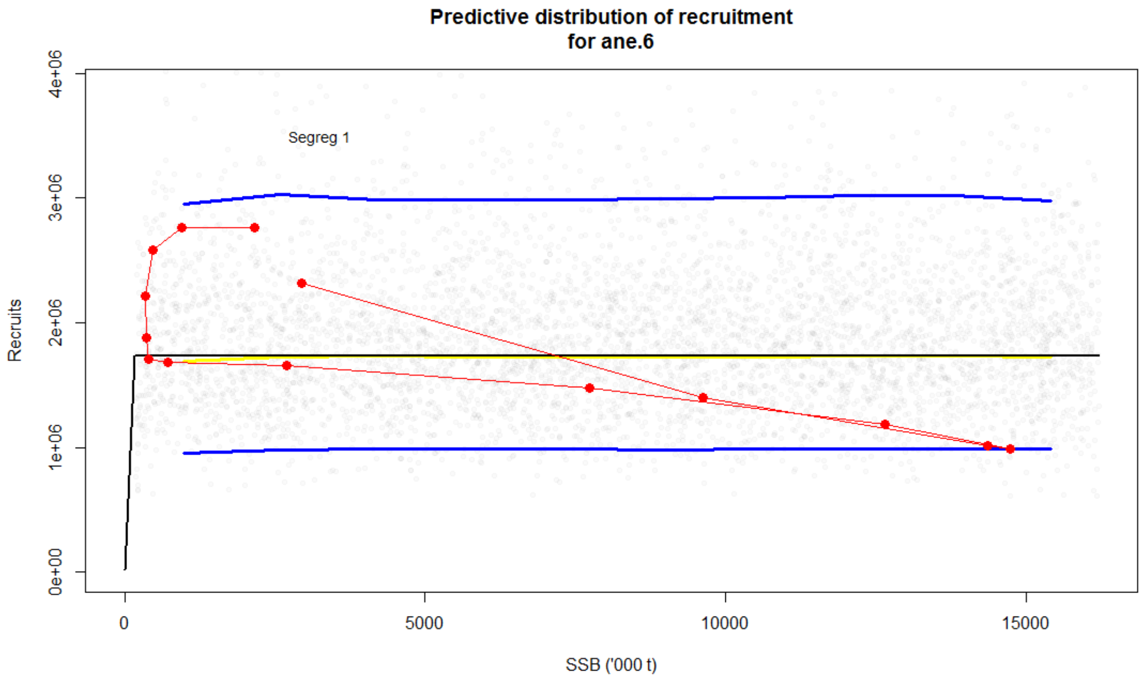
Fig. 5.1.2.8. Retrospective analysis of the stock assessment results of anchovy in GSA 06 when the last three, two or one years are omitted of the analysis.



5.1.2.1.3 Reference points

To estimate Blim (ICES, 2017) for anchovy in GSA 06, was tried a segmented regression stock recruitment relationship (Fig. 5.1.2.9). However, Blim estimated was very low (< 1000 tons). Therefore, Blim was calculated as the geometric mean of SSB (5009 tons). Blim was used to estimate Bpa. $Bpa = Blim * \exp(1.645 * \sigma)$, where σ was set equal to 0.2 (ICES, 2013). Thus, Bpa was estimated as 6960 tons. Fmsy was calculated as that value of fishing mortality that produces an exploitation rate (E=F/Z) equal to 0.4.

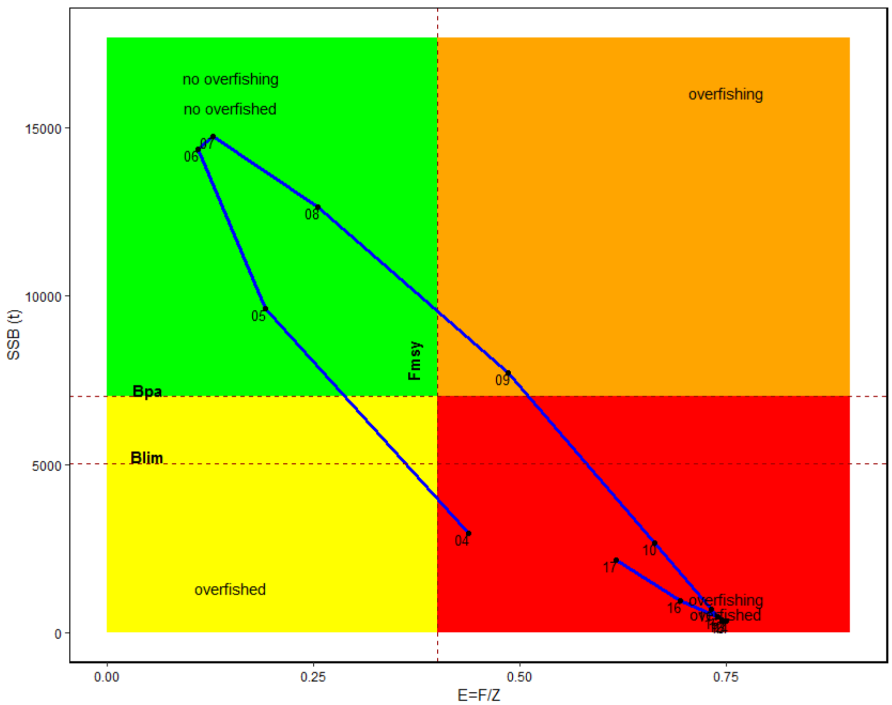
Fig. 5.1.2.9. Segmented regression performed with the R package msy ("ices-tools-prod/msy") used to estimate Blim of the anchovy in GSA 06.



5.1.2.1.4 Kobe plot

The stock of anchovy in GSA 06 is highly overexploited (SSB below Blim) and overfishing is occurring since 2009 (Fig. 5.1.1.10). From 2015 to 2017, the fishing mortality is decreasing but at levels that do not promote that overfishing stops nor the stock size overcome Bpa.

Fig. 5.1.2.10. Kobe plot for the anchovy stock in GSA 06 using Blim, Bpa and E of Patterson as reference points.



5.1.2.1.5 Summary

		Bpa							Fmsy
		6960							0.4
Year	recruits	ssb	f0	f1	f2	harvest (f0-1)	Observed catch	model catch	E
2004	2321153	2944	0.13	1.41	0.592098	0.77038	6343	7045	0.44
2005	1397649	9618	0.04	0.43	0.180699	0.23511	5702	4449	0.19
2006	1017975	14365	0.02	0.22	0.094195	0.12256	2463	2426	0.11
2007	987933	14734	0.03	0.27	0.11268	0.14661	1913	2676	0.13
2008	1186694	12651	0.06	0.62	0.261415	0.34013	3124	5473	0.26
2009	1476197	7728	0.16	1.71	0.718974	0.93546	12018	11038	0.49
2010	1660790	2688	0.34	3.56	1.49935	1.95081	9910	14397	0.66
2011	1687975	717	0.47	4.92	2.07135	2.69505	9468	13165	0.73
2012	1710594	395	0.50	5.25	2.20905	2.8742	11434	11858	0.74
2013	1880943	356	0.51	5.31	2.2376	2.91135	17178	12736	0.75
2014	2219490	350	0.52	5.43	2.28514	2.97321	16850	14318	0.75
2015	2581216	474	0.49	5.11	2.15355	2.802	16600	16191	0.74
2016	2766256	945	0.39	4.10	1.72461	2.2439	17502	15935	0.69
2017	2768113	2157	0.28	2.90	1.22077	1.58836	18242	15817	0.62

5.1.2.2 Anchovy GSA 07

5.1.2.2.1 Input data

The length structure of the anchovy harvested by the mid water trawler fleet in GSA 07 included individuals from 5 cm to 19 cm. Most of the caught individuals were between 10 and 14 cm. (Table 5.1.2.10).

Table 5.1.2.10. Length structure of the stock of anchovy harvested by the purse seine fleet in GSA 07. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length (cm)	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
5											74				
6											532				
7		687	1708				71	112	275		1738			42	246
8	572	1862	8185	94		872	619	6236	13296	136	6328			126	663
9	5662	17533	19632	535	525	5159	7822	15761	26002	1798	6495	2503	429	463	2499
10	16875	35774	35339	5772	6015	10265	33313	36655	67098	23418	17274	13570	2893	2273	23678
11	26858	83313	65684	9493	19456	20660	51960	77601	123425	83978	31936	38126	25899	6483	64192
12	87290	98562	96503	16184	20021	32616	51420	122995	126439	109165	44953	66418	74391	6525	38831
13	135565	95358	74857	35513	25433	46595	64202	86165	62192	55936	29044	60499	63757	1431	8031
14	108617	81952	41312	33572	26125	64689	50556	41929	18592	13232	6225	20084	15607	379	589
15	41864	28277	11093	16795	16664	42044	23103	11114	2484	1272	532	3562	2656	42	
16	4666	8085	778	4198	5881	14399	5495	2262	117	86	43		83		
17	407	192		284	1177	1808	686	103		176					
18					17	388									
19						49									

Length structure observed in the surveys before 2009 included individuals from 2 cm to 18 cm, although most of harvested sizes were from 12 to 14 cm (Table 5.1.2.11). Since 2009, the length structure observed by the Pelmed surveys indicated more abundance of sizes from 10 cm to 12 cm (Table 5.1.2.12).

Table 5.1.2.11. Length structure of anchovy recorded during the PELMED survey program in GSA 07. Number of individuals by length represent the total catch each year. Source: DCF. Length is expressed in centimeters.

Length	2002	2003	2004	2005	2006	2007	2008
2							348
3							813
4							1053
5							5100
6							11197
7	13				1384		2728
8	6	2947			2101		
9	1124	1251	25505		2070		
10	898	29018	256675	8167	3260		1134
11	145082	757380	625102		18578	1221	48205
12	836698	1223423	736841	19988	243184	36625	493521
13	1301320	454229	385078	268989	469294	139814	724030
14	895272	63482	133315	274556	390477	233367	315713
15	148275	7946	52075	131869	211334	233463	82912
16	4768		11508	97385	78956	68795	6537
17				20414	18689		1757
18					513		

Table 5.1.2.12. Length structure of anchovy recorded during the PELMED survey program in GSA 07. Number of individuals by length represent the total catch each year. Source: DCF. Length is expressed in centimeters.

Length	2009	2010	2011	2012	2013	2014	2015	2016
2								
3								
4								
5	8329						802	
6	9389					51		119
7	2339						1153	715
8				7780	8796	44465	1199	2742
9	30873	29289	158042	452417	510128	539453	140849	4514
10	486245	844998	1294897	2411640	1715868	1021944	1491269	197282
11	1029914	1263385	1080572	1681513	399095	1357819	2754053	969806
12	891049	526651	632180	522661	44849	711068	703442	770297
13	479798	123678	143638	55617	7126	138759	33343	242822
14	71354	19123	10395	10326		15880	11789	45176
15	23773			349			3032	6389
16	3219						122	
17								
18								

Given that raw data in otolith readings were not available to update the von Bertalanffy growth parameters of anchovy in GSA 07, the available information of otoliths readings in GSA 06 was borrowed to estimate the vBGP that were later used to estimate catch-at-age number in GSA 07 by slicing. The data and process used to estimate the vBGP of anchovy in GSA 06 are below explained. The Spanish Institute of Oceanography (IEO) has a large data set of otolith readings of anchovy in GSA 06 harvested by fisheries since 2005 (n=8054). Additionally, there are some otolith readings of larvae of this species from 1995 to 2003. The otolith readings obtained through two research projects; FIL in 1988 and 1989 (n= 179) and JUVALION in 2009 (n=58) were contributed by Dr. Isabel Palomera from the Marine Science Institute of Barcelona (ICM-CSIC). Additionally, Dr. Alberto Garcia of the IEO Malaga contributed several otolith readings of anchovy obtained from 1995 to 2003 (117 in 1995, 138 in 1997, 305 in 1998, 121 in 2000, 189 in 2001 and 118 in 2003). All these sources of information on growth were used to update the estimates of the von Bertalanffy growth parameters of anchovy. In order to merge the available information on growth, only were used those otolith readings derived from fisheries for the spawning peak of anchovy (June-August, n=2901). The updated estimates of the von Bertalanffy growth parameters were calculated by the Bayesian Von Bertalanffy Growth Model - B-VBGM (Catalan, 2018) (Table 5.1.2.13).

Table 5.1.2.13. von Bertalanffy growth parameters estimated by the B-VBGM - Bayesian Von Bertalanffy Growth Model (Catalan et al., 2018) as indicated in the deliverable 1.3.1.1. The vBGP were estimated using otolith readings from GSA7.

Linf	K	t0	n	period	method

18	0.984	-0.255	3510	1995-2003 (larvae) 2005-2017 (adults)	B-BVGM

The deliverable 1.3.2.1 (Report on gonadosomatic index, size at first maturity and reproductive parameters) explored and updated the percentage of mature individuals at age. This information was used to set the maturity vector of the anchovy stock (Table 5.1.2.14). The fecundity of the species has presumably decreased because individuals are smaller than before 2010, the percentage of maturity at age zero was precautionarily set to 0.

Table 5.1.2.14. Maturity vector used to set the maturity-at-age of anchovy in GSA 07.

Age	0	1	2	3
Maturity	0	0.98	0.99	1

The natural mortality used in recent stock assessments of anchovy is usually estimated with the Gislason's first equation, among other reasons, because it produces an M-at-age vector with values around 1. However, this vector is produced when the vBGP hold a t0 very negative (< -1.5). The updated vBGP obtained in this study to anchovy in GSA 06 and borrowed to anchovy in GSA 07 has a near zero t0 (> -0.3). Consequently, the Gislason's estimator produces M-at-age for the most fished ages (0 and 1) with too high values (between 1 and 3.5) (see deliverable D.1.4.1), resulting in the stock being perceived as slightly overexploited or even underexploited.

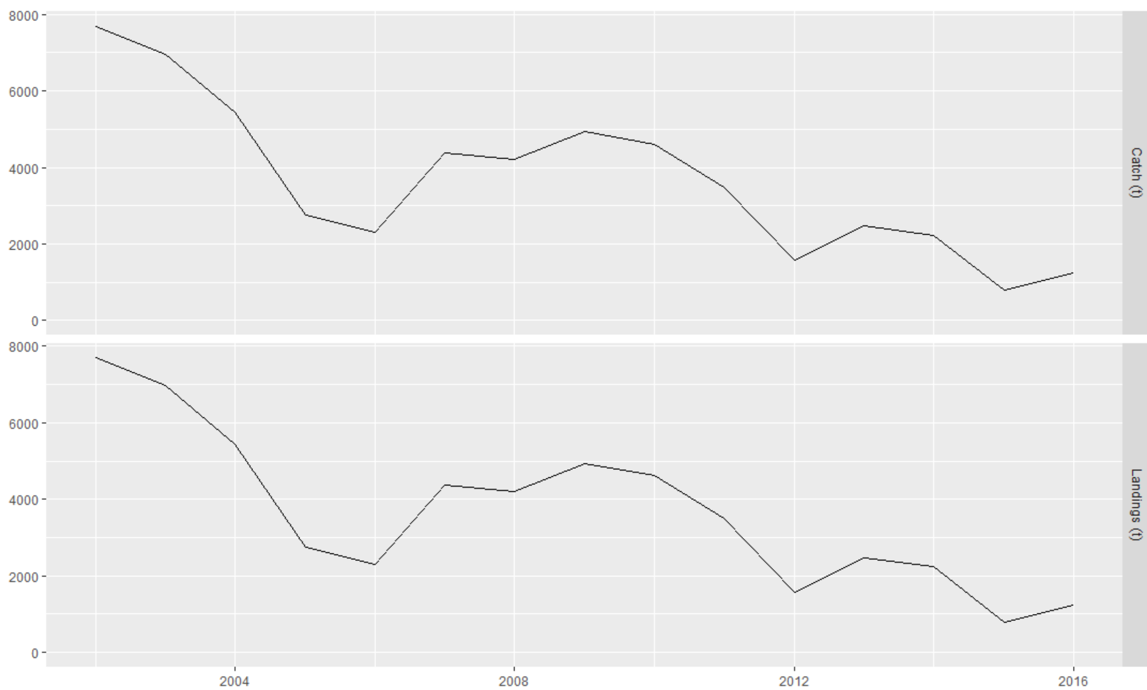
The updated vBGP of anchovy meets the biology rationale of a short-lived species, growing fast during the first year to follow a very low increase of size-at-age after this point. Thus, the t0 near zero makes sense for this species. In order to avoid too high values of M for younger individuals, it was preferred to use the Prodbiom estimator of natural mortality (Abella et al., 1997) (Table 5.1.2.15). This estimator relies on the fact that losses of biomass associated to natural mortality are compensated by production (growth). Therefore, this estimator may be reasonable used to estimate the M of species where there is indications of changes of mortality with age, as small pelagic species.

Table 5.1.2.15. Natural mortality at age (M-at-age) of anchovy in GSA 07 estimated by Prodbiom

Age	0	1	2	3
M	1.18	0.72	0.5	0.42

The reported catches of anchovy in GSA 07 have decreased since 2002 (Table 5.1.2.16). The highest value was reported in 2002 (7777 tons) and the lowest catch was obtained in 2015 (1108 tons). These results mean that catches of anchovy in recent years (after 2009) represent 49% of catches of early years of the time series (before 2009). Because there is no reliable temporal information of discards and values are absent or very low for most of the available period of catches, the discards were assumed as zero.

Table 5.1.2.16. Catches of anchovy in GSA 07. Discards are assumed as zero tons, meaning that catches correspond to the reported landings.



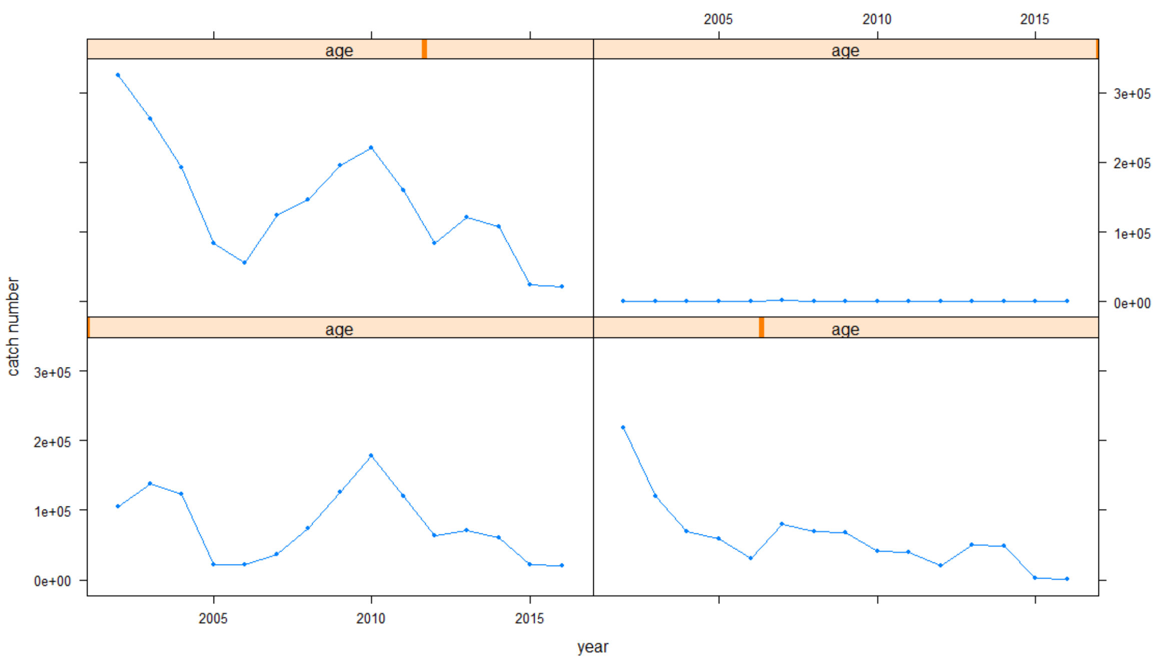
Weight at age used to estimate the total catches at age of anchovy in GSA 07. Data was obtained from the Data call framework DCF (Table 5.1.2.17).

Table 5.1.2.17. Weight at age of anchovy in GSA 07. Data obtained from the Spanish Institute of Oceanography

Age	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0	0.005	0.004	0.005	0.005	0.008	0.01	0.008	0.007	0.006	0.006	0.006	0.006	0.005	0.008	0.014
1	0.009	0.012	0.014	0.015	0.017	0.017	0.012	0.011	0.011	0.01	0.009	0.01	0.011	0.016	0.028
2	0.016	0.019	0.02	0.021	0.029	0.021	0.019	0.017	0.014	0.015	0.012	0.013	0.013	0.024	0.042
3	0.021	0.022	0.022	0.022	0.035	0.026	0.02	0.024	0.02	0.018	0.014	0.015	0.015	0.034	0.053
4	0.023	0.023	0.024	0.024	0.037	0.028	0.021	0.025	0.022	0.02	0.018	0.019	0.016	0.036	0.055

The fishery of anchovy in GSA 07 mainly harvest individuals of ages 0, 1 and 2, while those individuals of age three are scarce represented (Fig. 5.1.2.21).

Table 5.1.2.18. Number at age of anchovy individuals in GSA 07 after slicing using the updated vBGP above shown. Plus group has been set for age 3.



5.1.2.2.2 Stock assessment

The anchovy stock in GSA 07 was assessed using different source of data as showed in the Fig. 4.1.2.1. None stock assessment model produced acceptable diagnostics. The two source of catch-at-age data (ALK and slicing) led to different stock (Fig. 5.1.2.11).

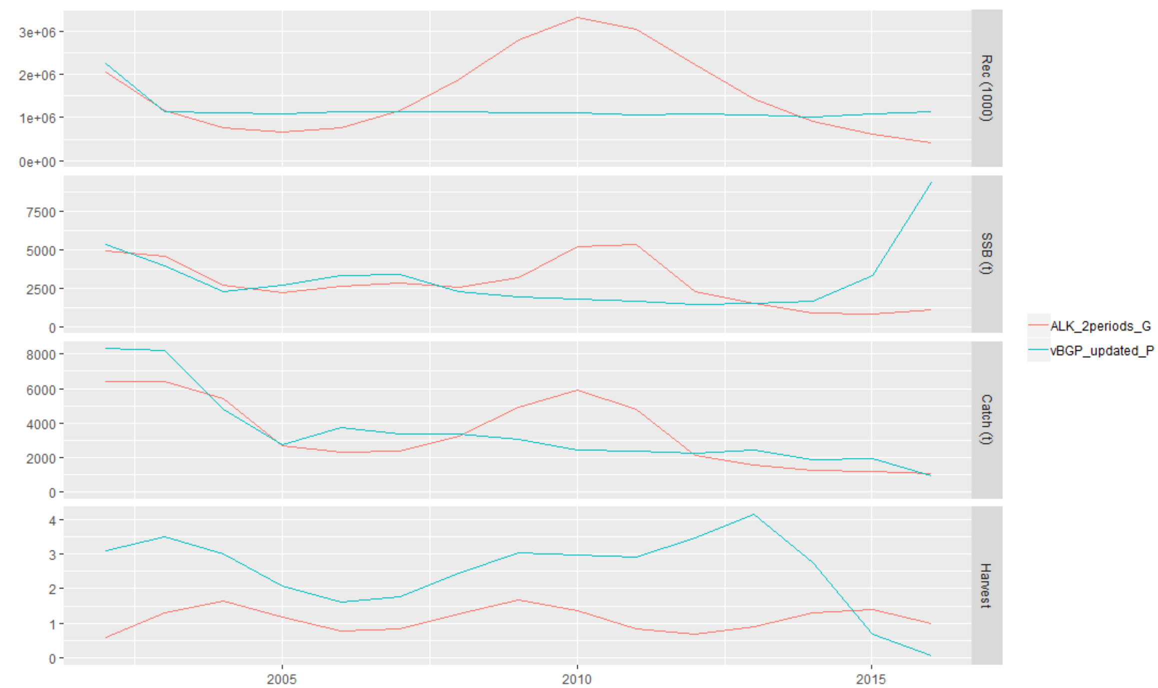


Fig. 5.1.2.11. Results of the stock assessment of the anchovy GSA 07 when catch-at-age matrix is obtained from ALK data aggregated in two periods (2002-2010 and 2011-2016) (ALK_2periods_G), sliced using the updated vBGP for 2+ age group (vBGP_updated_P).

Several settings of the submodels were tried but it was not possible to find an acceptable model fit for anchovy in GSA 07 (Table 5.1.2.19). Here are shown the submodel settings that produce a reasonable message on the stock trend. However, *F* was too high and poor diagnostics were found.

Table 5.1.2.19. Submodels setting of the the sca method

fmod=~s(replace(age, age>2,2), k=3)+s(year,k=7)
qmod=list(~s(age,k=3))
srmod=~geomean(CV=0.1)

The stock assessment of anchovy in GSA 07 did not have the minimum quality to be considered informative about the stock status. It is due to trend in residuals were found (Fig. 5.1.2.12), the fitted and observed catch-at-age were quite different among years (Fig. 5.1.2.13), the fitted and observed index at age was variable among years (Fig. 5.1.2.14), fishing mortality was very high for age 2 (Fig. 5.1.2.15) and the retrospective analysis did not converge. Although very low catches may suggest that fishing mortality is very low, a high increase in SSB is quite doubt (Fig. 5.1.2.14).

Fig. 5.1.2.12. Log residuals of catch and abundance indices obtained in the stock assessment of the anchovy in GSA 07.

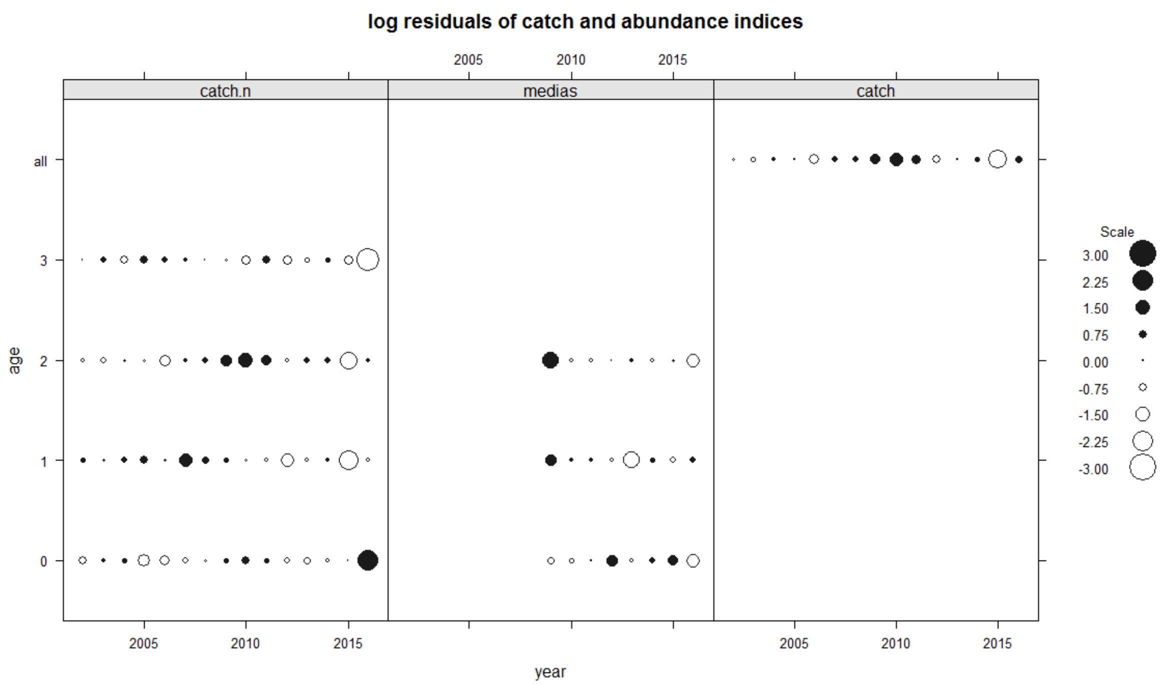


Fig. 5.1.2.13. Fitted and observed catch-at-age obtained in the stock assessment of the anchovy in GSA 07.

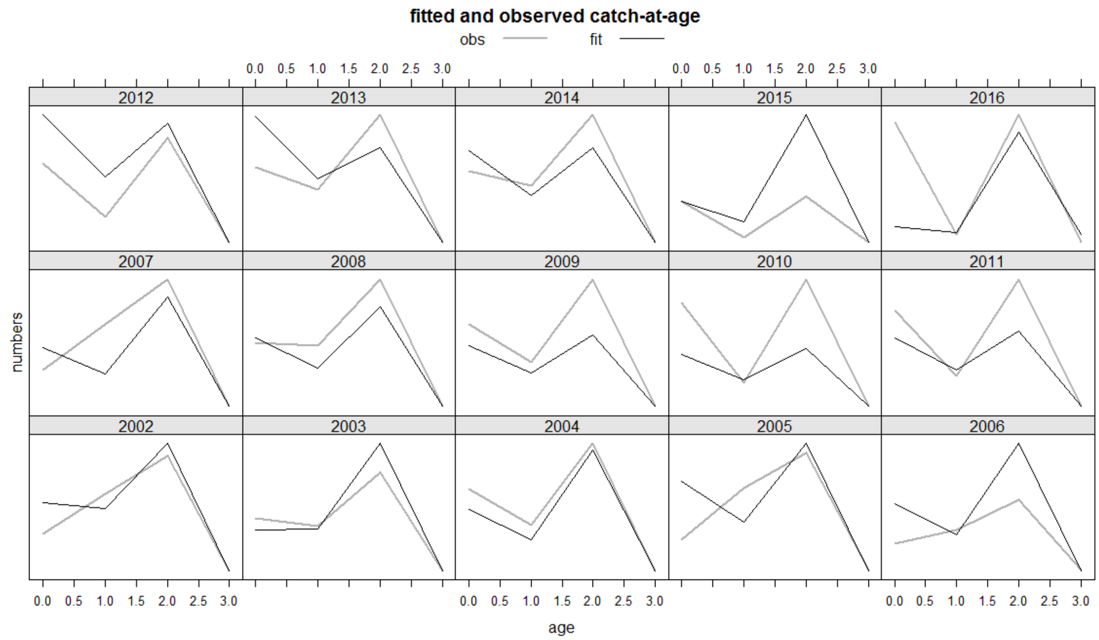


Fig. 5.1.2.14. Fitted and observed index at age obtained in the stock assessment of the anchovy in GSA 07.

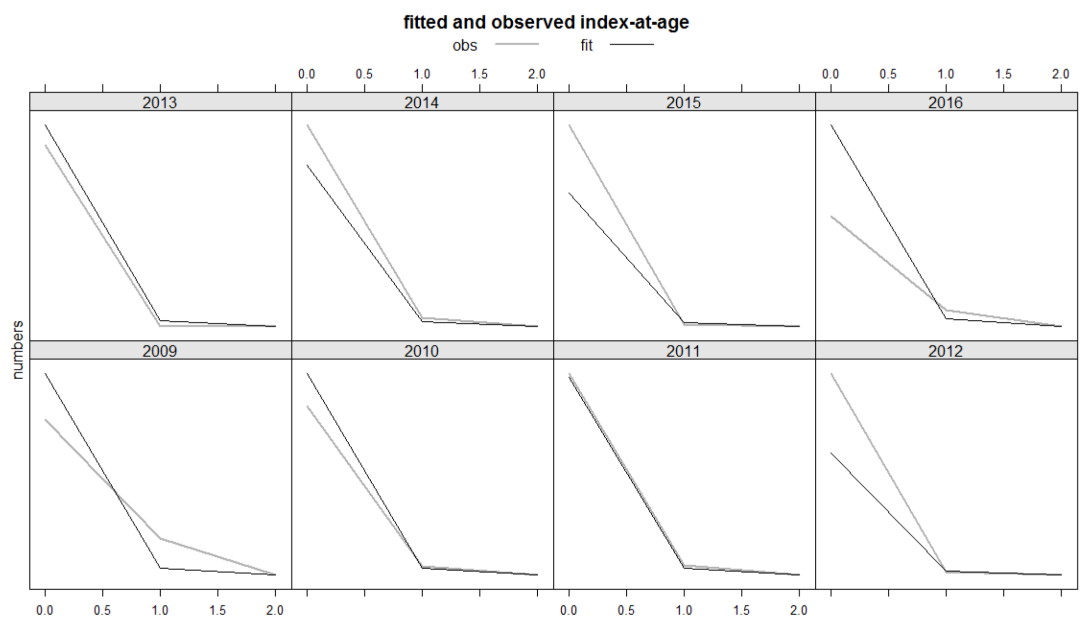


Fig. 5.1.2.15. Fishing mortality at age and year obtained in the stock assessment of the anchovy in GSA 07.

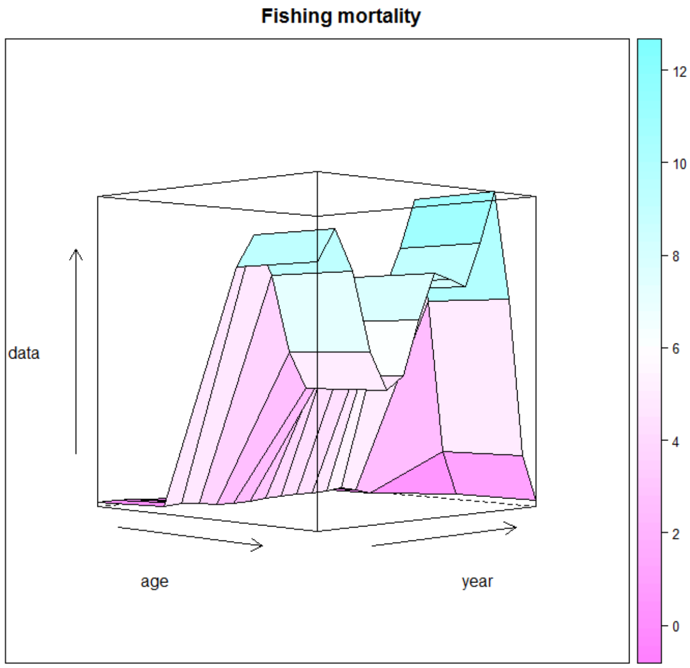
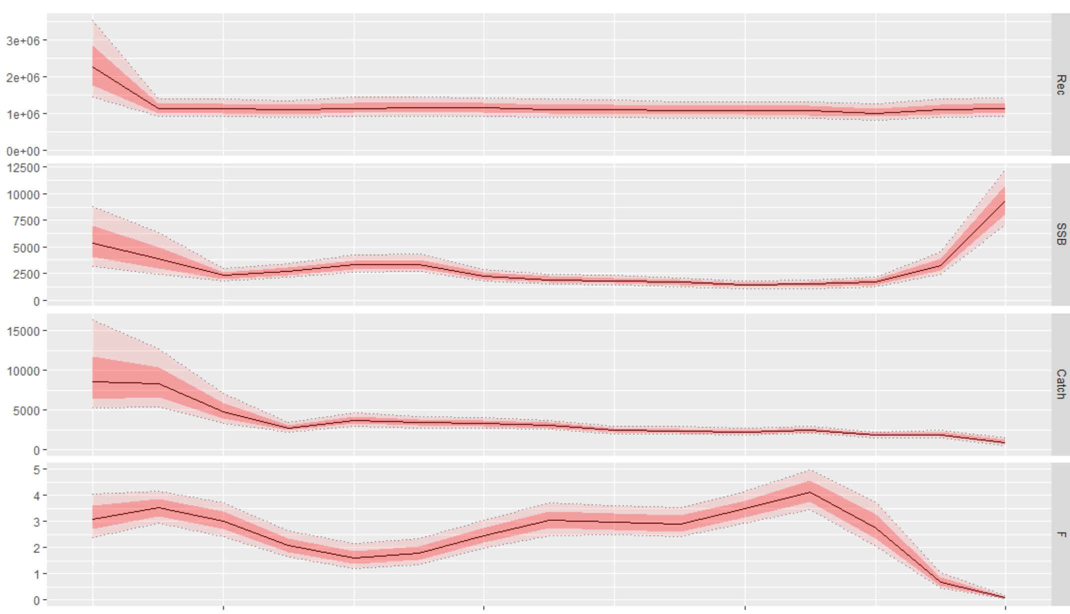


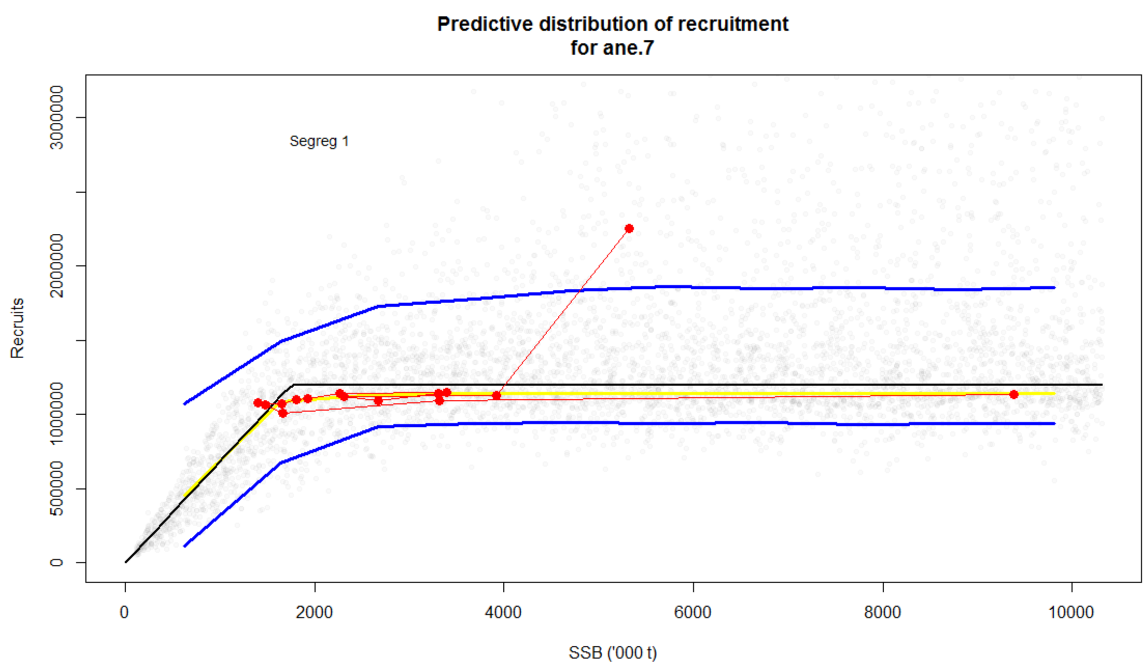
Fig. 5.1.2.16. Simulation of the fitted object that holds the stock assessment results of anchovy in GSA 07.



5.1.2.2.3 Reference points

To estimate Blim (ICES, 2017) for anchovy in GSA 07, was used a segmented regression stock recruitment relationship (Fig. 5.1.2.17). Blim was estimated in 1720 tons. Blim was used to estimate Bpa. $Bpa = Blim * \exp(1.645 * \sigma)$, where σ was set equal to 0.2 (ICES, 2013). Thus, Bpa was estimated as 2340 tons. Fmsy was calculated as that value of fishing mortality that produces an exploitation rate (E=F/Z) equal to 0.4.

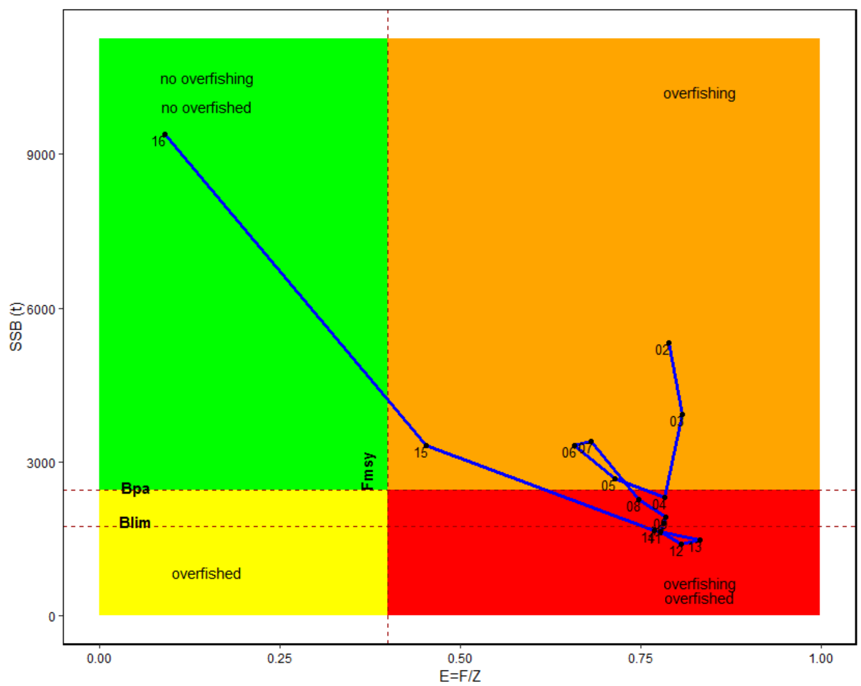
Fig. 5.1.2.17. Segmented regression performed with the R package msy ("ices-tools-prod/msy") used to estimate Blim of the anchovy in GSA 07.



5.1.2.2.4 Kobe plot

The stock of anchovy in GSA 07 is underexploited in 2016 (Fig. 5.1.2.18). Remember that diagnostics of the stock assessment model were very poor and fishing mortality may be biased. Little or no information may be derived from this analysis.

Fig. 5.1.2.18. Kobe plot for the anchovy stock in GSA 07 using Blim, Bpa and E of Patterson as reference points.



5.1.2.2.5 Summary

		Bpa								Fmsy
Year	recruits	ssb	f0	f1	f2	f3	harvest (f0-2)	Observed catch	model catch	E
2002	2256949	5317.9	0.16	0.28	8.85	8.85	3.10	8312.62	7695.30	0.79
2003	1127650	3919	0.18	0.32	10.01	10.01	3.50	8194.65	6967.90	0.81
2004	1121984	2307.6	0.15	0.27	8.61	8.61	3.01	4783.28	5447.90	0.78
2005	1094316	2669.4	0.11	0.19	5.92	5.92	2.07	2746.28	2760.90	0.71
2006	1140729	3311.7	0.08	0.15	4.59	4.59	1.60	3747.21	2313.30	0.66
2007	1149273	3395	0.09	0.16	5.09	5.09	1.78	3383.64	4367.90	0.68
2008	1144053	2271.5	0.13	0.22	7.03	7.03	2.46	3348.37	4215.40	0.75
2009	1107049	1923.8	0.15	0.28	8.68	8.68	3.04	3071.61	4937.20	0.79
2010	1100221	1809.8	0.15	0.27	8.52	8.52	2.98	2457.38	4617.10	0.78
2011	1071547	1649.8	0.15	0.26	8.28	8.28	2.90	2383.60	3497.60	0.78
2012	1078424	1406.1	0.18	0.31	9.90	9.90	3.46	2229.00	1572.70	0.81
2013	1064314	1477	0.21	0.38	11.84	11.84	4.14	2471.32	2481.90	0.83
2014	1012301	1663	0.14	0.25	7.89	7.89	2.76	1872.78	2232.80	0.77
2015	1096238	3323.4	0.04	0.06	1.97	1.97	0.69	1966.83	793.30	0.45
2016	1135715	9382.8	0.00	0.01	0.24	0.24	0.08	949.91	1237.80	0.09

5.1.2.3 Anchovy GSA 06 and 07

5.1.2.3.1 Input data

The length structure of the anchovy harvested by the mid water trawler and purse seine fleets in GSA 06 and GSA 07 included individuals from 5 cm to 19 cm (Table 5.1.2.20). Most of individuals caught have sizes from 10 cm to 14 cm.

Table 5.1.2.20. Length structure of the stock of anchovy harvested by the purse seine fleet in GSA 06 and 07. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
5	0	0	0	0	0	0	0	0	99	0	0	0	0
5.5	0	0	0	0	0	0	0	0	0	0	40	0	0
6	0	0	0	0	6	0	0	24	532	0	253	69	0
6.5	0	0	0	0	0	0	0	353	121	0	432	126	0
7	1708	0	0	0	105	112	330	673	2343	107	869	378	344
7.5	3	7	0	2	303	157	4	771	1639	343	1942	782	551
8	8428	94	0	876	1040	7181	13457	3611	10392	2703	3160	2260	1767
8.5	1573	14	0	7	877	2029	181	17130	9515	5534	6076	4641	2065
9	26491	576	525	5183	10181	20010	26467	30504	28594	15478	11902	17441	7401
9.5	10403	149	0	59	4816	10515	4197	28511	42052	22274	34478	32803	14171
10	45981	6805	6214	10336	42771	50371	77985	48993	84777	64625	87643	82833	62149
10.5	11219	2496	991	89	12997	18524	15857	39368	74597	78029	116482	146784	59732
11	80343	13490	22596	20726	70722	102433	146891	124892	113451	165533	173577	216845	136324
11.5	20896	8800	4596	134	20196	23420	33451	41748	77149	153102	167833	239961	136822
12	131088	26911	26678	33536	72184	151918	176450	161374	119675	258220	259710	231571	233475
12.5	48070	17215	10107	2168	18216	40564	82783	68176	68806	187290	162943	173256	168839
13	139936	55650	39720	50460	87495	160679	171794	139321	108407	236853	221599	153057	157848
13.5	58705	22746	15265	7561	22806	94030	109675	80071	70140	125859	114969	97168	134105
14	92953	67257	45784	75689	73532	150026	102760	86891	73763	113020	105618	52177	129028
14.5	30214	40886	14656	12329	16803	94433	53896	48570	51361	47668	45384	17582	76380
15	28498	59859	29807	55679	35197	83387	32782	30050	41256	30757	25444	6305	45166
15.5	7760	29704	8492	11650	5618	42715	12064	16307	20717	11550	6717	1169	12071
16	3612	21208	11464	23185	7618	18640	3955	3994	11400	3596	1938	51	4013
16.5	320	8166	3001	4651	646	5730	735	1139	3063	43	449	0	514
17	0	2724	2549	3474	788	1057	253	266	832	94	74	0	0
17.5	0	428	371	199	31	0	0	0	0	0	0	0	0
18	0	14	136	391	99	0	0	0	0	0	0	0	0
18.5	0	0	4	0	16	0	0	0	0	0	0	0	0
19	0	0	0	49	0	0	0	0	0	0	0	0	0

Length structure observed in the surveys (2004-2009) included individuals from 2 cm to 18 cm. The most recorded individuals belonged to sizes between 8 cm and 13 cm (Table 5.1.2.21.). Since 2009, the length structure observed by surveys indicated more abundance of sizes from 10 cm to 12 cm) (Table 5.1.2.22).

Table 5.1.2.21. Length structure of anchovy recorded during the PELMED survey program in GSA 06 and 07. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2003	2004	2005	2006	2007	2008
2	0	0	0	0	0	348
2.5	0	0	0	0	0	0
3	0	0	0	0	0	813
3.5	0	0	0	0	0	0
4	0	0	0	0	0	1053
4.5	0	0	0	0	0	0
5	0	0	0	0	1744	5100
5.5	557	2107	0	0	934	0
6	371	2447	236	0	4535	11197
6.5	1484	12074	236	0	9665	9921
7	2412	27250	236	1384	27962	242886
7.5	35111	65745	3517	746	60516	405636
8	190076	91633	4768	7178	119142	716241
8.5	445742	151145	15439	28504	150633	751598
9	607614	267462	84448	114215	150480	801389
9.5	590844	204337	87859	278520	176357	947786
10	662633	483927	93970	184803	112959	929895
10.5	521470	212324	71921	171197	61143	607392
11	1114896	801625	79070	237900	42500	380595
11.5	208110	111171	78473	203762	10609	108242
12	1351810	819490	75121	361208	47527	574532
12.5	33426	58962	42321	64815	5859	9712
13	472310	425691	310023	509659	143630	740151
13.5	29406	33404	29102	9769	1503	15136
14	74792	181754	295731	402042	236556	315713
14.5	16060	32385	16671	10988	3679	0
15	12696	79801	140364	225751	240200	82912
15.5	4750	10491	7180	10832	5259	0
16	0	17849	102377	88244	69887	6537
16.5	0	1974	2383	2088	742	0
17	0	0	20684	25275	0	1757
17.5	0	0	0	1544	0	0
18	0	0	0	851	0	0

Table 5.1.2.22. Length structure of anchovy recorded during the PELMED survey program in GSA 06 and 07. Number of individuals by length represent the total catch each year. Source: Spanish Institute of Oceanography. Length is expressed in centimeters.

Length	2009	2010	2011	2012	2013	2014	2015	2016
5	8329	0	1661	0	0	0	802	0
5.5	330	0	1775	0	0	5211	0	0
6	9389	0	4779	0	56	7186	0	119
6.5	0	0	8205	0	0	2882	216	0
7	8112	0	7183	0	0	7250	2770	715
7.5	29577	0	1664	0	1826	24042	863	0
8	90990	0	1980	7780	73622	134626	22138	2742
8.5	134951	3009	9106	33244	268860	160254	49531	9756
9	139033	41157	226091	645264	1152270	907475	240311	10579
9.5	156028	40812	87265	502911	780615	537076	321212	52701
10	728491	938007	1380149	3440657	2518803	1938392	2319466	444548
10.5	308815	204892	112195	2568621	898879	1100840	1511908	531169
11	1431876	1513362	1263946	3789837	1330372	2664303	5287013	2270676
11.5	381553	200585	173683	1193542	680579	879224	2266685	1648102
12	1169765	662168	817957	945986	518690	1231415	2036386	1956748
12.5	284931	124242	132679	208554	217729	362552	759801	670078
13	654011	229377	274072	139542	119481	593727	427681	591934
13.5	138742	147375	124649	38075	47297	338336	132178	256868
14	123808	165911	128522	29058	9589	221031	60725	131738
14.5	41701	130447	76337	4047	3506	86638	7915	49637
15	38779	91870	43494	349	3099	39708	4440	19049
15.5	2253	33653	23768	0	451	9574	1408	5188
16	4172	16149	3420	0	0	5537	122	1592
16.5	74	2167	0	0	0	0	0	0
17	74	0	0	0	0	0	0	0

Given that raw data in otolith readings were not available to update the von Bertalanffy growth parameters of anchovy in GSA 07, the available information of otoliths readings in GSA 06 was borrowed to estimate the vBGP that were later used to estimate catch-at-age number in GSA 06 and 07 combined by slicing. The data and process used to estimate the vBGP of anchovy in GSA 06 are below explained. The Spanish Institute of Oceanography (IEO) has a large data set of otolith readings of anchovy in GSA 06 harvested by fisheries since 2005 (n=8054). Additionally, there are some otolith readings of larvae of this species from 1995 to 2003. The otolith readings obtained through two research projects; FIL in 1988 and 1989 (n= 179) and JUVALION in 2009 (n=58) were contributed by Dr. Isabel Palomera from the Marine Science Institute of Barcelona (ICM-CSIC). Additionally, Dr. Alberto Garcia of the IEO Malaga contributed several otolith readings of anchovy obtained from 1995 to 2003 (117 in 1995, 138 in 1997, 305 in 1998, 121 in 2000, 189 in 2001 and 118 in 2003). All these sources of information on growth were used to update the estimates of the von Bertalanffy growth parameters of anchovy. In order to merge the available information on growth, only were used those otolith readings derived from fisheries for the spawning peak of anchovy (June-August, n=2901). The updated estimates of the von Bertalanffy growth parameters were calculated by the Bayesian Von Bertalanffy Growth Model - B-VBGM (Catalan, 2018) (Table 5.1.1.22).

Table 5.1.2.23. von Bertalanffy growth parameters estimated by the B-VBGM - Bayesian Von Bertalanffy Growth Model (Catalan et al., 2018) as indicated in the deliverable 1.3.1.1. The vBGP were estimated using otolith readings from GSA6.

Linf	K	t0	n	period	method
18	0.984	-0.255	3510	1995-2003 (larvae) 2005-2017 (adults)	B-BVGM

The deliverable 1.3.2.1 (Report on gonadosomatic index, size at first maturity and reproductive parameters) explored and updated the percentage of mature individuals at age. This information was used to set the maturity vector of the anchovy stock (Table 5.1.2.24). The fecundity of the species has presumably decreased because individuals are smaller than before 2010, the percentage of maturity at age zero was precautionarily set to 0.

Table 5.1.2.24. Maturity vector used to set the maturity-at-age of anchovy in GSA 06 and 07.

Age	0	1	2	3
Maturity	0	0.98	0.99	1

The natural mortality used in recent stock assessments of anchovy is usually estimated with Gislason’s first equation, among other reasons, because it produces an M-at-age vector with values around 1. However, this vector is produced when the vBGP has a very negative t0 (< -1.5). The updated vBGP obtained in this study to anchovy in GSA 06 and borrowed to anchovy in GSA 06 and 07 combined hold a t0 near zero (> -0.3). Consequently, the Gislason’s estimator produces M-at-age for the most fished ages (0 and 1) with too high values (between 3.5 and 1) (see deliverable D.1.4.1), promoting that the stock is perceived as lower overexploited or even underexploited.

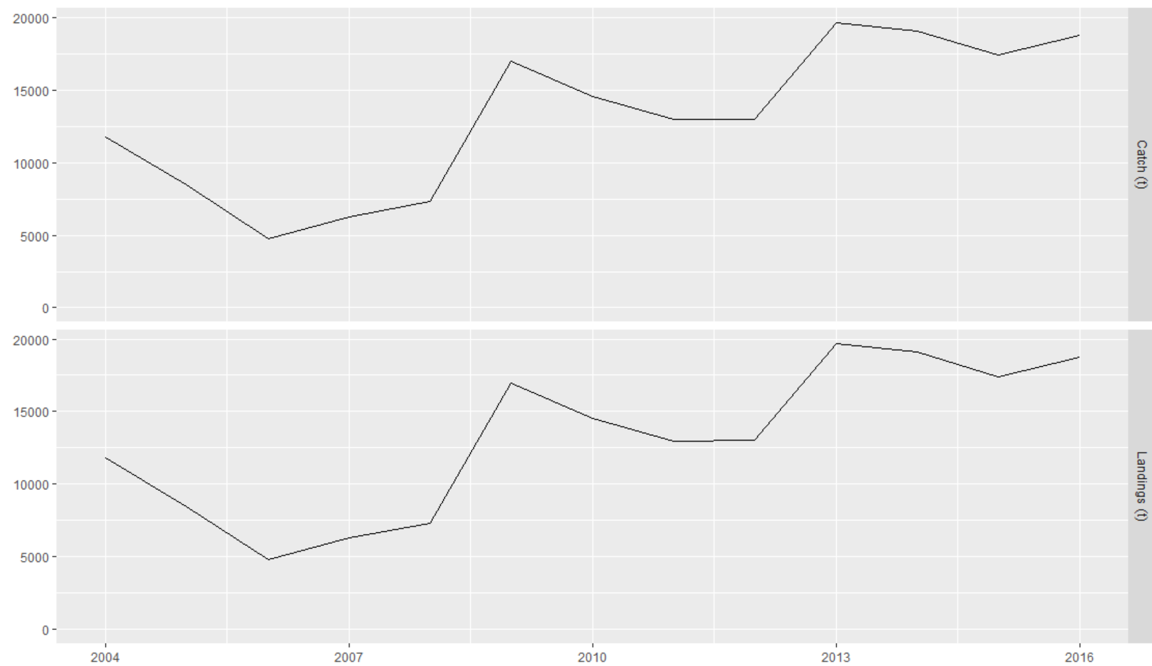
The updated vBGP of anchovy meets the biology rationale of a short-lived species, growing fast during the first year to follow a very low increase of size-at-age after this point. Thus, the t0 near zero makes sense to this species. In order to avoid too high values of M for younger individuals, it was preferred to use the Prodbiom estimator of natural mortality (Abella et al., 1997) (Table 5.1.2.25). This estimator relies on the fact that losses of biomass associated to natural mortality are compensated by production (growth). Therefore, this estimator may be reasonable used to estimate the M of species where there is indications of changes of mortality with age, as small pelagic species.

Table 5.1.2.25. Natural mortality at age (M-at-age) of anchovy in GSA 06 and 07 estimated by Prodbiom

Age	0	1	2	3
M	1.18	0.72	0.5	0.42

The reported catches of anchovy in GSA 06 and GSA 07 as combined stocks decreased from 2004 to 2006. Since 2007, the catches of this species has been increasing until reach the highest value in 2014 (19953 tons). These results mean that catches of sardine in recent years (after 2009) represent 159% of catches of early years of the time series (before 2008). Because there is no reliable temporal information of discards and values are absent or very low for most of the available period of catches, the discards were assumed as zero.

Table 5.1.2.26. Catches of anchovy in GSA 06 and 07. Discards are assumed as zero tons, meaning that catches correspond to the reported landings.



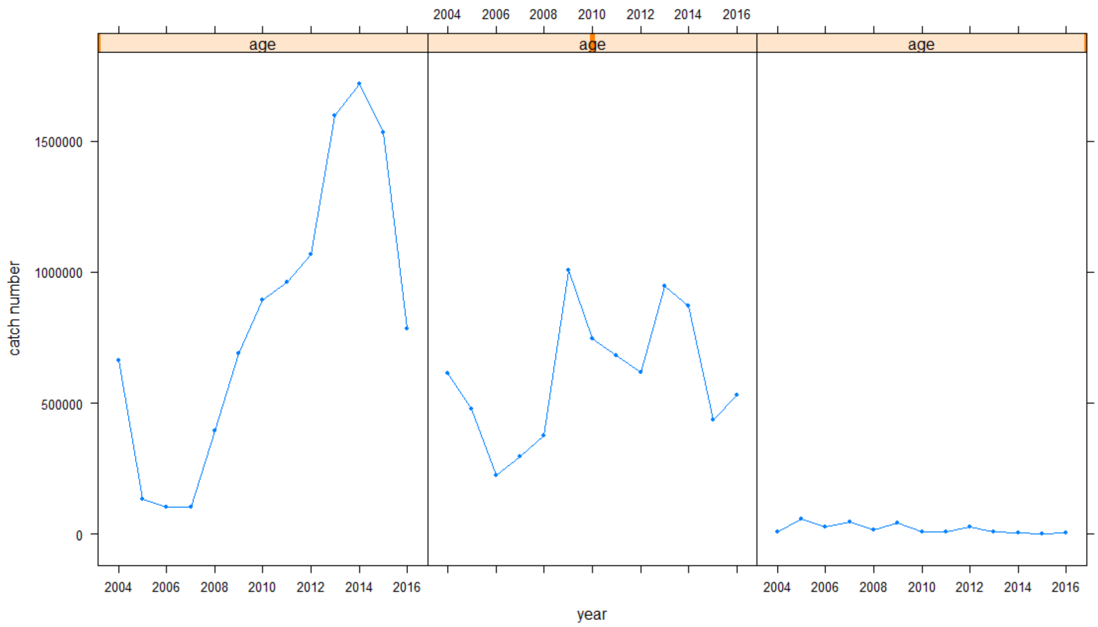
Weight at age used to estimate the total catches at age of anchovy in GSA 06 and GSA 07 as combined stocks. Data was obtained as average of the weight at age by year in GSA 06 and GSA 07 (Table 5.1.2.27).

Table 5.1.2.27. Weight at age of anchovy in GSA 06 and 07. Data obtained from the Spanish Institute of Oceanography

Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0	0.0055	0.006	0.0075	0.008	0.007	0.0065	0.0065	0.0055	0.006	0.006	0.0055	0.0075	0.0105
1	0.013	0.0135	0.0145	0.015	0.0115	0.0115	0.0115	0.011	0.01	0.0105	0.011	0.0135	0.0195
2	0.018	0.019	0.023	0.019	0.0175	0.0165	0.015	0.0155	0.014	0.0145	0.0145	0.02	0.029
3	0.0215	0.0225	0.029	0.025	0.021	0.023	0.0205	0.0195	0.018	0.018	0.018	0.027	0.037
4	0.024	0.024	0.037	0.028	0.021	0.025	0.022	0.02	0.018	0.019	0.016	0.036	0.055

The fishery of anchovy in GSA 06 and GSA 07 as combined stocks mainly harvest individuals of ages 0 and 1, while those individuals of age two are scarce represented (Fig. 5.1.2.19). There was a trend to show higher number of individuals after 2007.

Fig. 5.1.2.19. Number at age of anchovy individuals in GSA 06 and 07 after slicing using the updated vBGP above shown. Plus group has been set for age 2.



5.1.2.3.2 Stock assessment

The anchovy stock (GSA 06 and GSA 07 combined) was assessed using different source of data as showed in the Fig. 4.1.2.1. The catch-at-age matrix obtained from ALK (and *M* estimated by Gislason) suggested that *F* has decreased since 2004. Accordingly, the stock size started to increase since early years, showing higher increasing since 2010. The catch-at-age matrix derived from slicing using the updated vBGP suggested that *F* has increased along the time series until 2014, when started to decrease (Fig. 5.1.2.20). Once F decreased (after 2015), the stock size seemed to increase, although it is a short time to be confident about that trend. Therefore, both sources of catch-at-age matrix led to opposite results on the stock trend. Diagnostics provided by the stock assessment and rationale related to the life-history parameters data were used as indications to select the stock assessment model based on the slicing instead of ALK to assess the status of the combined stock of anchovy in GSA 06 and GSA 07.

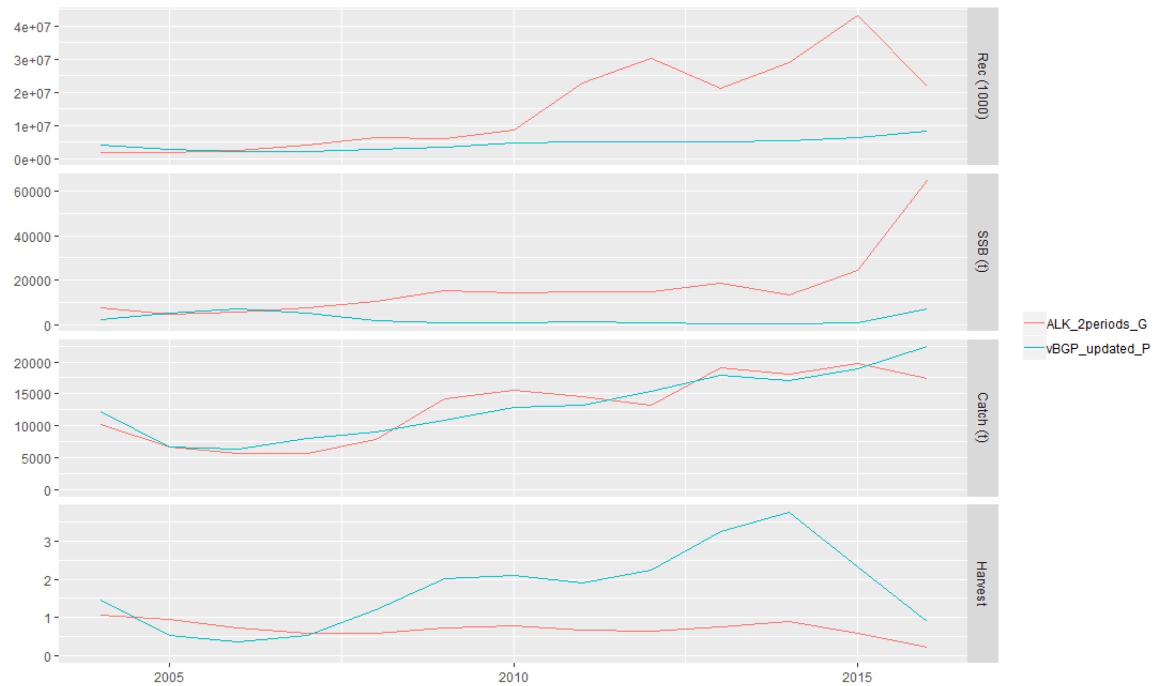


Fig. 5.1.2.20. Results of the stock assessment of the anchovy GSA 06 and GSA 07 (combined stocks) when catch-at-age matrix is obtained from ALK data aggregated in two periods (2002-2010 and 2011-2016) (ALK_2periods_G), sliced using the updated vBGP (vBGP_updated_P).

The stock assessment model set the fishing mortality submodel (fmodel) using a separable model in which age is modeled as dummy variable and year effects are modelled as (unpenalised) thin plate spline (Table 5.1.2.28). It should be assumed, as occurred in sardine that ages older than one have the same F than age one because the gear can entirely select all ages older than one. However, the stock assessment model produced poor diagnostics when this setting was used. Then, it was accepted that older ages might have lower F than the most fished ages. However, how the Fbar (the most fished ages) exclude older ages than 1, the perceived harvesting was not affected. The catchability submodel (qmod) was only related to the Medias and Pelmed index combined (since 2009), because the stock assessment diagnostics were worse when the index data before 2009 was included. It was considered that catchability at a specific age to be dependent on catchability on the other ages. It was also explored the trend in catchability with time because the index data did not properly fit the catch data. Finally, the stock-recruitment submodel used a smooth model with 9 degrees of freedom (Table 5.1.2.28).

Table 5.1.2.28. Submodels setting of the the sca method

fmod = ~factor(age) + s(year, k = 6)
qmod =list(~ s(age, k=3) + year)
srmod =~s(year, k = 9)
fit <- sca(stk, medias+pelmed, fmodel=fmod,qmodel=qmod,srmodel=srmod)

The stock assessment of anchovy GSA 06 and GSA 07 as combined stock produced low residuals (most of them below 1.5) (Fig. 5.1.2.21). The fitted and observed catch-at-age were comparable (

Fig. 5.1.2.22). The fitted and observed index at age were variable among years, in general, showing the same trend (Fig. 5.1.2.23). Fishing mortality was a little high for age 1 from 2013 to 2014, meaning that Fbar (0-1) could be slightly affected (Fig. 5.1.2.24). Simulation of submodel settings produce reasonable uncertainty (Fig. 5.1.2.25). The retrospective analysis suggest that the stock size is increasing while fishing mortality tends to decrease (Fig. 5.1.2.26). However, if one or more years are eliminated of the analysis, the fishing mortality trend may change.

Fig. 5.1.2.21. Log residuals of catch and abundance indices obtained in the stock assessment of the anchovy in GSA 06 and 07.

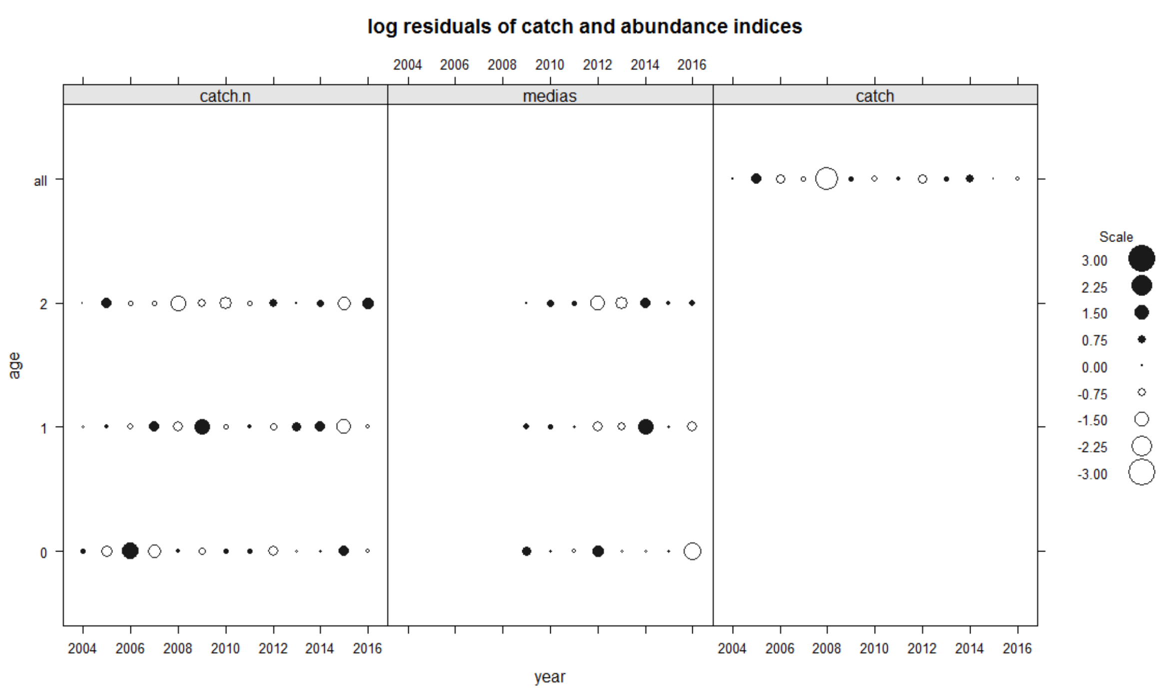


Fig. 5.1.2.22. Fitted and observed catch-at-age obtained in the stock assessment of the anchovy in GSA 06 and 07.

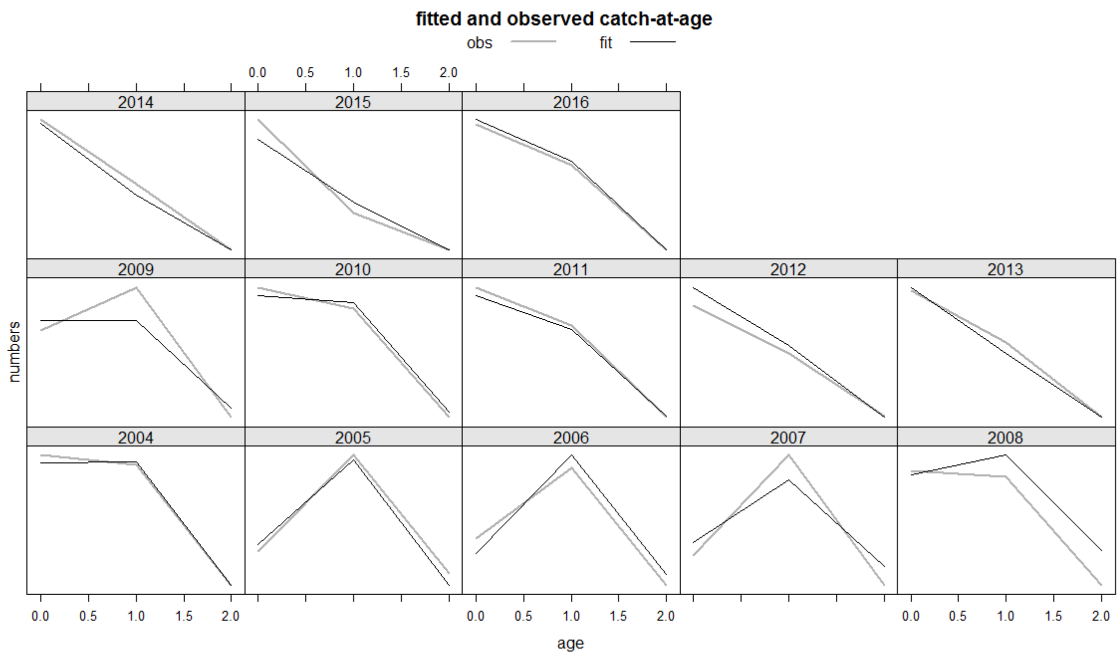


Fig. 5.1.2.23. Fitted and observed index at age obtained in the stock assessment of the anchovy in GSA 06 and 07.

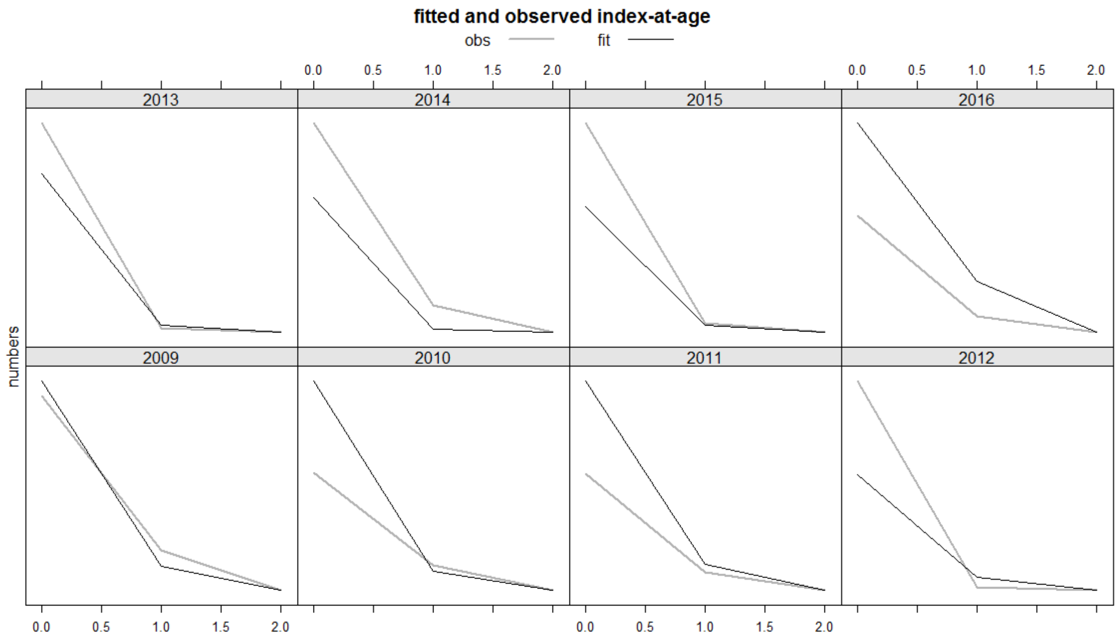


Fig. 5.1.2.24. Fishing mortality at age and year obtained in the stock assessment of the anchovy in GSA 06 and 07.

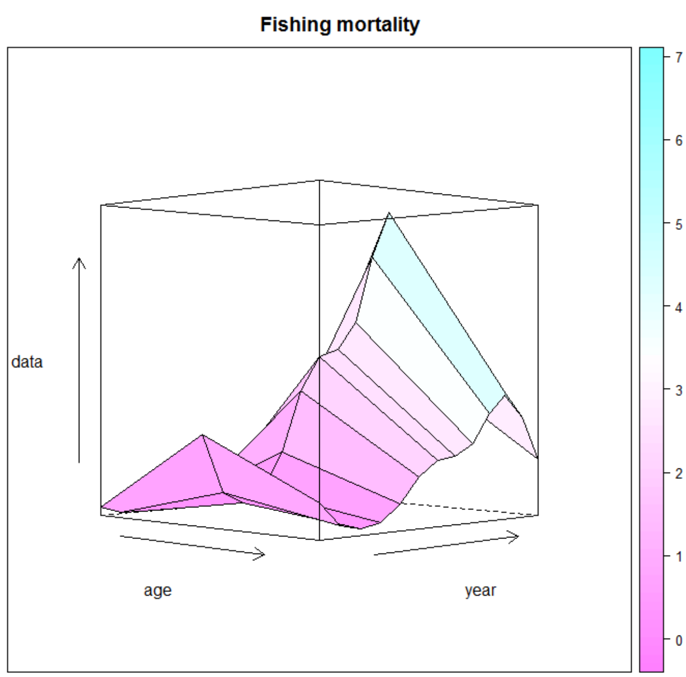


Fig. 5.1.2.25. Simulation of the fitted object that holds the stock assessment results of anchovy in GSA 06 and 07.

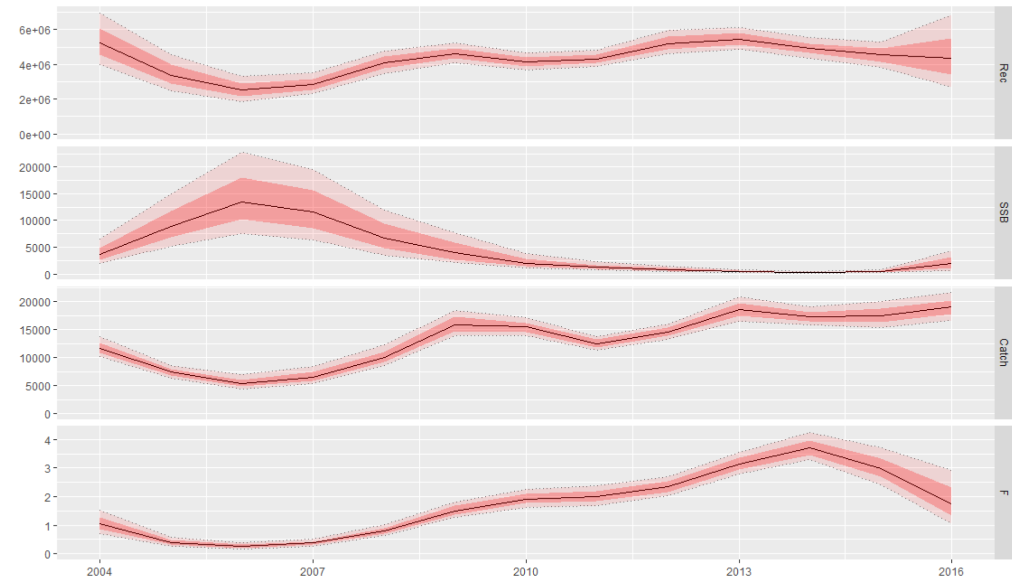
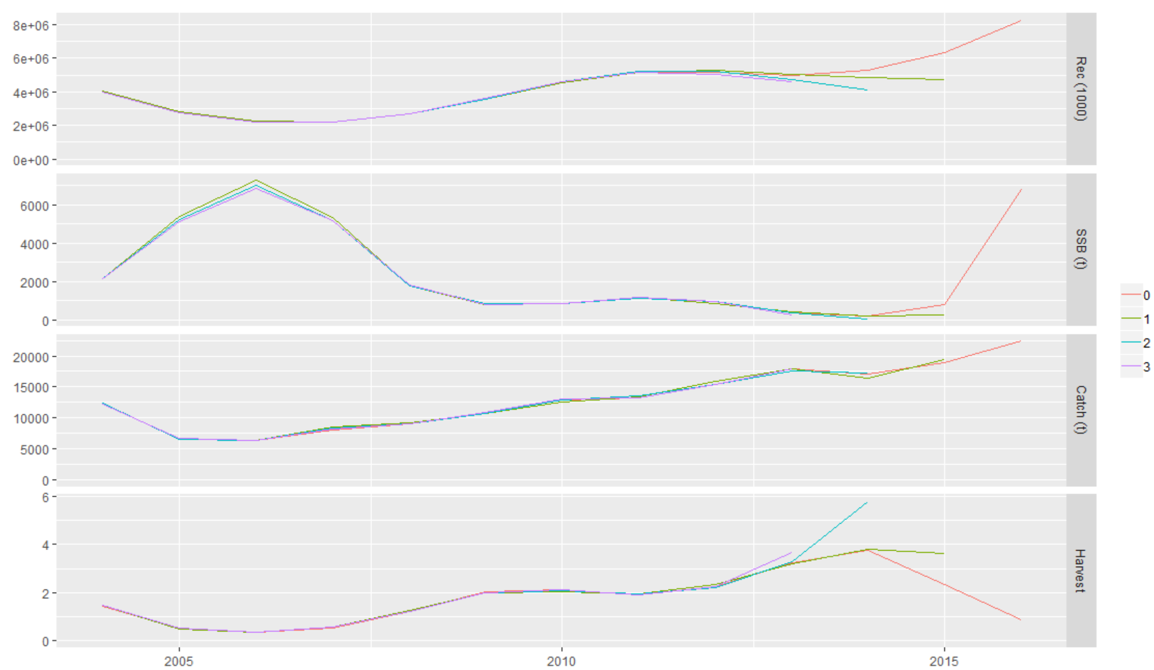


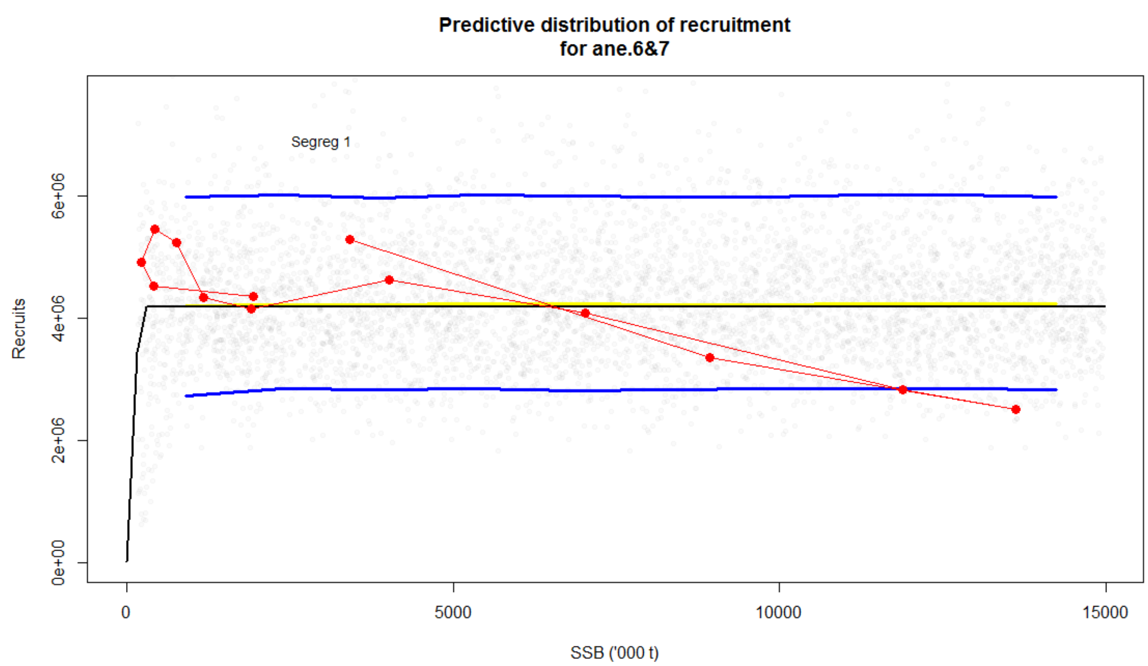
Fig. 5.1.2.26. Retrospective analysis of the stock assessment results of anchovy in GSA 06 and 07 when the last three, two or one years are omitted of the analysis.



5.1.2.3.3 Reference points

To estimate Blim (ICES, 2017) for anchovy in GSA 06 and GSA 07 as combined stocks, was tried a segmented regression stock recruitment relationship (Fig. 5.1.2.27). However, Blim estimated was very low (< 1000 tons). Therefore, Blim was calculated as the geometric mean of SSB (4289 tons). Blim was used to estimate Bpa. $Bpa = Blim * \exp(1.645 * \sigma)$, where σ was set equal to 0.2 (ICES, 2013). Thus, Bpa was estimated as 5960 tons. Fmsy was calculated as that value of fishing mortality that produces an exploitation rate (E=F/Z) equal to 0.4.

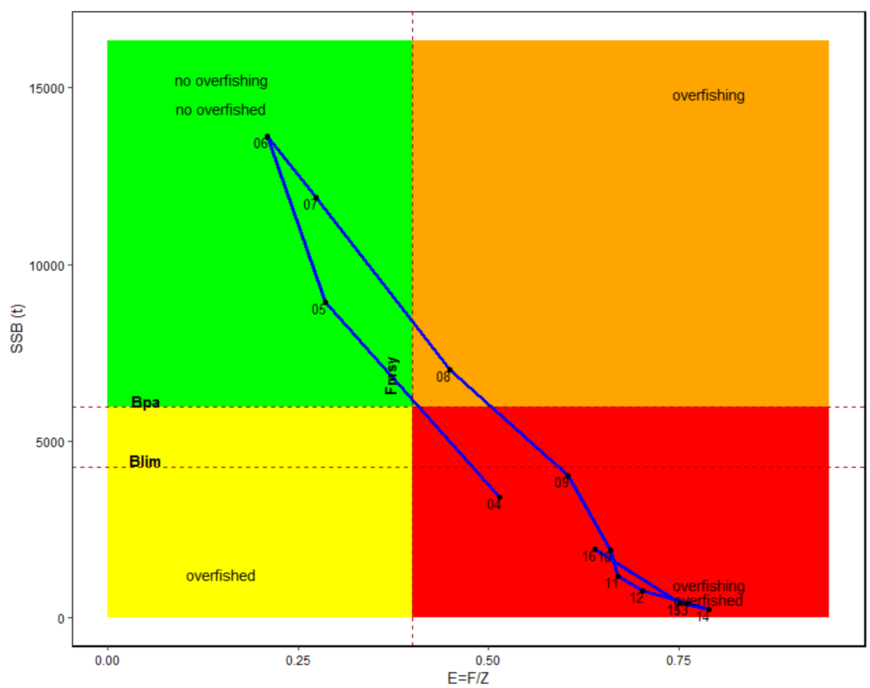
Fig. 5.1.2.27. Segmented regression performed with the R package msy ("ices-tools-prod/msy") used to estimate Blim of the anchovy in GSA 06 and 07.



5.1.2.3.4 Kobe plot

The combined stocks of anchovy in GSA 06 and GSA 07 are highly overexploited (SSB below Blim) and overfishing is occurring since 2008 (Fig. 5.1.2.28). From 2014 to 2016, the fishing mortality is decreasing but at levels that do not promote that overfishing stops nor the stock size overcome Bpa.

Fig. 5.1.2.28. Kobe plot for the anchovy stock in GSA 06 and 07using Blim, Bpa and E of Patterson as reference points.



5.1.2.3.5 Summary

		Bpa							Fmsy
		5960.00							0.4
Year	recruits	ssb	f0	f1	f2	harvest (f0-1)	Observed catch	model catch	E
2004	5274990	3424	0.22	1.88	0.75	1.05	11790.90	11727	0.59
2005	3363099	8928	0.08	0.71	0.28	0.40	8462.90	7444	0.35
2006	2504631	13616	0.06	0.47	0.19	0.26	4776.30	5416	0.27
2007	2830169	11883	0.08	0.67	0.27	0.37	6280.90	6611	0.36
2008	4090983	7032	0.17	1.44	0.57	0.81	7339.40	10318	0.55
2009	4631903	4021	0.32	2.70	1.08	1.51	16955.20	16139	0.67
2010	4142087	1913	0.41	3.43	1.37	1.92	14527.10	15423	0.68
2011	4329422	1174	0.43	3.58	1.43	2.00	12965.60	12486	0.66
2012	5234349	770	0.50	4.17	1.66	2.34	13006.70	14558	0.69
2013	5460652	428	0.67	5.62	2.24	3.15	19659.90	18547	0.77
2014	4917931	225	0.79	6.64	2.65	3.72	19082.80	17287	0.79
2015	4524748	413	0.64	5.34	2.13	2.99	17393.30	17496	0.70
2016	4350350	1936	0.38	3.14	1.25	1.76	18739.80	19328	0.47

5.1 Two-stage biomass model - 2-stage

5.1.1 European sardine (Sardina pilchardus)

5.1.1.1 Sardine GSA 06

Table 5.1.1.1 shows the data for the two surveys and the landings reported for sardine in GSA 06. Table 5.1.1.2 shows the model parameters. Model parameter *g* represents the net growth of the population (in biomass) and was derived using Gras et al. (2014) suggested method which takes into account natural mortality (M) and the von Bertalanffy growth parameters. The latter were the updated parameters shown in this report. Note that the validity of the value of *g* = 0.497 introduced was compared to the likelihood profile of *g* in the range 0.1 – 1.5, which produced minimum values in the range 0.25 to 0.60.

Table 5.1.1.1. Data for the application of the two-stage model to sardine in GSA06. Note that survey indices are scaled to mean 0 and unit variance.

year	Survey1 Adults	Survey1 Recruits	Survey2 Adults	Survey2 Recruits	landings (t)
2004	1.05281	2.04681			22833
2005	1.57545	1.39979			20983
2006	1.96584	1.06652			27145
2007	0.76706	0.37872			22911
2008	0.15189	0.48841			16186
2009	0.48694	0.61975	0.24929	1.00963	8997
2010			0.71378	0.54810	8752
2011			1.77249	1.05695	12135
2012			0.72121	1.59694	9193
2013			0.87361	1.78109	9734
2014			0.35185	0.19062	9659
2015			0.93191	0.94197	6309
2016			1.22179	1.02290	9934
2017			2.16408	0.85181	4590

Table 5.1.1.2. Mortality, growth and timing of indices (fraction of the year):

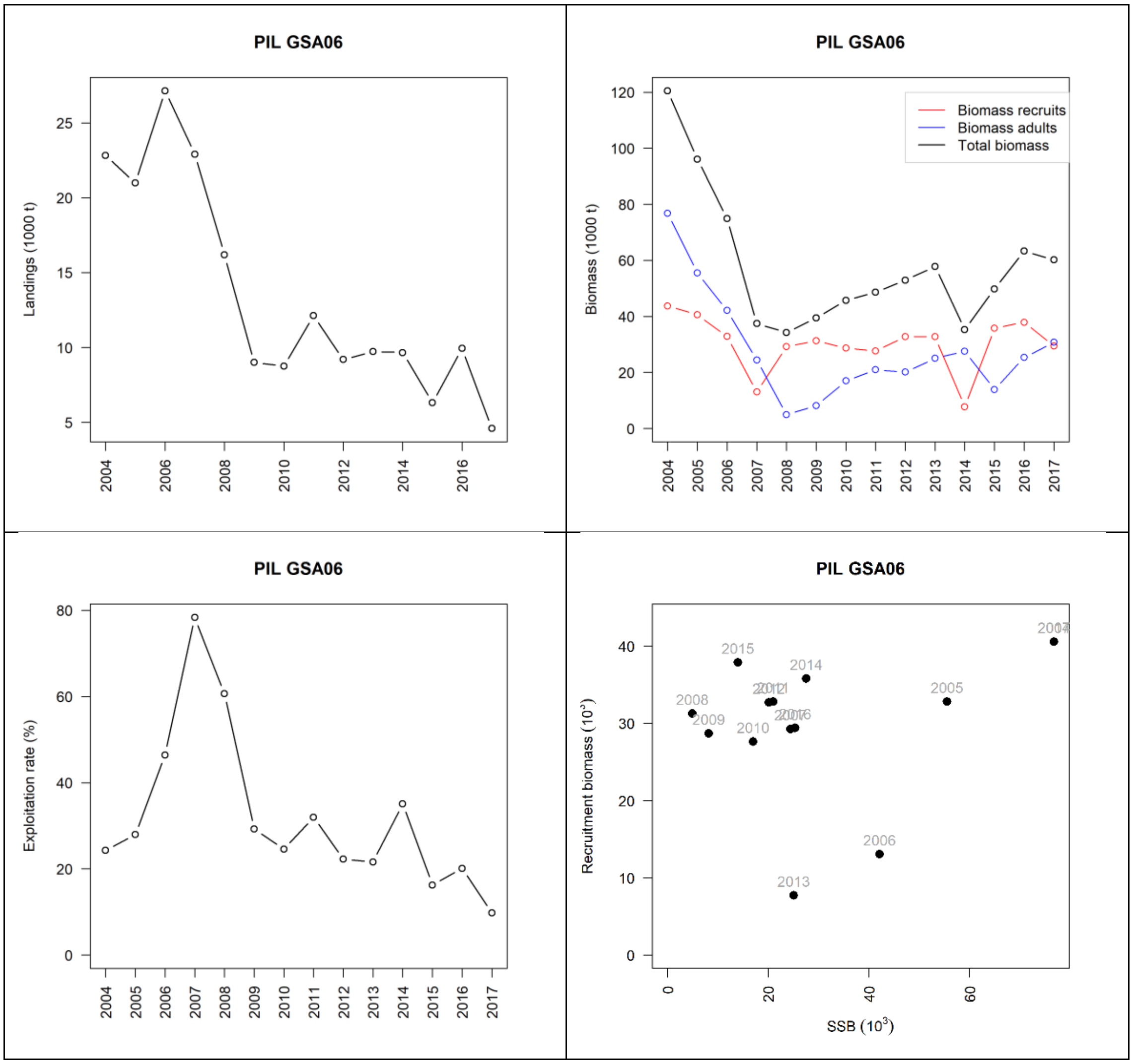
Natural mortality (weighted average)	0.65 yr^{-1}
g (Gras et al., 2014 method)	0.497 yr^{-1}
Survey1 Juveniles	0.0
Survey1 Adults	0.0
Survey2 Juveniles	0.5
Survey2 Adults	0.5
Fishing pulse	0.5

Table 5.1.1.3. Initial starting values for estimates of the population and the catchability

	Biomass	Catchability of survey
Juveniles	30000 (range explored: 15000 to 70000)	k_J= exp(-9) = 0.000122341
Adults	80000 (range explored 75000 to 150000)	K_A= exp(-9) = 0.000122341

The results of the two-stage biomass model for sardine in GSA06 with the data and parameters given are shown in Fig. 5.1.1.1. The series of landings shows an important decline from 2008, with a decrease by more than half from the earlier values of 20-25 000 t annually to around 10 000 t annually (and only 5 000 in the last year of the series 2017). This strong decrease in biomass coincides with a high exploitation rate pulse in 2006-2008, when the exploitation rate increased over 40%. Note also how during the period of low landings and low biomass (2008-2017) practically all years show higher biomass of age 0 individuals (recruits) than age 1+ (adults). No consistent stock / recruitment relationship is apparent in the series (Fig. 5.1.1.1 bottom right).

Fig. 5.1.1.1. Sardine in GSA06. Top left: Landings (1000 t). Top right: Biomass (1000 t) of recruits (red line), adult (blue line) and total. Bottom left: exploitation rate (landings / biomass). Bottom right: spawning stock (adults) – recruitment.



5.1.1.2 Sardine GSA 07

Table 5.1.1.4 shows the index data for the summer survey and the landings reported for sardine in GSA 07. Table 5.1.1.5 shows the model parameters. The value of the model parameter *g* derived using Gras et al. (2014) was 0.497, which was not within the range of minimum values produced by the likelihood profile (tested over the range 0.1 – 1.5). The minimum value obtained was 0.7 and it was used as *g* in the model. Note that this result suggests that sardine in GSA07 grows faster than sardine in GSA 06.

Table 5.1.1.4. Data for the application of the two-stage model to sardine in GSA 07. Note that survey indices are scaled to mean 0 and unit variance.

year	Survey2 Adults	Survey2 Recruits	landings (t)
2002	1.68044	0.38567	9534.5
2003	1.89393	0.48532	5788.0
2004	2.91150	0.98052	8540.5
2005	3.55410	0.83819	10305.5
2006	1.39654	0.01191	10736.6
2007	1.14317	0.00065	13739.3
2008	0.59874	1.59922	6934.2
2009	0.22274	1.36588	7418.0
2010	0.21854	1.46512	1826.3
2011	0.17979	1.01228	819.3
2012	0.43379	1.62331	642.2
2013	0.13624	1.47545	1036.3
2014	0.29740	0.95556	632.8
2015	0.20323	1.28509	347.5
2016	0.12985	1.51583	819.9

Table 5.1.1.5. Mortality, growth and timing of indices (fraction of the year):

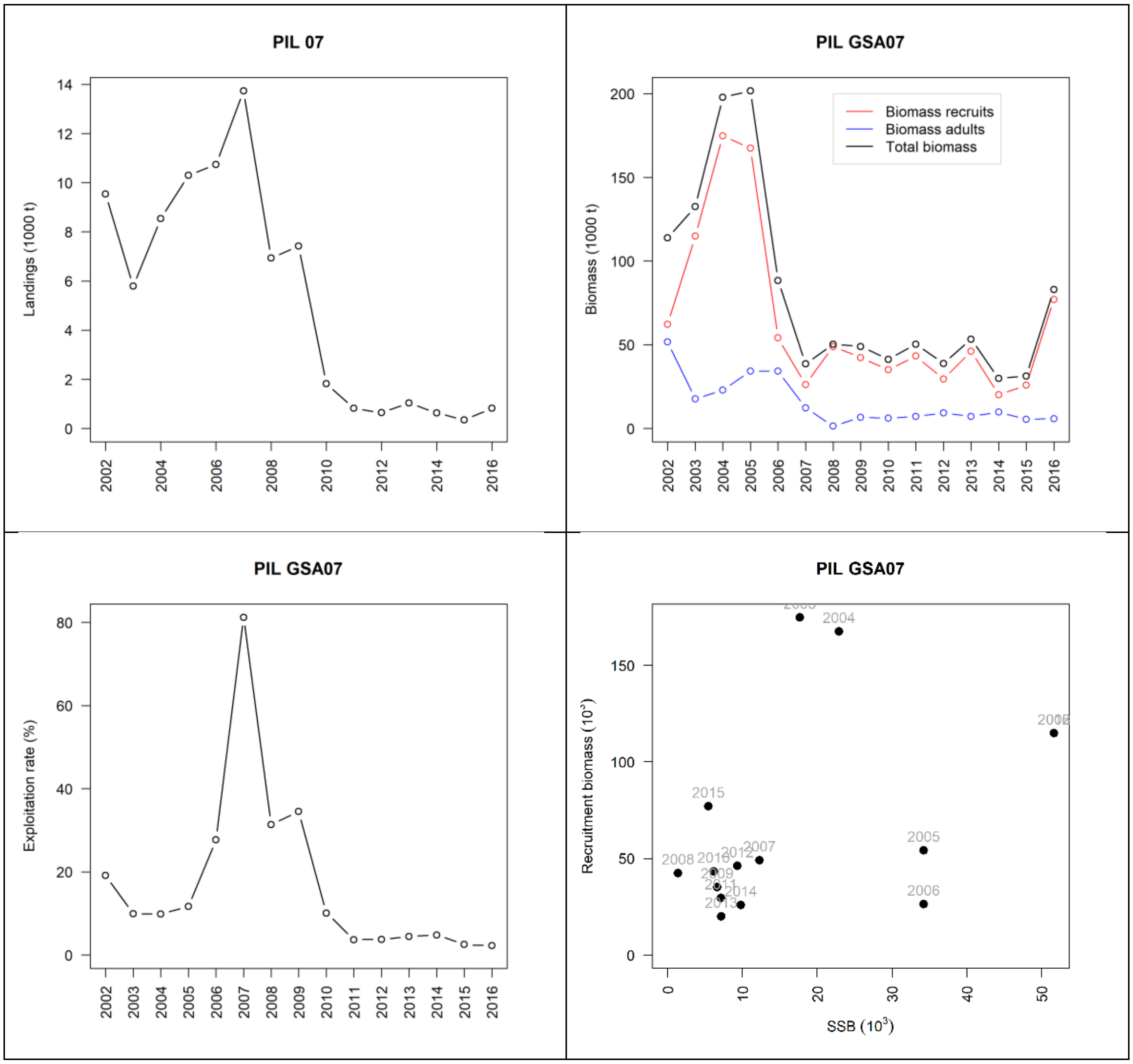
Natural mortality (weighted average)	0.65 yr^{-1}
g (likelihood profile)	0.7 yr^{-1}
Survey2 Juveniles	0.5
Survey2 Adults	0.5
Fishing pulse	0.5

Table 5.1.1.6. Initial starting values for estimates of the population and the catchability

	Biomass	Catchability of survey
Juveniles	40000 (range explored: 15000 to 70000)	k_J= exp(-9) = 0.000122341
Adults	80000 (range explored 50000 to 150000)	K_A= exp(-9) = 0.000122341

The results of the two-stage model for sardine in GSA 07 are given in Fig. 5.1.1.2The landings fluctuated between 6 and 14 000 t between 2002 and 2009 and later decreased to levels below 2000 t. However, note how the high landings of 2007 coincided with low values of biomass and very high exploitation rates (80%). The high value of landings in the early period are attributable to a large extent to the high recruitment of 2003-2005. Since 2006, recruitment has fluctuated around 50 000 t, but the adult fraction of the population has continued at very low levels.

Fig. 5.1.1.2. Sardine in GSA07. Top left: Landings (1000 t). Top right: Biomass (1000 t) of recruits (red line), adult (blue line) and total. Bottom left: exploitation rate (landings / biomass). Bottom right: spawning stock (adults) – recruitment.



5.1.1.3 Sardine GSA 6&7

Table 5.1.1.7. shows the index data for the summer survey and the landings reported for sardine in GSAs 06+07 combined. Note that data could be combined for the period 2009-2016 only because acoustic surveys in GSA06 were carried out in winter prior to that date. Table 5.1.1.8 shows the model parameters. Here the *g* parameters used was 0.7 as in the previous section, and was consistent with range of minimum values produced by the likelihood function.

Table 5.1.1.7. Data for the application of the two-stage model to sardine in GSAs 06+07. Note that survey indices are scaled to mean 0 and unit variance.

year	Survey2 Adults	Survey2 Recruits	landings (t)
2009	0.75160	1.01095	16415.0
2010	0.91870	0.90265	10578.3
2011	1.21372	0.85412	12954.3
2012	1.55483	1.33638	9835.2
2013	0.73834	1.32665	10770.3
2014	1.01087	0.53202	10291.8
2015	0.95792	0.94845	6656.5
2016	0.85404	1.08878	10753.9

Table 5.1.1.8. Mortality, growth and timing of indices (fraction of the year):

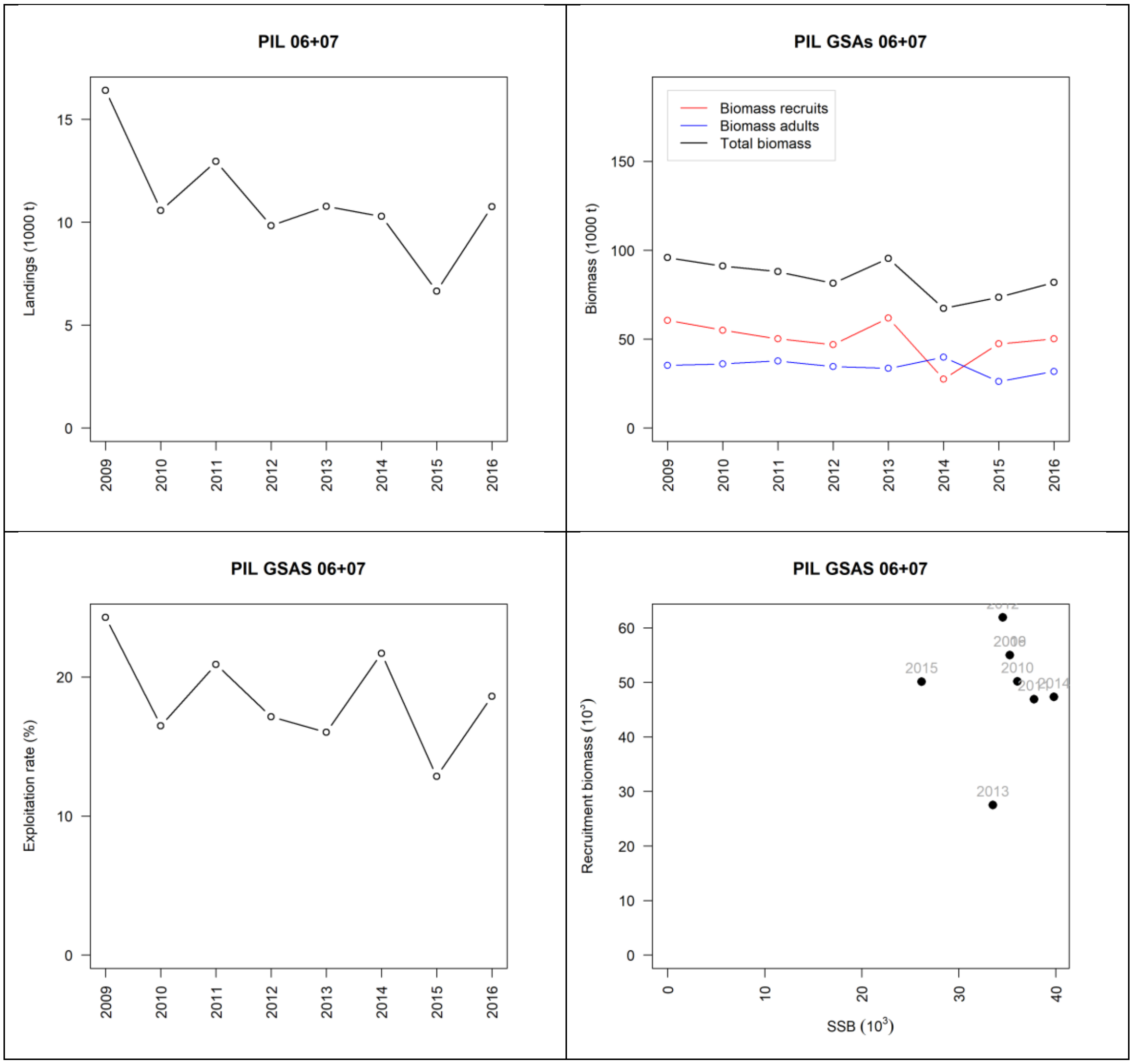
Natural mortality (weighted average)	0.65 yr^{-1}
g (likelihood profile)	0.7 yr^{-1}
Survey2 Juveniles	0.5
Survey2 Adults	0.5
Fishing pulse	0.5

Table 5.1.1.9. Initial starting values for estimates of the population and the catchability

	Biomass	Catchability of survey
Juveniles	30000 (range explored: 15000 to 70000)	k_J= exp(-9) = 0.000122341
Adults	70000 (range explored 50000 to 150000)	K_A= exp(-9) = 0.000122341

The results of the two-stage model for sardine in GSAs 06+07 are given in Fig. 5.1.1.3. All the quantities (landings, biomass, and exploitation rate) decreased slowly over the period 2009-2016, repeating the same trends for the same period in the two GSAs separately. Note however that the values of biomass estimated for the two combined areas are lower than the sum of biomasses estimated for the two areas. The combined analysis does not add more information than the separate analyses, probably because the data series is shorter.

Fig. 5.1.1.3. Sardine in GSAs 06+07. Top left: Landings (1000 t). Top right: Biomass (1000 t) of recruits (red line), adult (blue line) and total. Bottom left: exploitation rate (landings / biomass). Bottom right: spawning stock (adults) – recruitment.



5.1.2 European anchovy (Engraulis encrasicolus)

5.1.2.1 Anchovy GSA 06

Table 5.1.2.1 shows the data for the two surveys and the landings reported for anchovy in GSA 06. Table 5.1.2.2 shows the model parameters. Model parameter g was derived using Gras et al. (2014) method which takes into account natural mortality (M) and the von Bertalanffy growth parameters. The latter were the updated parameters shown in this report. Note that the validity of the value of g = 1.222 introduced was compared to the likelihood profile of g in the range 0.1 – 1.5, which produced minimum values in the range 1.15 to 1.45.

Table 5.1.2.1. Data for the application of the two-stage model to anchovy in GSA 06. Note that survey indices are scaled to mean 0 and unit variance.

year	Survey1 Adults	Survey1 Recruits	Survey2 Adults	Survey2 Recruits	landings (t)
2003	0.88004	1.41229			8538
2004	2.10079	0.62760			8097
2005	1.36979	0.22937			6216
2006	1.22872	0.52075			3096
2007	0.27142	0.35555			2820
2008	0.32608	2.23565			3532
2009	0.82315	1.61879	0.64891	0.48096	12137
2010			1.02818	0.21109	9886
2011			0.79343	0.21124	9534
2012			0.22081	1.63896	11434
2013			0.26888	1.14356	17178
2014			1.73855	1.24760	16850
2015			0.89402	1.92983	16600
2016			1.16159	1.12152	17502
2017			2.24562	1.01524	18242

Table 5.1.2.2. Mortality, growth and timing of indices (fraction of the year):

Natural mortality (weighted average)	0.83 yr^{-1}

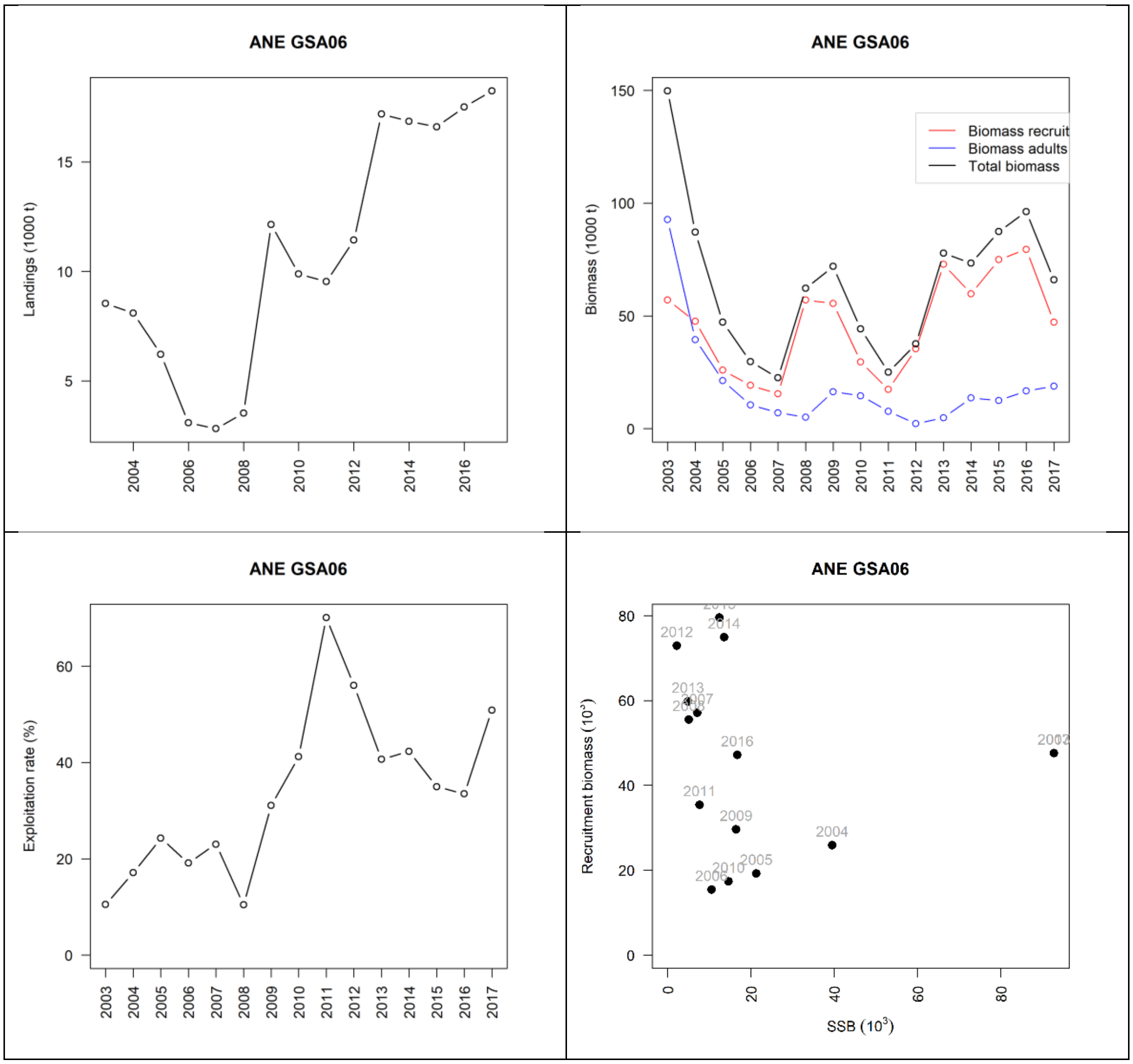
g (Gras et al., 2014 method)	1.222 yr^{-1}
Survey1 Juveniles	0.5
Survey1 Adults	0.5
Survey2 Juveniles	0.0
Survey2 Adults	0.0
Fishing pulse	0.5

Table 5.1.2.3. Initial starting values for estimates of the population and the catchability

	Biomass	Catchability of survey
Juveniles	40000 (range explored: 15000 to 70000)	k_J= exp(-9) = 0.000122341
Adults	100000 (range explored 50000 to 150000)	K_A= exp(-9) = 0.000122341

The results of the two-stage model for anchovy in GSA 06 are given in Fig. 5.1.2.1. In the initial period 2003-2008 the important decreasing landings correlated with a sharp decrease in the stock biomass, from ca. 150 000 t to ca. 30 000 t. Exploitation rate was not excessive, fluctuating around 20%. However, after 2009 exploitation rate increased, stabilizing around 40% in the later years of the series and resulting in the important increase in landings observed. Note also how the very high exploitation rate of 2011 resulted in reduced biomass but not particularly in high landings for that year. In the biomass series it is interesting to highlight also that the biomass of adults and recruits was similar in the initial period 2003-2008 but after 2009 the population is dominated by recruits. Because this species is exploited jointly with sardine, it is possible that the low productivity of the sardine stock since 2009 (cf.Fig. 5.1.1.1) can help explain the high exploitation rate and landings of anchovy, as the fleet switched to a more productive alternative.

Fig. 5.1.2.1. Anchovy in GSA 06. Top left: Landings (1000 t). Top right: Biomass (1000 t) of recruits (red line), adult (blue line) and total. Bottom left: exploitation rate (landings / biomass). Bottom right: spawning stock (adults) – recruitment.



5.1.2.2 Anchovy GSA 07

Table 5.1.2.4 shows the data for the summer survey and the landings reported for anchovy in GSA 07. Table 5.1.2.5 shows the model parameters. Contrary to sardine in GSA 07, here the growth parameter *g* derived from Gras et al. (2014) method was consistent with the values produced by the minimization of the likelihood function.

Table 5.1.2.4.Data for the application of the two-stage model to anchovy in GSA 07. Note that survey indices are scaled to mean 0 and unit variance.

year	Survey2 Adults	Survey2 Recruits	landings (t)
2002	4.06425	0.45690	7695.3
2003	0.90925	0.93534	6968.0
2004	1.00667	0.76356	5447.9
2005	1.37205	0.01308	2760.9
2006	2.02252	0.12566	2313.3
2007	1.16833	0.01758	4367.9
2008	1.95625	0.26198	4215.4
2009	1.00004	1.14160	4937.2
2010	0.24701	1.23736	4617.1
2011	0.26644	1.47020	3497.6
2012	0.11467	2.35738	1572.7
2013	0.01233	1.24405	2481.9
2014	0.26748	1.70664	2232.8
2015	0.08352	2.36517	793.3
2016	0.50921	0.90351	1237.8

Table 5.1.2.5. Mortality, growth and timing of indices (fraction of the year):

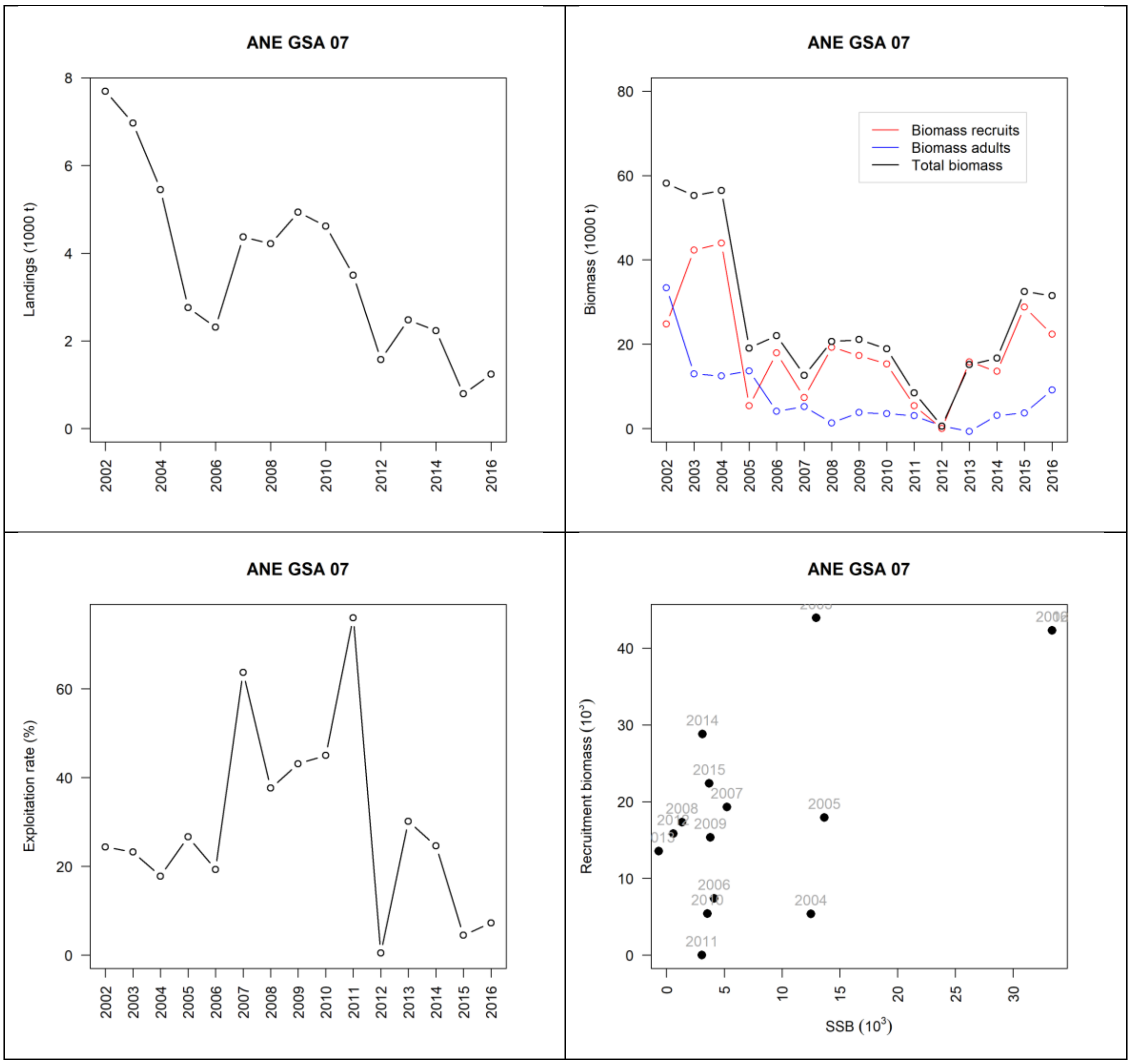
Natural mortality (weighted average)	0.83 yr^{-1}
g (Gras et al., 2014 method)	1.222 yr^{-1}
Survey2 Juveniles	0.0
Survey2 Adults	0.0
Fishing pulse	0.5

Table 5.1.2.6. Initial starting values for estimates of the population and the catchability

	Biomass	Catchability of survey
Juveniles	18000 (range explored: 10000 to 30000)	k_J= exp(-9) = 0.000122341
Adults	20000 (range explored 10000 to 40000)	K_A= exp(-9) = 0.000122341

The results of the two-stage model for anchovy in GSA 07 are shown in Fig. 5.1.2.2. In the period 2002-2006 the landings decreased progressively with moderate exploitation rates (20-25%), with relatively high biomass in the first 3 years of the series, particularly the recruitment peak of 2003-2004. From 2007 to 2011 the exploitation rate was above 40% every year and the biomass decreased low levels, particularly that of adults. Since 2005 the stock is dominated by the recruit fraction. The stock biomass is increasing in the last 3-4 years of the data series, although landings continue to decrease following the low exploitation rate of recent years.

Fig. 5.1.2.2. Anchovy in GSA 07. Top left: Landings (1000 t). Top right: Biomass (1000 t) of recruits (red line), adult (blue line) and total. Bottom left: exploitation rate (landings / biomass). Bottom right: spawning stock (adults) – recruitment.



5.1.2.3 Anchovy GSA 6&7

Table 3.2.2.16 shows the index data for the summer survey and the landings reported for anchovy in GSAs 06+07 combined. Note that data could be combined for the period 2009-2016 only because acoustic surveys in GSA06 were carried out in winter prior to that date. Table 5.1.2.7 shows the model parameters. Here the *g* parameters used was 1.222, as in the previous sections, and was consistent with range of minimum values produced by the likelihood function.

Table 5.1.2.7. Data for the application of the two-stage model to anchovy in GSAs 06+07. Note that survey indices are scaled to mean 0 and unit variance.

year	Survey2 Adults	Survey2 Recruits	landings (t)
2009	0.57611	0.73975	17074.2
2010	0.23156	0.85644	14503.1
2011	0.23386	0.94557	13031.6
2012	1.59787	1.33933	13006.7
2013	1.10738	0.73242	19659.9
2014	1.23631	1.23515	19082.8
2015	1.87572	1.45686	17393.3
2016	1.14118	0.69447	18739.8

Table 5.1.2.8. Mortality, growth and timing of indices (fraction of the year):

Natural mortality (weighted average)	0.83 yr^{-1}
g (Gras et al., 2014 method)	1.222 yr^{-1}
Survey2 Juveniles	0.0
Survey2 Adults	0.0
Fishing pulse	0.5

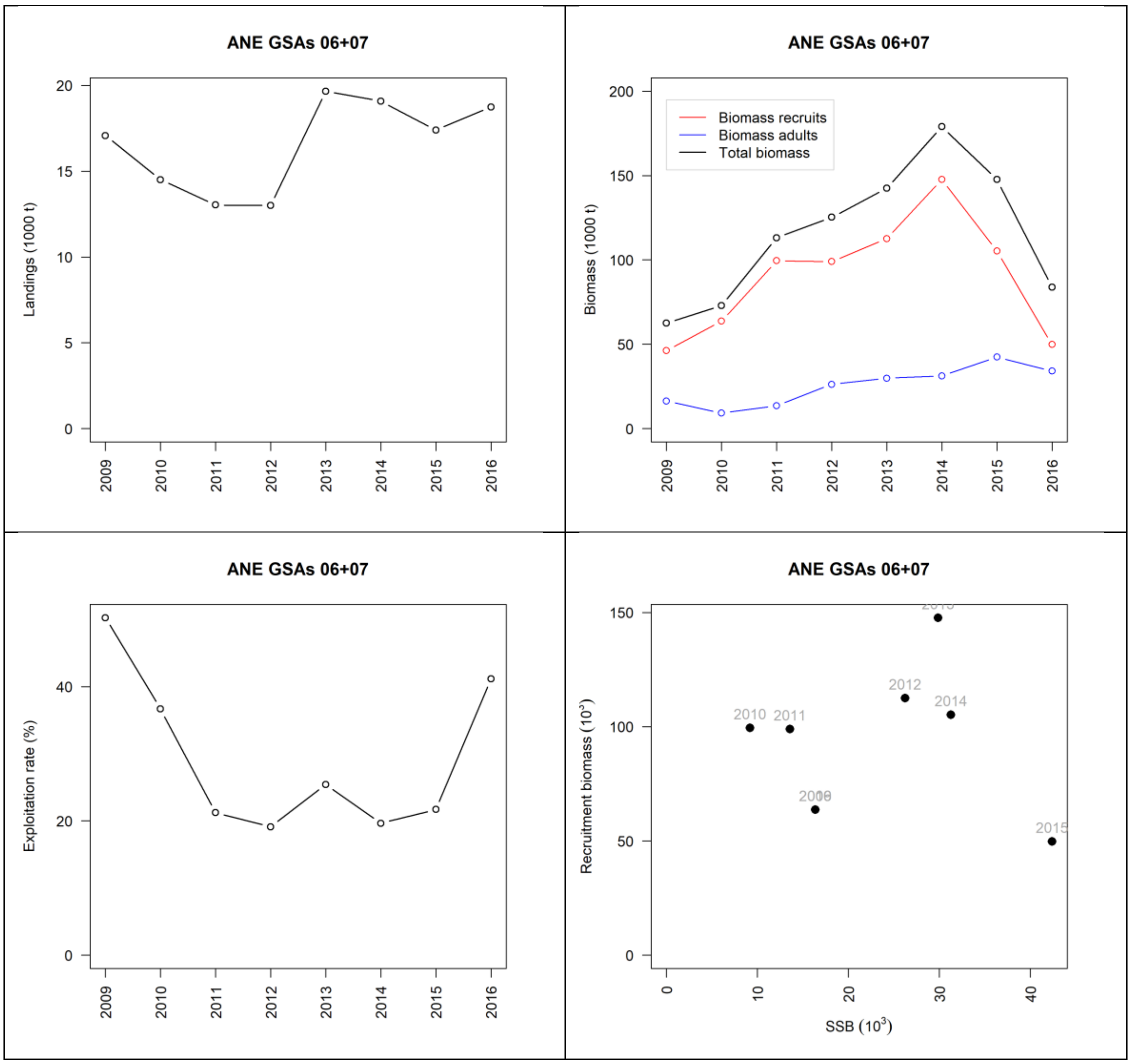
Table 5.1.2.9. Initial starting values for estimates of the population and the catchability

	Biomass	Catchability of survey

Juveniles	47500 (range explored: 30000 to 80000)	k_J= exp(-9) = 0.000122341
Adults	95000 (range explored 50000 to 120000)	K_A= exp(-9) = 0.000122341

Fig. 5.1.2.3 shows the result of the two-stage model for anchovy for the combined areas. As in the case of sardine, the results are not particularly informative because of the shortness of the series. Note however that the results reflect basically the dynamics of the anchovy stock in GSA06 for the period 2009-2016. The biomass of the combined stock is clearly dominated by the recruits fraction, increasing from 2009 to 2013 and decreasing in the last two years of the series. The estimated biomass values are higher in the combined stocks than the estimates for the two stocks separately. At the same time, exploitation rates are lower than the exploitation rates estimated separately for the two stocks, although more similar to the results of GSA06.

Fig. 5.1.2.3. Anchovy in GSAs 06+07. Top left: Landings (1000 t). Top right: Biomass (1000 t) of recruits (red line), adult (blue line) and total. Bottom left: exploitation rate (landings / biomass). Bottom right: spawning stock (adults) – recruitment.



5.2 Consistency of two-stage model with VPA assessments

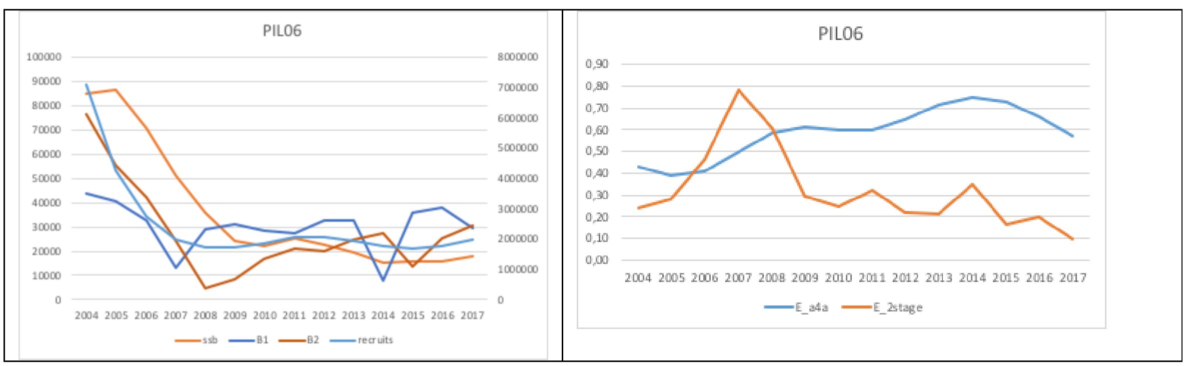
The quantities provided by the two-stage model and the results of VPA (a4a) assessments by species and GSA show in general that the trends in stock size of recruits and adults are comparable, while the exploitation rates provided by the two methods are completely different. The following comparative charts assume that the number of recruits (R) produced by a4a can be compared with the biomass of recruits (B1) produced by the two-stage model, while the spawning stock biomass (SSB) can be equated with the biomass of adults (B2). Similarly, the exploitation rate computed from the fishing mortality in a4a models can be compared with the exploitation rate derived from the two-stage models.

5.2.1 European sardine (Sardina pilchardus)

5.2.1.1 Sardine GSA 06

Both types of models reproduced approximately the same trends in recruits and adult stock size, with high stock size in the early years of the series and low stock size since 2007 approximately. Exploitation rates show very different patterns. The a4a model suggests increasing exploitation rate along the time series, while the two-stage model suggests a high exploitation rates in the years 2006-2008 and decreasing afterwards.

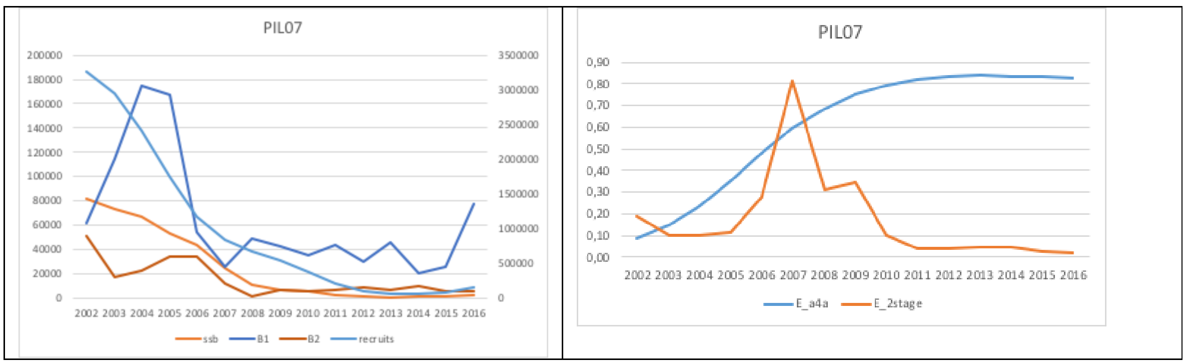
Fig. 5.2.1.1.



5.2.1.2 Sardine GSA 07

Similarly to GSA06, both models reproduce the important reduction in stock size in the latter part of the series (2006 onwards). The two-stage model estimates comparatively higher amount of recruits (and increasing in the last year of the series 2016) than the a4a model. Both models estimate very low levels of adults since 2009 approximately. As in GSA06, the exploitation rates produced by the two models are very different.

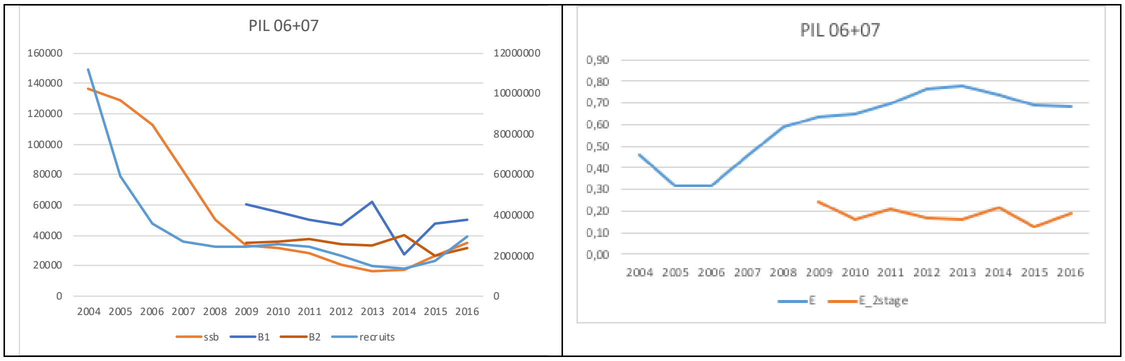
Fig. 5.2.1.2.



5.2.1.3 Sardine GSA 6&7

The stock assessment for the two areas combined produced approximately the same results than for the two areas separately. Note that the two-stage biomass model could only be run for the period 2009-2016, i.e. excluding 2004-2008 when the abundance index in GSA06 was based on winter surveys, and 2017 for which no data on landings was available for GSA07.

Fig. 5.2.1.3.

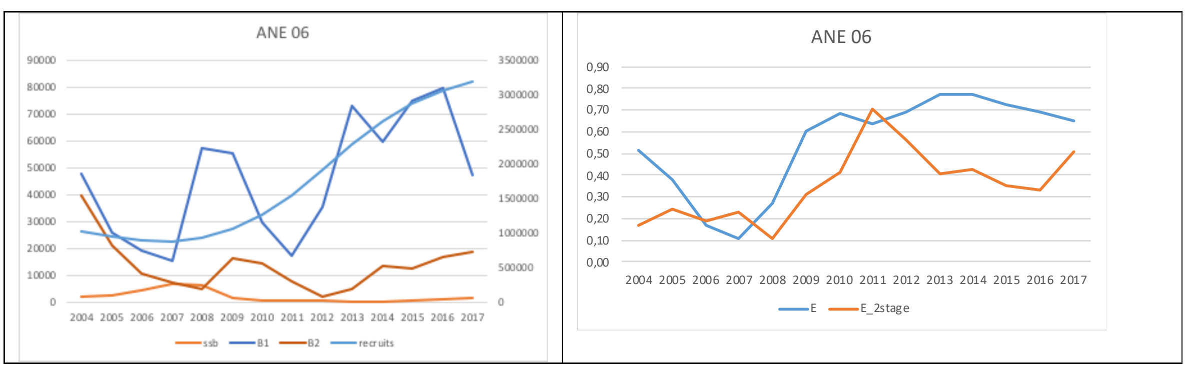


5.2.2 European anchovy (Engraulis encrasicolus)

5.2.2.1 Anchovy GSA 06

The estimation of recruits number for anchovy in GSA06 with a4a is consistent with the estimation of recruits biomass with the two-stage model in the sense of overall increase in age 0 stock size, but the details vary. On the other hand, the estimates of adult stock size produced by the two methods is different in magnitude and trend. The two estimates of exploitation rates have certain similarities, i.e. lower exploitation rate up to 2008 estimated with the two methods and high exploitation rates since 2009, but the two lines are not perfectly in phase.

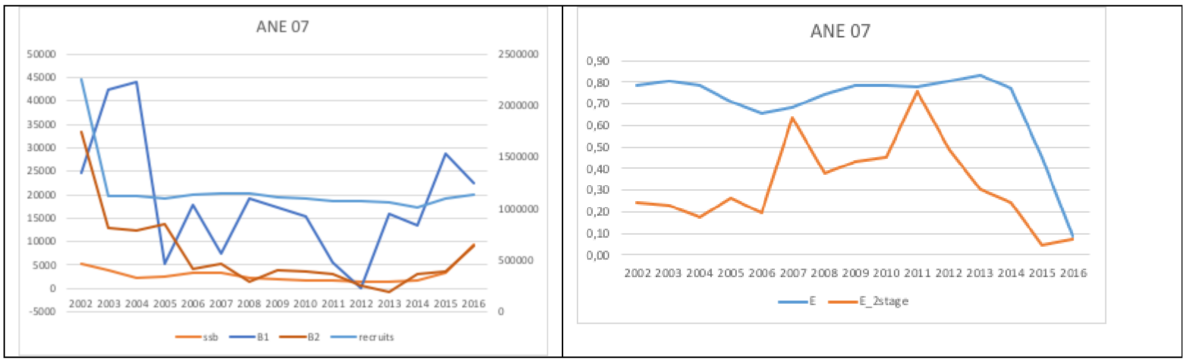
Fig. 5.2.2.1.



5.2.2.2 Anchovy GSA 07

The stock size estimates produced by the two methods differ in important details and both, in magnitude and trend. The only similarity is the increasing adult biomass (SSB or B2) in the last two years of the series. In terms of exploitation rates, both stock assessments provide different results, although they coincide in estimating very low exploitation rates in the last 1-2 years of the series.

Fig. 5.2.2.2.



5.2.2.3 Anchovy GSA 6&7

As in the case of GSA07, both methods provide different estimates of stock size and exploitation rate. Note also that the data series used in the two-stage model is necessarily shorter than in the a4a model, for the same reasons given in GSA06+07 – Sardine.

6. Description of data gaps and recommendations

- When weight at age and catch-at-age numbers were used to estimate total catch, the results did not match with the observed catch. Although the SOP correction may be used to fix the differences between the estimated and observed catches, priority should be given to obtaining better estimates of weight at age .
- Consensus on the uncertainty derived from the lack of knowledge on discards (or other pre-catch mortality, such as that derived from “slipping”) should be achieved, in order to consider this important source of uncertainty as part of the stock assessment scenarios.
- The stock results are quite sensitive to settings of the submodels in a4a (fmod, qmod and srmod). Both, consensus on the good practices to set the stock assessment model for a4a and use other catch-at-age models (Example: SAM or Stock synthesis) should be achieved to compare the quantitative results and trend on fishing mortality and stock size.

- More than one vector of natural mortality should be used to present the results of the stock assessment, in order to identify the status uncertainty when several assumptions or natural mortality estimators are used.
- The official data of both species in GSA 07 should be checked because several gaps in raw data were found. For instance, no information of catch-at-length number in 2011, unrealistic high catch-at-length number in 2013, no information on weight-at-age for some ages during several years, there is confusing information on vessel number per year. All these gaps in raw data probably prevented a better performance of the catch-at-age model used.

7. References

Gras, M., Roel, B. A., Coppin, F., Foucher, E., and Robin, J-P. A two-stage biomass model to assess the English Channel cuttlefish (*Sepia officinalis* L.) stock. – ICES Journal of Marine Science, 71: 2457–2468.

ICES, 2017. ICES fisheries management reference points for category 1 and 2 stocks. ICES Advice Technical Guidelines. Published 20 January 2017. DOI: 10.17895/ices.pub.3036.

Jardim, E., Millar, C., Scott, F., Osio, C and Mosqueira, I. 2017. Assessment for All initiative (a4a). The a4a Stock Assessment Modelling Framework. 53 p.

Pope, J. 1972.Aninvestigation of the accuracy of virtual population analysis using cohort analysis. ICNAF Research Bulletin, 9: 65–74.

Roel, B. A., and Butterworth, D. S. 2000. Assessment of the South African chokka squid *Loligo vulgaris reynaudii*. Is disturbance of aggregations by the recent jig fishery having a negative impact on recruitment? Fisheries Research, 48: 213–228.

Scott, F., Jardim, E., Millar, C. and Cerviño, S. An Applied Framework for Incorporating Multiple Sources of Uncertainty in Fisheries Stock Assessments. 2016. PLoS ONE 11(5): e0154922. doi:10.1371/journal.pone.0154922