RELATÓRIOS DE CAMPANHA

INTERNATIONAL SURVEY FOR THE ASSESSMENT OF THE STRENGTH OF THE SARDINE AND ANCHOVY RECRUITMENT IN ATLANTIC IBERIAN WATERS

"IBERAS0921"

Pablo Carrera, Sílvia Rodríguez, Pedro Amorim, Dina Silva, Gema Hernández e Ana Moreno

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INTERNATIONAL SURVEY FOR THE ASSESSMENT OF THE STRENGTH OF THE SARDINE AND ANCHOVY RECRUITMENT IN ATLANTIC IBERIAN WATERS

INSTITUTO ESPAÑOL DE OCEANOGRAFÍA

IPMA Instituto Português do Mar e da Atmosfera

IBERAS 0921
SURVEY REPORT

INSTITUTO ESPAÑOL DE OCEANOGRAFÍA
INSTITUTO PORTUGUÊS DO MAR E DA ATMOSFERA

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EXECUTIVE SUMMARY

IBERAS0921 was carried out on board the R/V Ramón Margalef from 18th to 20th September (9aN) and from 9th to 18th October 2021 (9aCN and 9aCS) with the aim of estimating the strength of recruitment of the Iberoatlantic stock of sardine (*Sardina pilchardus*). The big gap between the first and the second leg was due to an interruption of the survey because the R/V was sent to assist the explosion of La Palma volcano in the Canary Islands. The calibration of the echosounder took place on the 17th of September, just before the start of the survey. The survey covered subdivisions 9aN and 9aCN as planned and 9aCs was covered only north of Sines.

Survey design consists of parallel transects 6 nmi apart, with a random start, and covering a depth range from 20-15 m to 100 m. This surveyed area coincides with the main potential distribution of sardine recruitment of the Iberoatlantic stock. In addition, in the main recruitment area (e.g. central part of 9aCN, historically observed), the sampling intensity was increased up to 4 nmi between transects to increase the sampling resolution.

For ground-truthing the fish community and to obtain length/age distributions for each species, 23 fishing hauls with pelagic trawls were conducted and fishing with a purse seiner (on the second leg) was used for a further 9 hauls in coastal areas. The total NASC was in the same order of magnitude as in previous years (439*10^3 S_A). 22% of this NASC was unallocated due to the lack of time to perform specific fishing stations to verify all echotraces. 51% of the total NASC was allocated to sardine, 9.4% was allocated to horse mackerel, 6% to anchovy and a further 5.9% to Chub mackerel.

As a main result, biomass estimate for sardine was 289*10^3 metric tonnes that corresponds to 5.6*10^9 fish. The most representative year was age 2. The center of gravity was found around Figueira da Foz in subdivision 9aCN, deeper than in previous years. Anchovies this year were concentrated in the north, with almost no individuals in the rest of the surveyed area. The estimated biomass for anchovy was 31*10^3 metric tonnes, corresponding to 1.4*109 fish. The recruitment index for the present year, 10*10^3 metric tonnes and 0.7*10^9 fish, quite low when compared with previous years.

Overall, IBERAS is providing a good indicator of the strength of the sardine recruitment for the Iberoatlantic stock. The recruitment index for the 2021 survey was 23*10^3 metric tonnes and 0.9*10^9 fish, which is lower than the observed in 2019 and 2020. The good relationship between these figures with those at age 1 estimated in the spring surveys PELAGO and PELACUS allows IBERAS to provide a recruitment index for this stock.

TECHNICAL SUMMARY

Institution: INSTITUTO ESPAÑOL DE OCEANOGRAFÍA/INSTITUTO PORTUGUÊS DO MAR E DA ATMOSFERA
Survey name: IBERAS0922
Vessel name: Ramón Margalef (46.70 m length, 10.50 width with 988 GRT and 900 kW diesel electric)
Dates: 18/09-18/10/2021
Area: WESTERN IBERIAN COAST (9aN-9aCN-9aCS)
Type: Acoustic-Trawl
Main objective: Biomass estimation by means of echointegration of the main pelagic fish population present in the surveyed area. Physical, chemical and biological characterisation of the pelagic ecosystem.
Sampling strategy: Systematic grid with random start, tracks 4/6 nmi apart from 20 to 100 isobath
Main sampling procedures: EK-80 at 18-38-70-120-200 kHZ acoustic frequencies. 882 nmi prospected only during the day
Pelagic fishing stations: 23 + 9 Purse seiners
Hydrological characterisation.

Personnel

1st leg Vigo/Vigo, Dates:16-20/09/2021

MORENO, ANA (chief scientist)
AMORIM, PEDRO MIGUEL
HUGO MENDES
CRISTINA NUNES
HERNÁNDEZ MILIÁN, GEMA
CÓRDOBA SELLÉS, Mª PILAR
DA CONCEIÇÃO, ANTONIO PEDRO
MARIA SANCHEZ BARBA
AUTÓN DÍAZ, URBANO
JOSÉ ANTONIO BONALES

2nd leg, Vigo/Lisboa, Dates:7-18/-/10/2021

AUTÓN DÍAZ, URBANO (chief scientist)
AMORIM, PEDRO MIGUEL
DA CONCEIÇÃO, ANTONIO PEDRO
DOS SANTOS BARRA, JORGE
SILVA, DINA
MORAIS, DELFINA
MARIA SANCHEZ BARBA
HERNÁNDEZ MILIÁN, GEMA
BENTO, TIAGO (onboard purse-seiner)

Report authors: Pablo Carrera, Sílvia Rodríguez, Ana Moreno

Other collaborators: Pedro Amorim, Dina Silva, Gema Hernández

1. INTRODUCTION

IBERAS is a new acoustic trawl time series designed to estimate the strength of the sardine recruitment in Atlantic Iberian waters. The survey is conducted over the main potential distribution area of the recruitment for the Iberoatlantic sardine (*Sardina pilchardus*) stock. The first survey was done in November 2018.

Due to the poor weather conditions and in order to make a synoptic coverage with the JUVENA survey - which also covers the Bay of Biscay - the timing has been moved to September in following years. This shift did not change the availability of recruits. The present survey (2021) is the fourth year of the time series.

The rationale for this new time series was based on the low productivity level of the sardine stock in this area during several years since 2011. Although sardine is not considered a short-lived species, the lack of good year classes has resulted in a very low presence of older ages (e.g. very low expectation of reaching ages older than 5 years due to the high natural mortality), with the bulk of the population composed of younger fish, which in turn, makes this species look like a short-lived species. Under such conditions, any recovery in biomass is likely to be driven by the strength of the recruitment. Therefore, if juveniles can be assessed at age 0, the estimates can be used to predict the relative strength of the future recruitment to the fishery. This strategy is of particular interest for the management of fisheries for short-lived species because of the short time between spawning and the subsequent recruits.

The IBERAS survey was designed on the basis of experience gained by IPMA through the JUVESAR survey (targeting sardine recruitment in north-west Portugal), by AZTI and IEO through the JUVENA survey (to improve the assessment/management of anchovy in the Bay of Biscay) and by IEO through the ECOCADIZ recruitment survey (targeting sardine and anchovy recruitment in the Gulf of Cadiz). The main objective of IBERAS is to obtain a recruitment index for both species in the Atlantic waters of the Iberian Peninsula, in order to improve the estimation of the recruitment strength of the Iberoatlantic sardine and the western component of the southern anchovy population.

2. OBJECTIVES

i. Acoustic estimates by echointegration of the strength of the sardine recruitment in Atlantic waters of the Iberian Peninsula, between Cape Ortegal and São Vicente.
ii. Oceanographic (physical -CTD- and biological _Bongo nets) characterization of the surveyed area.
iii. Assess the relative abundance of apical predators along the surveyed area.

3. MATERIAL AND METHODS

The survey was carried out on board the R/V Ramón Margalef from the 18th to 20th September 2021 and from the 9th to 18th October 2021 (Figure 1). The first leg departed from and arrived at the port of Vigo, and the second leg departed from and arrived at the port of Lisbon. The big gap between the first leg (18-20/09), which covered area 9aN and the second leg (9-18/10) which covered 9aCN-9aCS, was due to an interruption of the survey because the La Palma volcano

Cumbre Vieja entered in explosion and the vessel used for the survey was needed to assist the works overthere.

Depending on vessel availability, the IBERAS survey is carried out on the R/V Ramón Margalef or on a similar vessel: R/V Angeles Alvariño (used in year 2019); the similarity of the two vessels makes the vessel uncertainty effect low and facilitates the comparison of results.

3.1 Working Area

From Fisterra to Sines, from the shoreline (20 m) to an isobath of 100-200 m, using an adaptive grid of 53 tracks spaced between 6-8 nmi, taking into account the potential recruitment distribution area of both sardine and anchovy. The spatial distribution of sardine found in previous year´s survey was used as a reference. Transects are adaptative: they were enlarged or shortened according to the presence of sardines and anchovies. The start of the survey is random. Figure 1 shows the planned survey track and Table 1 shows the expected survey coverage and schedule.

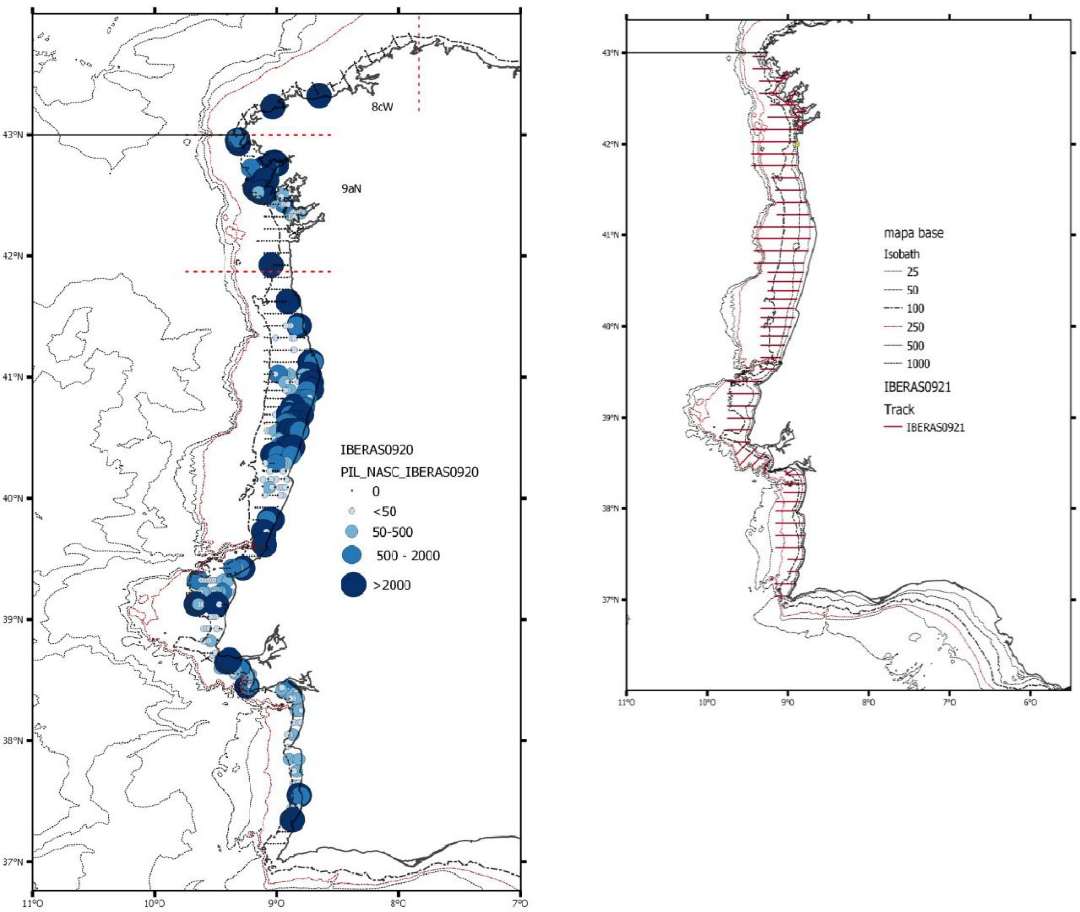


Figure 1 Sardine NASC distribution obtained during IBERAS0920 (left) and the proposed survey track for IBERAS0921 (right).

The methodology used was similar to that used in previous surveys and is summarised in ICES Cooperative Research Report No. 332. 268 pp. https://doi.org/10.17895/ices.pub.4599. The backscattering acoustic energy from marine organisms was measured continuously during the day, except in the northern area where some tracks were steamed at night. Pelagic trawls were carried out whenever possible to help identify the species (and size classes) that reflect the acoustic energy. During daylight hours, concurrently to acoustics, a trained observer recorded the presence and abundance of marine mammals, seabirds, floating litter (debris) and vessel presence and abundance.

Table 1 Expected survey coverage and time scheduled in each ICES Sub-Division.

Tabla 1. Previsión de actividades y días

Zona	No radiales	No. millas		Navegación (horas-días)	Pesca (n-horas-días)	TOTAL (días)	FECHA
		Radial	Unión				
Calibración							16/09
Plataforma 9a-N	6	70	54	11.6-1	4-6-0.5	2	17-18*/09
Rías Baixas (9a-N)	23	112	0	11.2-1	6-12-1	2	18-19/09
Plataforma 9a N	3	75	24	9-0.7	4-6-0.6	2	20-21/09
O. Norte (9a-CN): Caminha-Porto	6	144	78	21-2.	5-10-0.6	3	22-24/09
O. Norte (9a-cn): Porto-Nazaré	15	283	117	39.2-3.9	6-10-0.85	3.5	24-28/09
O Norte (9a-cs): Nazaré-Roca	5	70	41	10-1.3	3-5-0.42	1.7	28-29/09
O Sul (9a-cs): Roca-Espichel	8	68	61	12-1.1	6-10-0.8	2	29/09-1/10
O Sul (9a-cs): Roca-Troia	5	63	34	9.0-0.75	2-3-0.3	1.	1-2/10
O Sul (9a-cs): Troia-São Vicente	7	84	48	13.-1.1	2-3-0.3	1.2	2-3/10
Total	55-23	935	432	137-11.4	38-98-8.17	19	
Días de respeto:							0.5 días

At night, when acoustic transects are not conducted, CTD profiles for hydrography and zooplankton sampling (Bongo 60) were collected on some of the opportunistically selected acoustic transects.

3.2 Acoustic

The acoustic equipment consisted of a Simrad EK-80 scientific echosounder, operating in CW mode at 18, 38, 70, 120 and 200 kHz. All frequencies were calibrated before the survey (16-17th September) according to the standard procedures (ICES-CRR326). The elementary sampling distance unit (EDSU) was fixed at 1 nmi. Acoustic data were collected only during the day at a cruising speed of 8-10 knots, although some tracks were also steamed at night. Data was then stored in raw format and post-processed using SonarDataEchoview software (Myriax Ltd) (Higginbottom et al, 2000). All echograms were first scrutinized, the bottom line was included, and background noise was also removed according to De Robertis and Higginbottom (2007). Fish abundance was calculated using the 38 kHz frequency as recommended by the PGAAM (ICES 2002), although echograms from 18, 70, 120 and 200 kHz frequencies were used to visually discriminate between fish and other scatter-producing objects such as plankton or bubbles, and to distinguish different fish species according to the frequency response. The 18, 70, 120 and 200 kHz frequencies were also used to create a mask to better discriminate between swimbladder fish species and other organisms. The threshold used to scrutinize the echograms was –70 dB. Integration values were expressed as nautical area scattering coefficient (NASC) units or s_A values (m^2 nmi^{-2}) (MacLennan et al., 2002).

Figure 2 Calibration of the echosounder.

3.2.1 NASC allocation

A Gloria HOD 352 pelagic trawl was used in combination with a 63.5/51 pelagic trawl to identify the species and size classes responsible for the acoustic energy detected and to provide samples. The duration of the hauls was variable and ultimately depended on the number of fish entering the net and the fishing conditions, although a minimum duration of 20 minutes was always attempted. The quality of the hauls for ground-truthing the acoustic data was classified according to the weather conditions, haul performance, catch composition in number, and the length distribution of the fish caught (Table 2).

Table 2 Ground-truth quality criteria used to classify the validity of fishing stations in the survey.

	0	1	2	3
Gear performance Fish behaviour	Crash	Bad geometry Fish escaping	Bad geometry No escaping	God geometry No escaping
Weather conditions	Swell >4 m height Wind >30 knots	Swell: 2 -4 m Wind: 30-20 knots	Swell: 1-2m Wind 20-10 knots	Swell <1 m Wind < 10 knots
Fish number	total fish caught <100	Main species >100 Second species <25	Main species > 100 Second species< 50	Main species > 100 Second species > 50
Fish length distribution	No bell shape	Main species bell shape	Main species bell shape Seconds: almost bell shape	Main species bell shape Seconds: bell shape

Hauls considered to be the best representation of the fish community for a given area were used to allocate NASC to each EDSU within that area, where direct allocation was not possible. This process involved the application of the Nakken and Dommasnes method (1975, 1977) for multiple species, but instead of using the mean backscattering cross section, the full length class distribution (1 or 0.5 cm length classes) was used, as follows:

$$NASC_l = NASC \cdot \left(\frac{\sigma_{l,\rho}}{\sigma_\rho}\right)$$

Where *NASC* is the total backscattering energy for calculating densities by length, $NASC_l$ is the proportion of the total *NASC* which can be attributed to length group *l* for a given fish species. $\sigma_{l,p}$ is the backscattering cross-section at length *l* for a given species at length *l* multiplied by the proportion of (p_l) of length of this particular species on the overall catch and σ_p is the sum of all $\sigma_{l,p}$ for all species,

$$\sigma_{l,\rho} = \rho_l * \sigma_l$$

$$\sigma_\rho = \sum_l \quad \sigma_{l,\rho}$$

Finally, σ_l is backscattering cross-section (m^2) for a fish of length *l* for a particular species and is computed as follows:

$$\sigma_l = \frac{l^{\left(\frac{m}{10}\right)} * 10^{\left(\frac{b_{20}}{10}\right)}}{4 * \pi}$$

This is calculated using the formula TS =20 $\log L_T$+ b_{20} (Simmonds and MacLennan, 2005), where L_T is the length class. The b_{20} values for the most important species present in the surveyed area are given in Table 3.

Table 3 b_{20} values from the length target strength relationship of the main fish species assessed in IBERAS survey. PIL is sardine (Sardina pilchardus); ANE anchovy (Engraulis encrasicolus); HKE hake (Merluccius merluccius); BOG bogue (Boops boops); BOC boarfish (Capros aper); MAC mackerel (Scomber scombrus); HOM horse mackerel (Trachurus trachurus); VMA chub mackerel (Scomber colias) and WHB is blue whiting (Micromesistius poutassou).

Species FAO acronym	b_{20}	Refererence	Observations	Otherb_{20}	Reference
PIL	-72.6	Degnbol et al., 1985	TS for clupeids	-71.2 -70.4 -74.0 -72.5	ICES ,1982 Patti et al., 2000 Hannachi et al., 2005 Georgakarakos et al., 2011
ANE	-72.6	Degnbol et al., 1985	TS for clupeids	-71.2 -76.1 -71.6 -74.8	ICES 1982 Barange et al., 1996 Zhao et al., 2008 Georgakarakos et al., 2011
HKE	-67.5	Foote et al., 1986; Foote, 1987		-68.5 -68.1	Lillo et al., 1996 Henderson, 2005; Henderson and Horne, 2007
BOG	-67.5	Foote et al., 1986	Adapted from gadoids		
BOC	-66.2	Fässler et al., 2013			
MAC	-84.9	Edwards et al., 1984; ICES, 2002		-86.4 -88.0	Misund and Betelstad, 1996 Clay y Castonguay, 1996
HOM	-68.7	Lillo et al., 1996		-68.15 -66.8 -66.5/-67.0(*)	Gutiérrez and McLennan, 1998 Barange et al. (1996) Georgakarakos et al., 2011
VMA	-68.7	Lillo et al., 1996	Adapted from HOM;l (Sawada, com. pers.)	-70.95	Gutiérrez and McLennan, 1998
WHB	-65.2	Pedersen et al., 2011			

* day and night respectively

Where possible, direct allocation was done, considering the shape of the school and also the relative frequency response of that school (Korneliussen and Ona, 2003, De Robertis et al., 2010). Fish schools were extracted using the settings described in Table 4.

Table 4 Main morphological and backscattering energy characteristics used for school detection in Echoview software.

Sv threshold	**-60/-70 dB for all frequencies**
Minimum total school length	2/20 m
Min. total school height	1/5 m
Min. candidate length	1 m
Min. candidate height	0.5 m
Maximum vertical linking distance	2/5 m
Max. horizontal linking distance	10/25 m
Distance mode	Vessel log
Main frequency for extraction	38/120 kHz

For all school candidates, several variables were extracted, including: the NASC (s_A, m^2/nmi^2) together with the proportioned region to cell (ESDU, 1 nmi) NASC, the s_V mean, s_V max geographic position and time. PRC_NASC values were summed for each ESDU and distances were referenced to a single starting point for each transect. Results for the 38 and 120 kHz frequencies were compared. In addition, the frequency response for each valid school (i.e. those with length and s_V which allows them to be properly measured) was calculated as the ratio $s_{A(fi)}/s_{A(38)}$, being f_i the s_A values for 18, 70, 120 and 200 kHz.

3.2.2 Echointegration estimates

Once the backscattering energy is allocated to fish species, the spatial distribution for each species is analysed using both the NASC values and the length frequency distributions (LFDs) to provide homogeneous assessment polygons. These are calculated as follows: one empty track defines the coast-boundary of the polygon, while three consecutive empty ESDU´s define a gap or the cross-coast boundary. Within each polygon, the LDF is analysed.

LFDs should be obtained for all positive hauls for a given species (either from the total catch or from a representative random sample of 100-200 fish). Only LFDs, based on a minimum of 30 individuals, were considered for acoustic assessment. Differences in probability density functions (PDFs) were tested using the Kolmogorov-Smirnov test. PDF distributions without significant differences were merged to create a homogeneous PDF stratum. Spatial distributions were then analysed within each stratum and finally a mean s_A value and area (square nautical miles) were calculated using a GIS-based system (Q-gis). These values, together with the length distributions, were used to calculate the fish abundance in number as described in Nakken and Dommasnes (1975) (see previous section for further details). Estimates for each species were calculated on each strata (polygon) using the arithmetic mean of the backscattering energy (NASC, s_A) attributed to each fish species and the area expressed in square nautical miles using the following formula:

$$\rho_l = \frac{NASC_l}{\sigma_l}$$

$$N_l = \rho_l * A_p$$

Where ρ_l is the areal density of fish (numbers per square nautical mile in length group *l*); the total number for length group *l* (N_l) within each stratum is calculated as the product of ρ_l times the total area of the strata (A_p) expressed in square nautical miles.

Numbers were converted to biomass using the length-weight relationships derived from the fish measured on board. Results by ICES subdivisions (9aS, CS, CN and N) are given for comparison.

3.2.3 Center of Gravity

For each main species, a center of gravity (Woillez et al. 2007) was calculated as a weighted average of each sample location (allocated NASC value as weighting factor). Due to the particular topography, instead of longitude and latitude, we have used depth and a new variable called "distance from the origin" where distance (nautical miles) is calculated as (Lat-37.0)*60, where *Lat* is the latitude of the midpoint of a given EDSU.

3.3 Fishing stations

Fishing stations were used for both NASC allocation and length analysis. They were therefore located in the light of the results obtained during the acoustic prospection (i.e. opportunistically accounting the echotraces).

A Gloria HOD 352 was used in combination with a 63.5/51 pelagic trawl with a vertical opening of approximately 13 m and 16 m respectively. The general rigging consisted of 200/400 kg clump weights on either side of the setback (2 m below the wing). The 100 m Dyneema bridles (wings) were shortened to 50 m in shallower waters. A set of 3.5 m^2 *Apollo Poly-Ice* doors with a weight of 750 kg was used. Gear performance was monitored by a wired Simrad Sonar FS20 net sounder. For surface hauls, a fence buoy was placed in the upper bridle, opposite the clumps. Fishing stations were conducted during the day.

Additional biological information was provided by a chartered purse-seiner, who sampled around Aveiro, Figueira da Foz (9aCN) and Lisbon.

3.4 Plankton and hydrological characterisation

Continuous records of Sea Surface Salinity (SSS), Sea Surface Temperature (SST) and Sea Surface Fluorometry (SSF) were taken using a SBE21 Thermosalinograph coupled with a Turner fluorometer. CTD casts and plankton sampling were conducted each evening after acoustic and fishing operations were completed. Survey stations were spaced 3 nmi apart along the transects and the number of stations completed each night depending on the time available (until approximately 24:00h). CTD profiles were collected with an SBE911plus probe and zooplankton samples were collected from the top 60 m of the water column, using a Bongo net (60 cm diameter, 200µm and 500µm mesh size nets); samples were preserved (200µm: in formalin, 500µm: in ethanol) for further analysis in the laboratory.

3.5 Fish sampling

Catches from trawl and purse seine hauls were sorted and weighted.

3.5.1 Catch and length distribution per species

After sorting the catch for all species, a length distribution was estimated. If the number of specimens caught was greater than 100, a random sample was collected. The sample was then weighted and the specimens measured to the nearest length class. This was 0.5 for sardine and anchovies, and 1 cm for other species. The catch length distribution was estimated by raising the sample length distribution according to the weighting factor: total catch weight vs total sample weight (TCW/TSW).

3.5.2 Weight Length relationship

A weight-length relationship (WLR) was calculated for all assessed species, either from the results of biological sampling (see below) or from a specific sampling procedure. In the latter case, a stratified random sampling scheme was used with the length class (*i.e.* 0.5 or 1 cm) as the stratum.

3.5.3 Biological sampling

Full biological sampling was carried out on a sub-sample for the main target species caught in each fishing haul (e.g. anchovy and sardine). The following data were collected: length (mm); weight (g); sex; maturity stage; otolith collection; fat content; stomach colour and stomach repletion state. For sardine, the tail was also collected for further genetic analysis.

3.6 Apical predators

Apical predator observations were carried out only in the first leg of the survey (18-20th September). Thus, only the area 9aN was covered.

4. RESULTS

The survey did not go ahead as planned. The Cumbre Vieja volcano (in La Palma, Canary Islands) exploded and ship support was required, so the survey was interrupted and the second leg had to be postponed. This explains the large gap between the first leg (18-20/09) and the second leg (9-18/10). These circumstances meant that there were few people on board to carry out the core tasks, and therefore some secondary tasks, such as the marine mammal observations, were not carried out during the second leg of the survey. Additionally, there was a reduction in the planned surveyed area. The weather was good during the survey.

4.1 Hydrographic conditions

The temperatures registered during the survey ranged from 15.4 to 22.7 °C, being the north warmer than the south. This fact can possibly be explained by the fact that the first leg (9aN) was carried out 1 month earlier (september) than the second leg (october) (Figure 3). Waters were saltier in the south, and the fluorescence showed higher lower values in the south, intermediate values in the north, and maximum values in the area surrounding Figueira da Foz (~40°N).

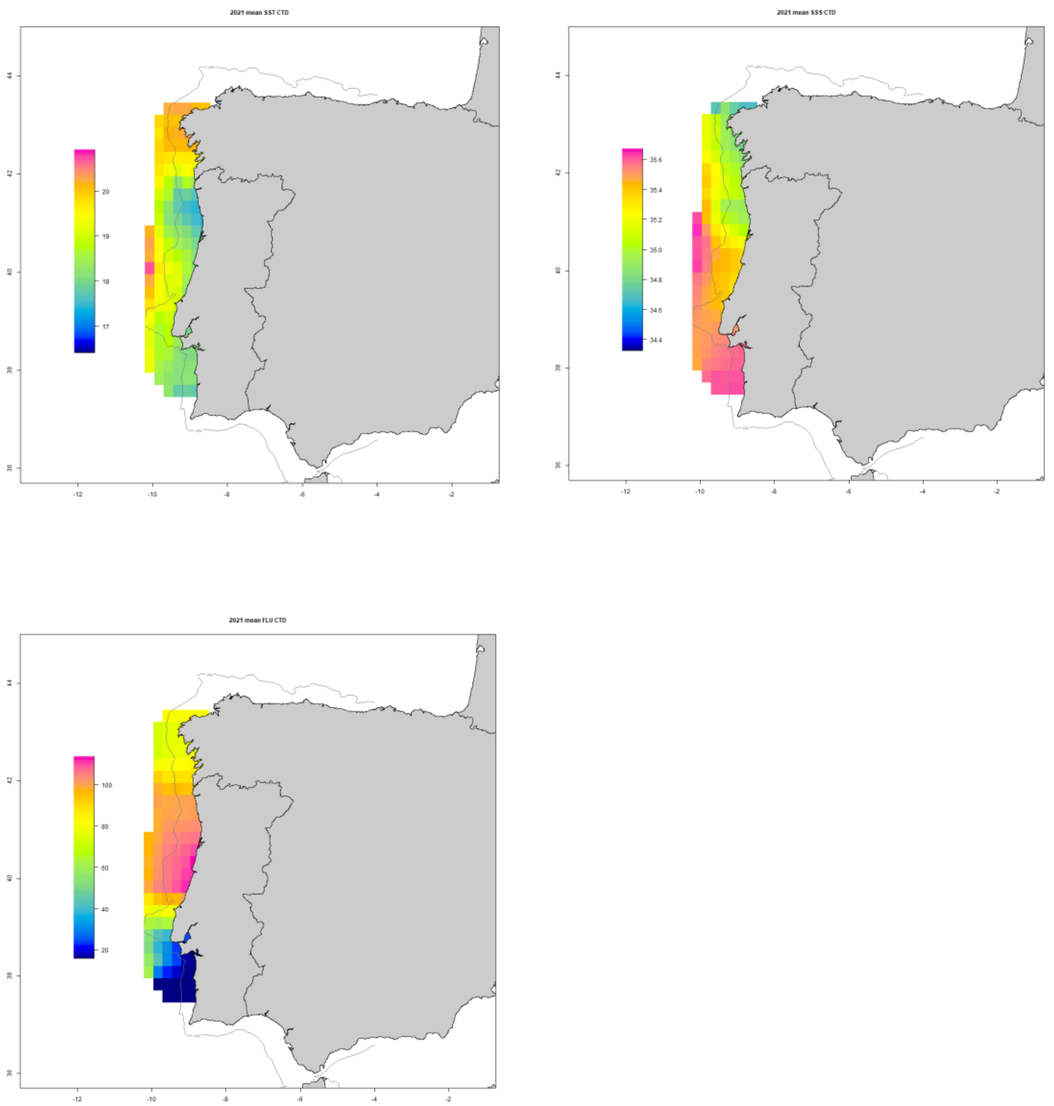


Figure 3 Sea Surface Temperature (SST), sea surface salinity (SS) and sea surface fluorimetry (FLU) registered in the survey IBERAS0921.

4.2 Acoustics

4.2.1 School extraction and total backscattering energy

A total of 3520 echotraces were extracted, accounting for a total NASC (s_A) of 439616 m^2 nmi^{-2}.Figure 4 shows the sum of NASC per track along the surveyed area.

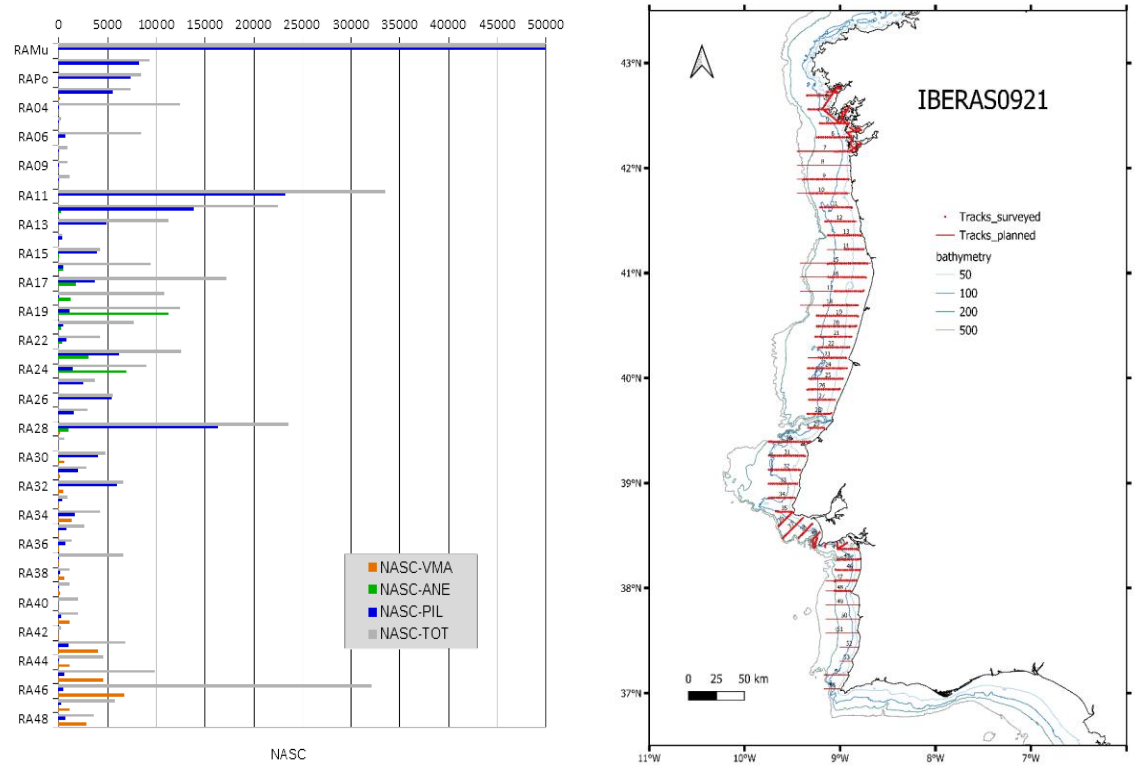


Figure 4 Cumulated NASC by species (VMA-Chub mackerel, ANE-anchovy, PIL-sardine) and transect (RA) (right). Map showing the prediction of the parallel transects to be carried out during the survey (left).

Fish schools occurred more or less in the same areas as recorded last year, with some of them (e.g. Ría de Muros or north Figueira da Foz) having an important contribution to the total backscattering.

4.3.2 Fishing station and echotrace allocation

As mentioned last year, it was a challenge to carry out inshore stations when most of the area was occupied by static gear, which limited the areas available to carry them out and increased the time needed to search for them. Of the 32 fishing stations carried out, 9 were purse seine tows, which helped to characterise the fishing community (Table 5).

Table 5 Summary of the fishing stations carried out in the survey. WHB-blue whiting; MAC-mackerel; HKE-hake; HOM-horse mackerel; PIL-sardine; HMM-Mediterranean horse mackerel; BOG-bogue; VMA-chub mackerel; BOC-boarfish; SEAB-seabream species; ANE-anchovy; SNS-longspine snipefish. B denotes "big" individuals (adults, mature), and "S" small (juveniles, immature).

IBERAS 0921	TOTAL CAP (Kg)	No ind.	No Fishing st	Sample weight (kg)	Measured fish	Mean length	%PRES	% Catch_W	% Catch_No
WHB	1	16	1	1	16	17.63	4.35	0.01	0.01
MAC	206	1426	12	37	258	26.97	52.17	2.79	0.58
HKE	1	10	2	1	10	21.30	8.70	0.01	0.00
HOM	577	48458	12	38	1007	15.64	52.17	7.82	19.81
PIL	4478	103577	17	86	1699	17.88	73.91	60.66	42.33
HMM	0	0	0	0	0	0.00	0.00	0.00	0.00
BOG	21	150	3	14	95	25.36	13.04	0.28	0.06
VMA	116	1526	9	24	310	20.98	39.13	1.57	0.62
BOC	1	20	1	0	6	12.50	4.35	0.01	0.01
SEAB	34	334	3	13	112	19.49	13.04	0.47	0.14
ANE	1813	77286	8	17	813	14.54	34.78	24.56	31.59
SNS	135	11862	1	1	50	13.07	4.35	1.83	4.85

Sardine accounted for more than 60% of the total catch in weight, and was present in 74% of the hauls. It should be also noticed the high presence of Atlantic mackerel (52% of the hauls) and horse mackerel (52% of the hauls) as well. Nevertheless, the contribution of Atlantic mackerel for the catch in numbers was very low (<1%). Anchovy was only present in 25% of the total catch in weight, being present in 35% of the hauls. Chub mackerel was present in 39% of the hauls. The other pelagic species were present in less than 15% of the hauls (Table 5).

4.3.2.1 Sardine echotrace identification

As stated in previous years, the survey targeted only juvenile sardine and anchovy (main objective) due to the lack of time.

Sardine schools were thick and close to the bottom (Figure 5). In some cases they were found in mixed schools, mixed with anchovy (Figure 6) or horse mackerel (Figure 7).

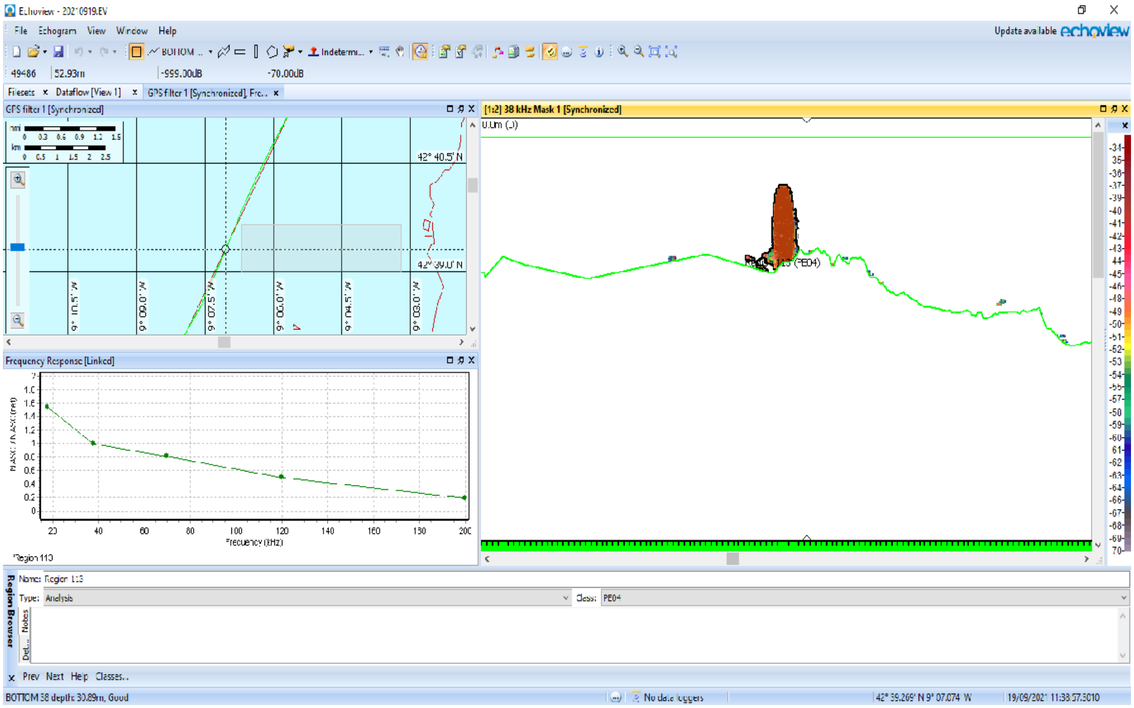


Figure 5 Echogram showing echotraces attributed to sardine (38kHz).

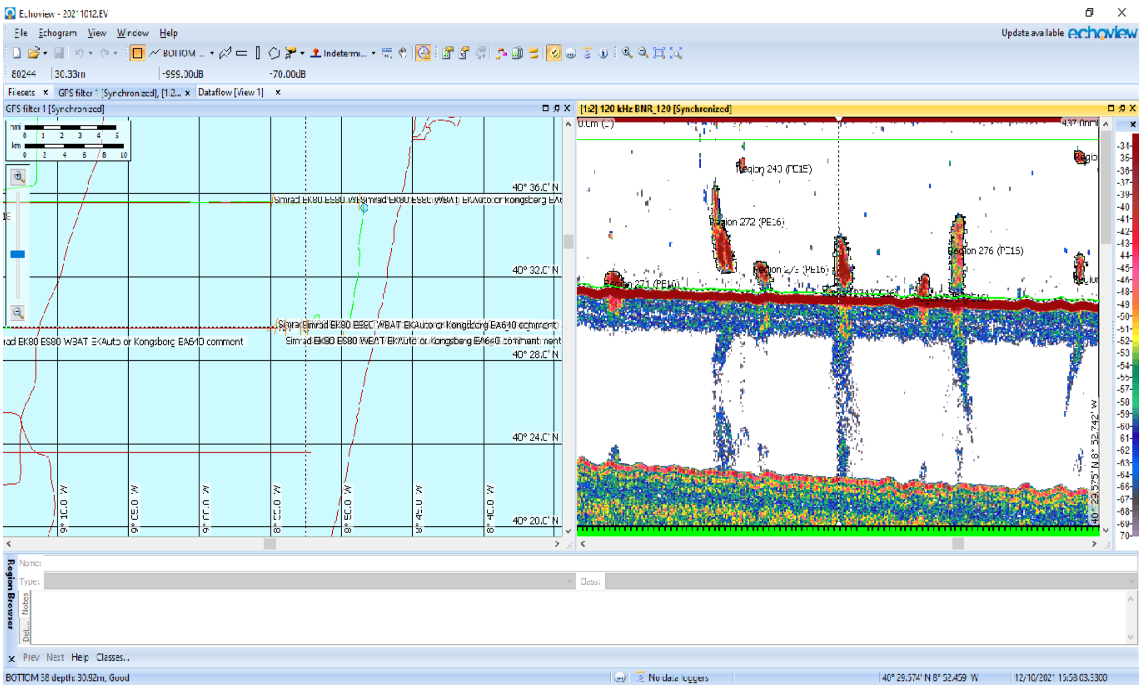


Figure 6 Echogram showing echotraces of sardine mixed with anchovy (38kHz).

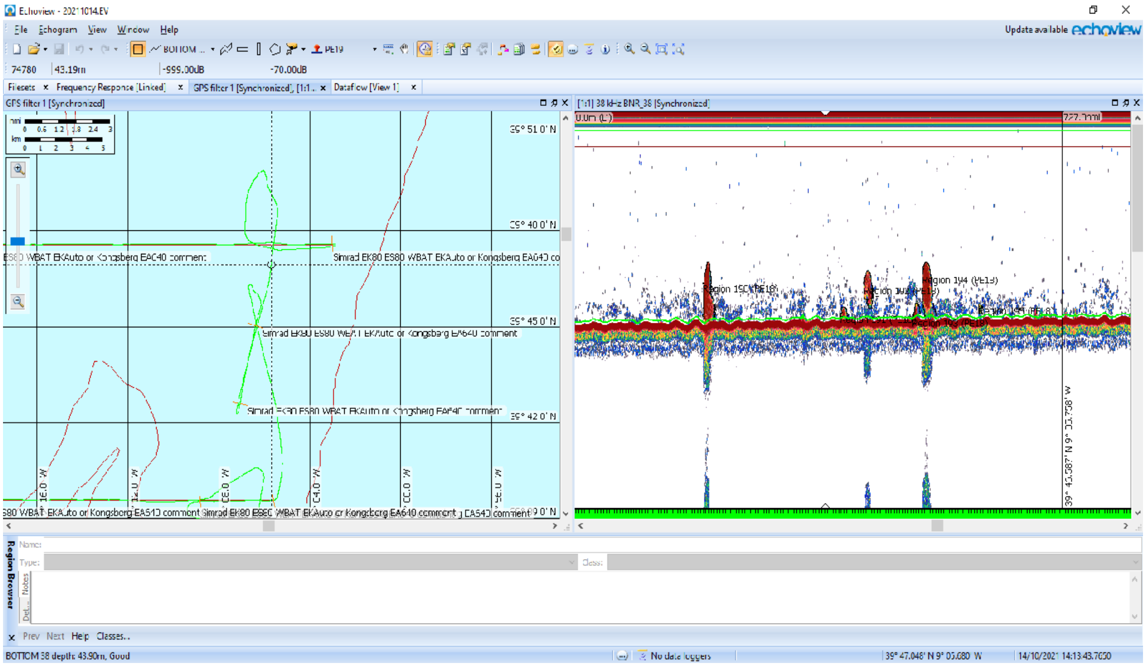


Figure 7 Echogram showing echotraces of sardine mixed with horse mackerel (38kHz).

4.3.2.2 Anchovy echotrace identification

Anchovy was mainly found in the surface and in small aggregations (Figure 8).

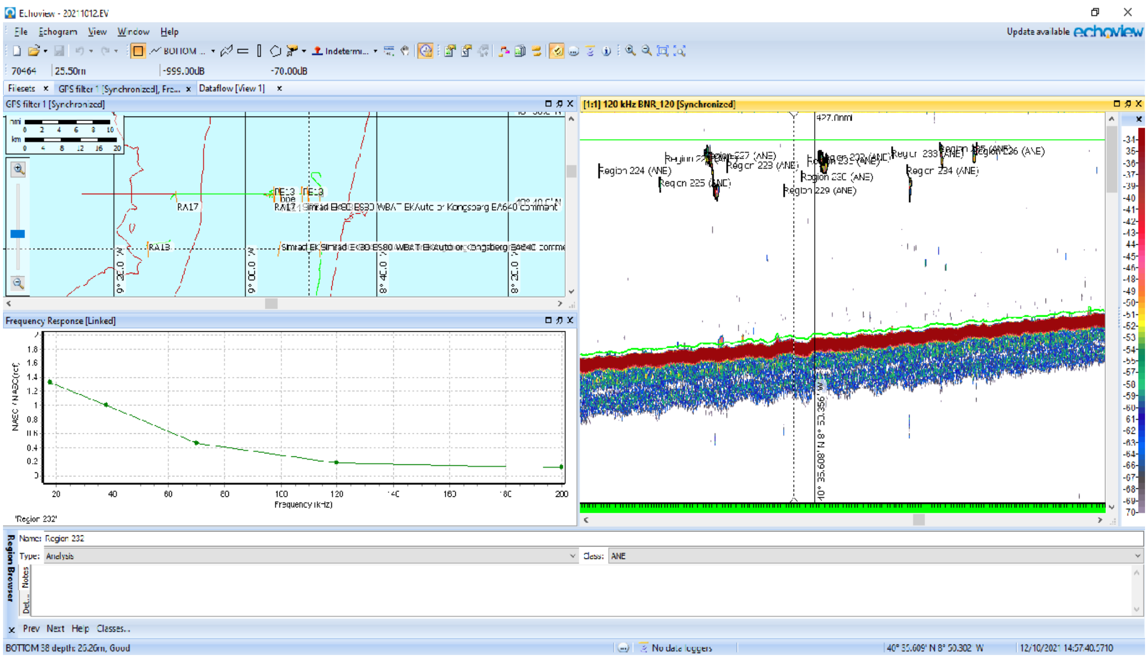


Figure 8 Echograms showing echotraces attributed to anchovy (38kHz in both cases).

4.3.2.3 Krill echotrace identification

This year krill echotraces were found mixed with anchovy echotraces (Figure 9).

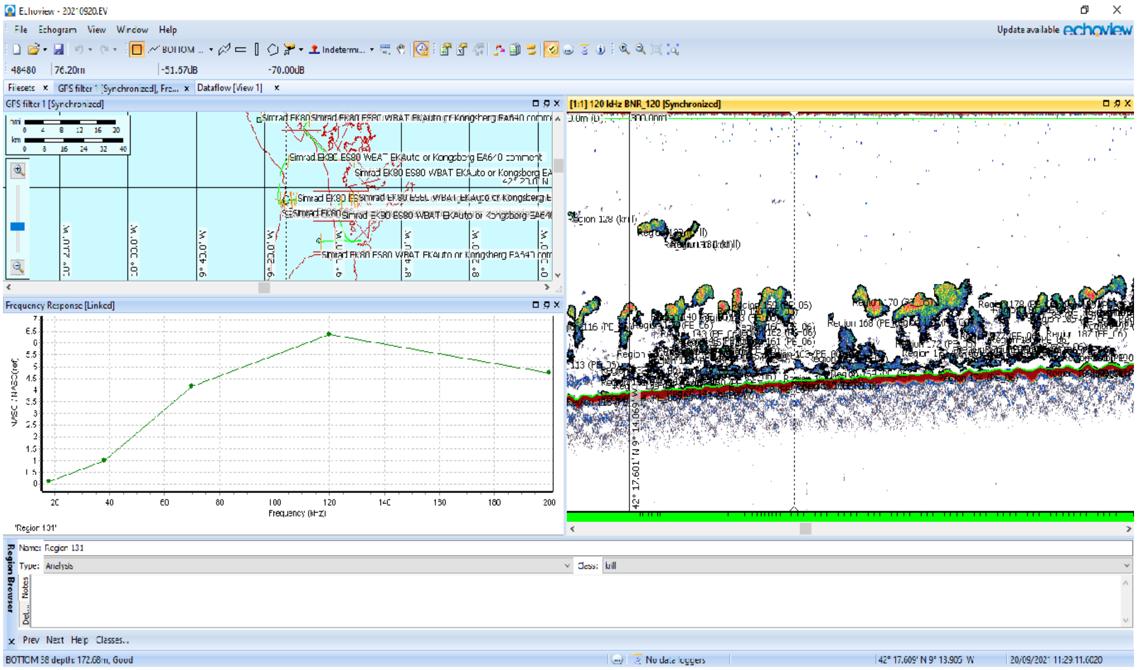


Figure 9 Echogram showing echotraces of krill (38kHz frequency).

4.3.2.4 Longspine snipefish echotrace identification

We were able this year to identify echotraces of Longspine snipefish (*Macroramphosus scolopax*) in shallow depths near Aveiro (9aCN area; Figure 10).

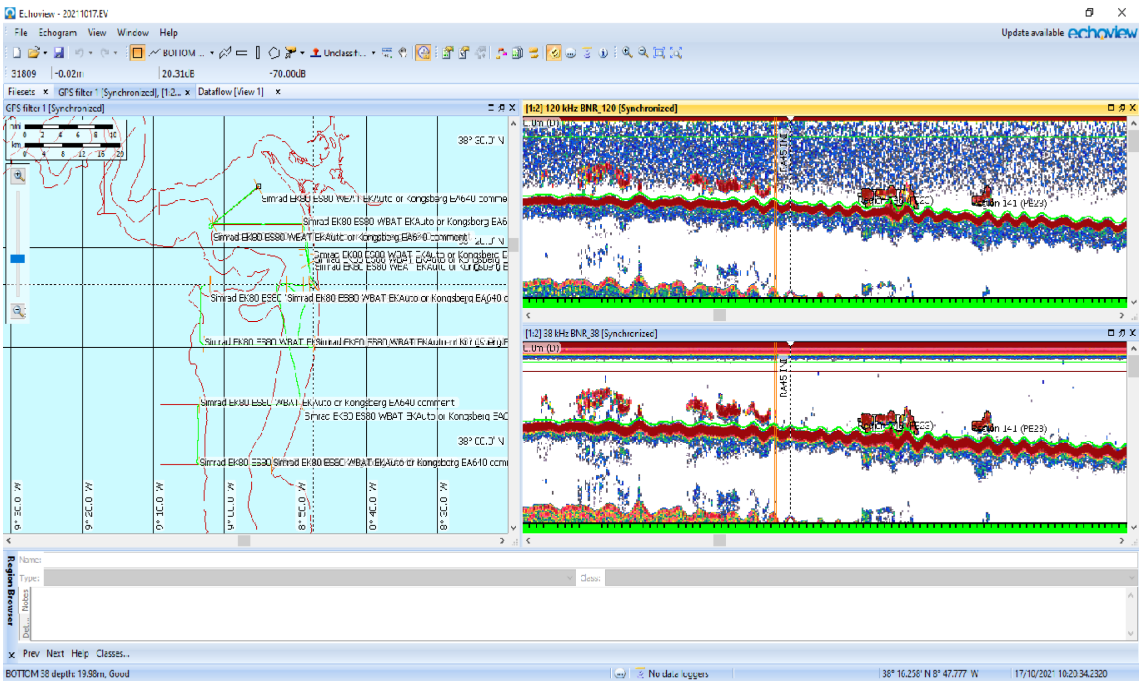


Figure 10 Echogram showing echotraces of longspine snipefish (38kHz frequency).

4.3.2.5 Fishing stations used for echotrace allocation

The total NASC found in this survey IBERAS0921: 439*10^3 S_A was in the same order of magnitude as in previous years. On survey tracks, from the total of 439616 m^2 nmi^{-2}, 136294 were directly allocated to fish species (31%). From this, 51% of the total NASC was allocated to sardine in one category, 9.4% of the total NASC was allocated to horse mackerel, 6% to anchovy and a further 5.9% to chub mackerel. It is important to note that 22% of the total NASC (97*10^3 S_A) was allocated to the "undetermined category", which means that even with the ground-truthing and expert judgement, it was not possible to determine what species it was.

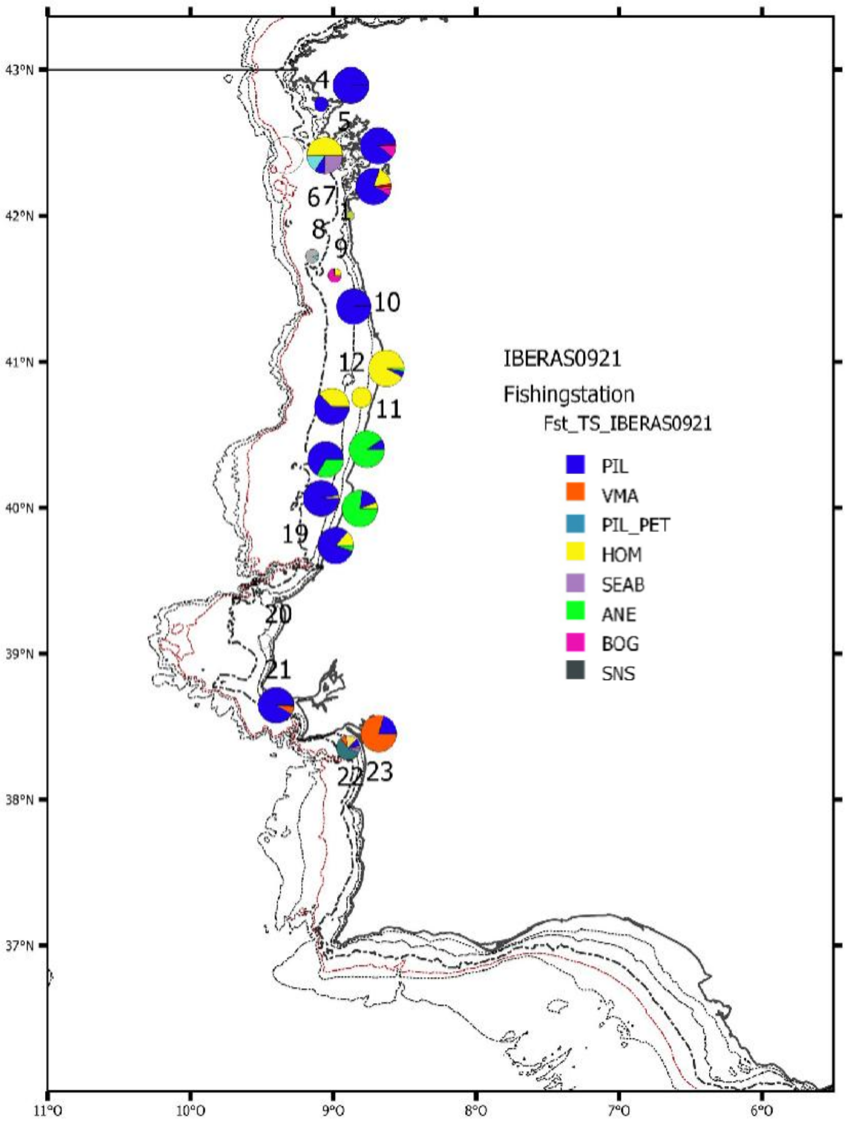


Figure 11 Pie charts showing the location of the fishing stations and the fish proportion in each station by the Nakken and Dommaness method. MAC-Atlantic mackerel; HOM-horse mackerel; PIL-sardine: BOG-bogue; VMA-chub mackerel; ANE-anchovy; SEAB-seabream species; PET denotes"small"(juvenile) individuals.

For allocation purposes, the area was divided into different strata taking into account the echotypes and, within the echotype, the representative near fishing stations. These echotypes are areas where the echotraces were similar, and where the proportion of species found by the fishing station on each stratum was also similar.

4.3.3 Length weight-relationship

Length weight relationships for the target species were calculated using individual weights (0.001 g) and lengths (mm). Group weights for length classes were also recorded but were not used for the present estimates. The relations were estimated by ICES sub-divisions, but the overall relationship was the one used for assessment purposes.

4.3.3.1 Sardine LWR

542 individuals were considered for the length-weight relationship of sardine. A soft bimodal distribution can be perceived in the data (Figure 12). A single LWR for the whole data was calculated with parameters equal to a=0.004 and b=3.275 and used for the assessment of the species.

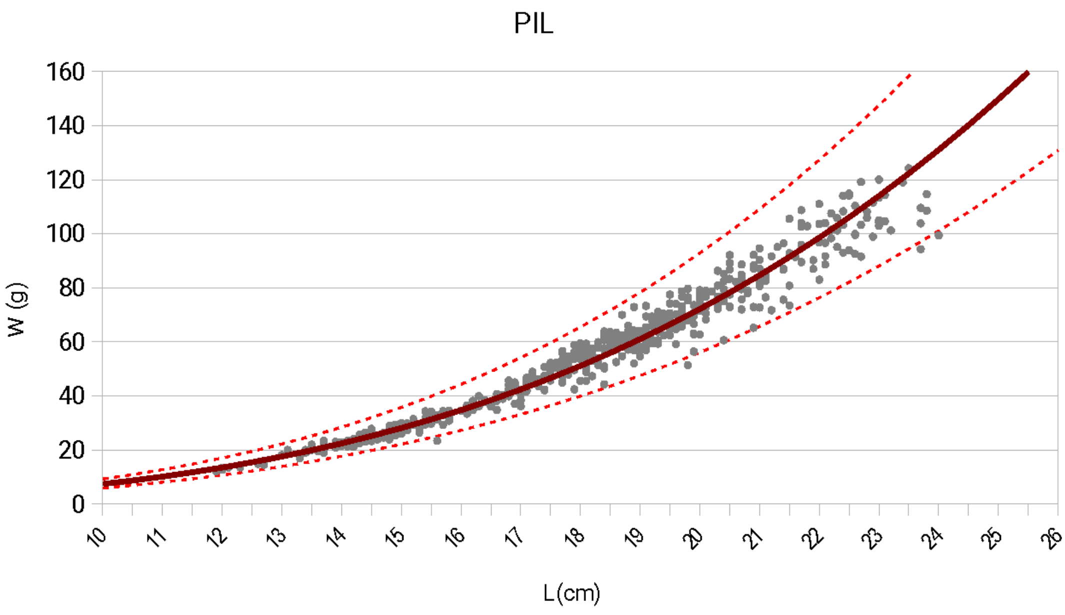


Figure 12 Length weight relationship for sardine used for assessment purposes. Grey dots are individual measurements; dotted red lines represent 95% confidence intervals.

4.3.3.2 Anchovy LWR

205 anchovy individuals were used to calculate the LWR. LWR parameters for anchovy were 0.006 and 3.04 a and b respectively (Figure 13).

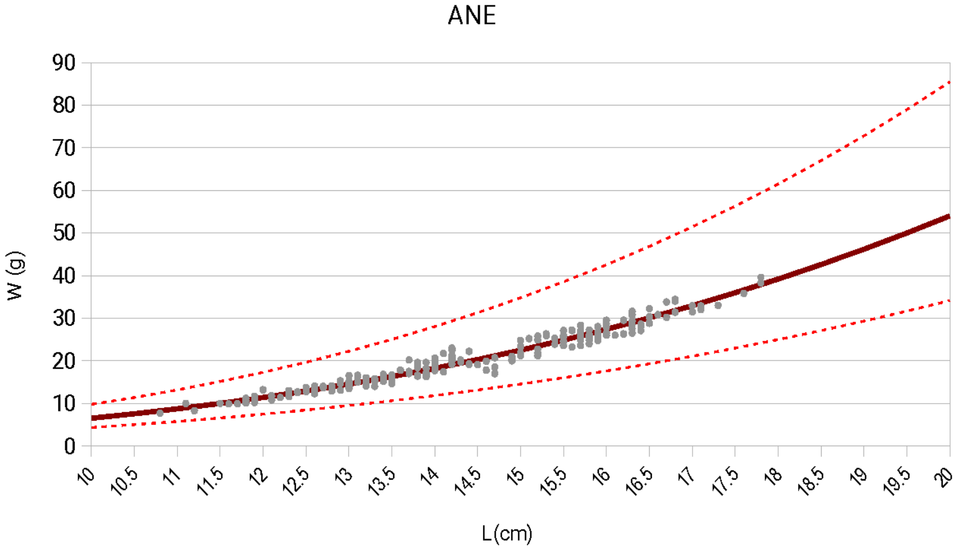


Figure 13 Length weight relationship for anchovy used for assessment purposes. Grey dots are individual measurements; dotted red lines represent 95% confidence intervals.

4.3.3.3 Chub mackerel LWR

136 Chub mackerel individuals were used to calculate the LWR. LWR parameters for chub mackerel were 0.004 and 3.17 a and b respectively (Figure 14).

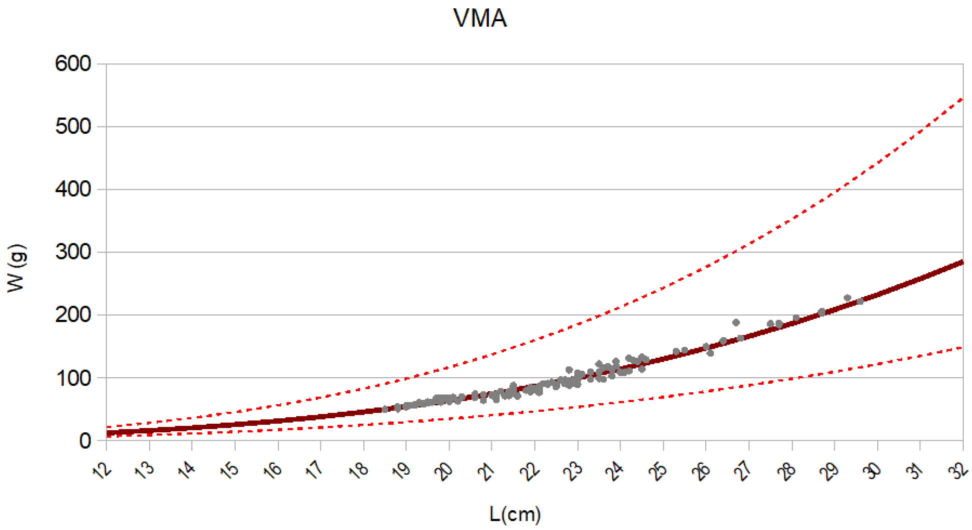


Figure 14 Length weight relationship for chub mackerel used for assessment purposes. Grey dots are individual measurements; dotted red lines represent 95% confidence intervals.

4.3.3.4 Horse Mackerel LWR

153 horse mackerel individuals were used to calculate the LWR. LWR parameters for horse mackerel were 0.009 and 2.99 a and b respectively (Figure 15).

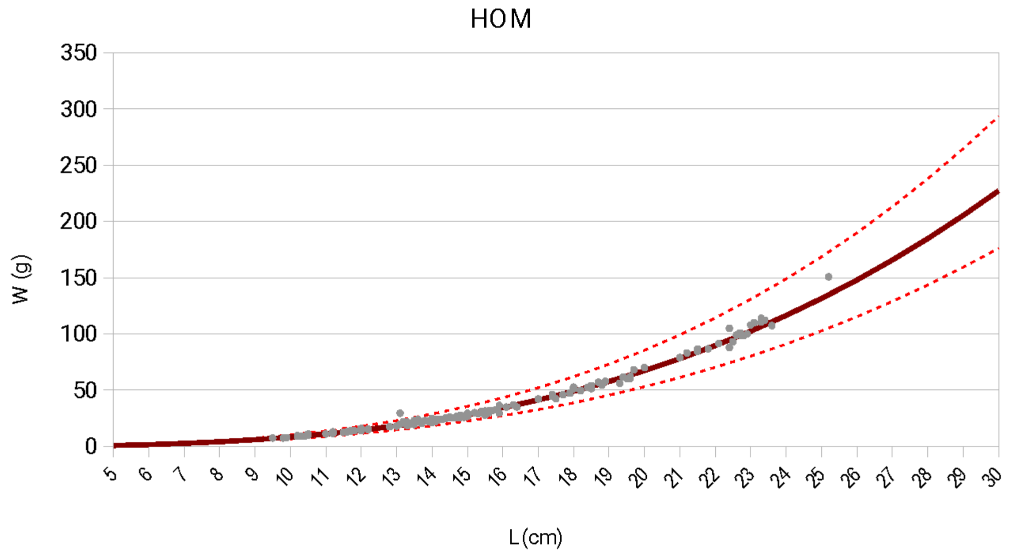


Figure 15 Length weight relationship for horse mackerel used for assessment purposes. Grey dots are individual measurements; dotted red lines represent 95% confidence intervals.

4.3.3.5 Mackerel LWR

68 mackerel individuals were used to calculate the LWR. LWR parameters for mackerel were 0.0016 and 3.45 a and b respectively (Figure 16).

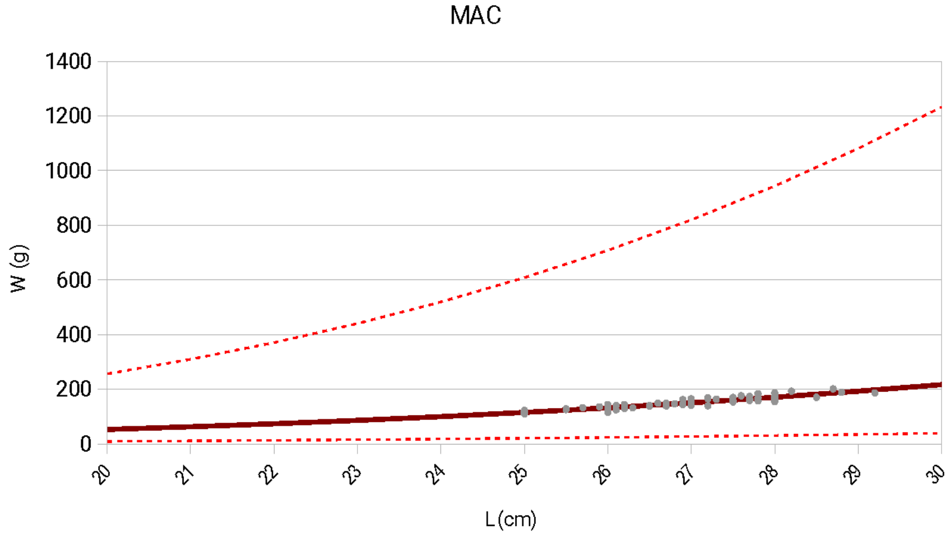


Figure 16 Length weight relationship for Atlantic mackerel used for assessment purposes. Grey dots are individual measurements; dotted red lines represent 95% confidence intervals.

4.3 Acoustic assessment

Table 6 shows the total energy attributed to the main species as well as the center of gravity, using as coordinates the distance from the origin, located at 37ºN, and depth.

Table 6 Total NASC allocated to the main pelagic species together with the location of the coordinates of the center of gravity (PIL_PET, juvenile sardine; MAC, mackerel; HOM, horse mackerel; PIL, sardine; VMA, chub mackerel; SEAB, seabream; ANE, anchovy; SNS, longspine snipefish; KRILL, euphasidae; MAV, pearlside Maurolicus spp.)

	MAC	HKE	HOM	PIL	JAA	BOG	VMA	SEAB	ANE	KRILL
NASC	366	1786	41236	223614	34	19014	25946	3335	27063	26
Depth	31.34	69.31	49.89	53.96	21.24	51.02	37.40	61.43	21.09	76.34
s.d.	14.56	11.93	18.36	20.87	1.04	6.60	13.35	14.46	11.00	7.34
ic	2.07	1.69	2.61	2.96	0.15	0.94	1.89	2.05	1.56	1.04
Dist	321.81	318.98	259.03	275.43	221.50	276.19	82.55	312.49	201.74	302.26
s.d.	9.82	2.98	24.29	39.05	0.24	6.40	14.40	17.19	8.78	9.81
ic	1.39	0.42	3.45	5.54	0.03	0.91	2.04	2.44	1.25	1.39

Figure 17 shows the spatial distribution of the center of gravity as well as the cumulated NASC along distance from the origin. Chub mackerel is clearly located in the 9aCS area, while anchovy, sardine and horse mackerel were more abundant in the north-central area (9aCN). Sardine was found in deeper waters (~ 50 m) than anchovy (~25 m).

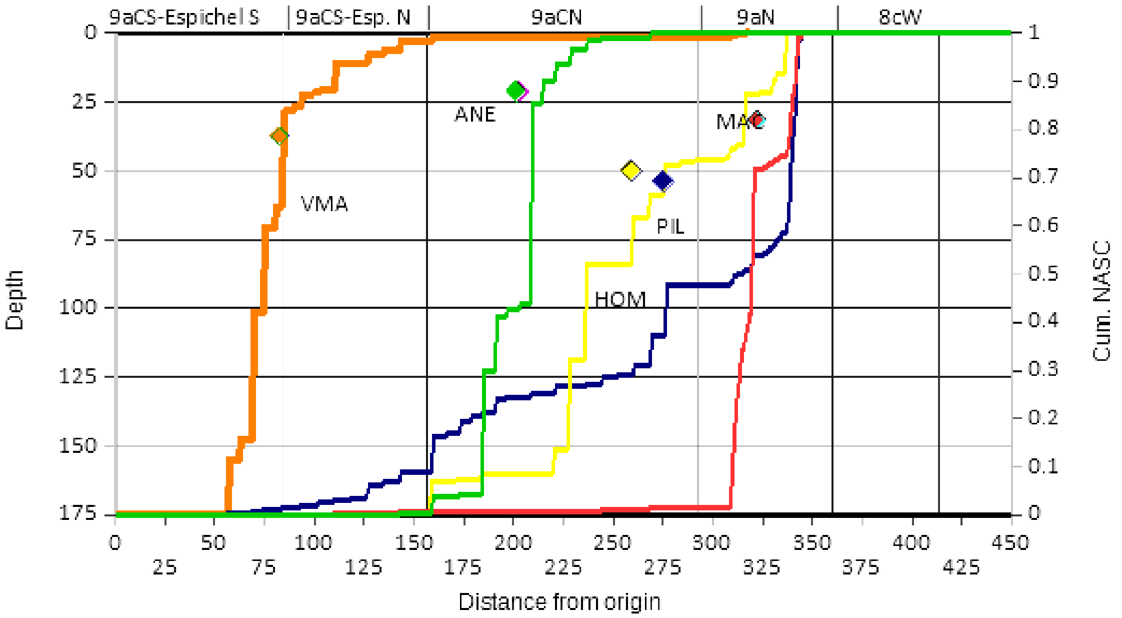


Figure 17 Center of gravity and cumulated NASC for the most important pelagic species (green-anchovy (ANE), blue-sardine (PIL), yellow-horse mackerel (HOM), red-mackerel (MAC), orange-chub mackerel (VMA)).

4.3.1 Sardine assessment

Sardine assessment for IBERAS0921 was estimated as only one echotype. The bulk of the species was concentrated in area 9aCN. The estimated biomass for sardine was of $289*10^3$ tonnes and $5.6*10^9$ fish (Table 7 and Figure 18).

Table 7 Summary of the adult sardine assessment (length>15.0cm), by strata, number of positive nautical miles (No), mean NASC value (m^2 nmi^{-2}), Surface (nmi^2), fishing station used for the estimation and biomass estimated.

		SURVEY:	IBERAS 0921 SARDINE						
ICES-Div	**Region**	**No**	**Mean**	**Surface**	**Fishing st.**	**PDF**	**No (million fish)**	**Biomass (tonnes)**	**Density (Tn/nmi-2)**
9aN	9aN	188	621.72	671	P01-P02-P04	S01	1642	106540	159
	Total	**188**	***621.72***	**671**			**1642**	**106540**	**159**
9aCN	Oc North	161	540.68	1282	P10-P11-P14-P15-P16-PE17-PE18-PE19-C06-PE27-PE28	S02	3228	157363	123
	Total	**161**	***540.68***	**1282**			**3228**	**157363**	**123**
9aCS	Ericeira	54	287.65	339	PE19-PE21	S03	620	18419	54
	Lisbon	9	60.00	67	PE21-PE22	S04	21	952	14
	Alentejo	23	156.96	115	PE22	S05	58	5848	51
	Total	**86**	***228.87***	**521**			**699**	**25219**	**48**
	Total Spain	***188***	***622***	***671***			***1642***	***106540***	**159**
	Total Portugal	***247***	***432***	***1802***			***3927***	***182581***	**101**
	TOTAL	**435**	***514***	**2474**			**5569**	**289121**	**117**

The most representative year was age 2, with $177*10^3$ metric tonnes and $3.28*10^9$ fish (Figure 19).

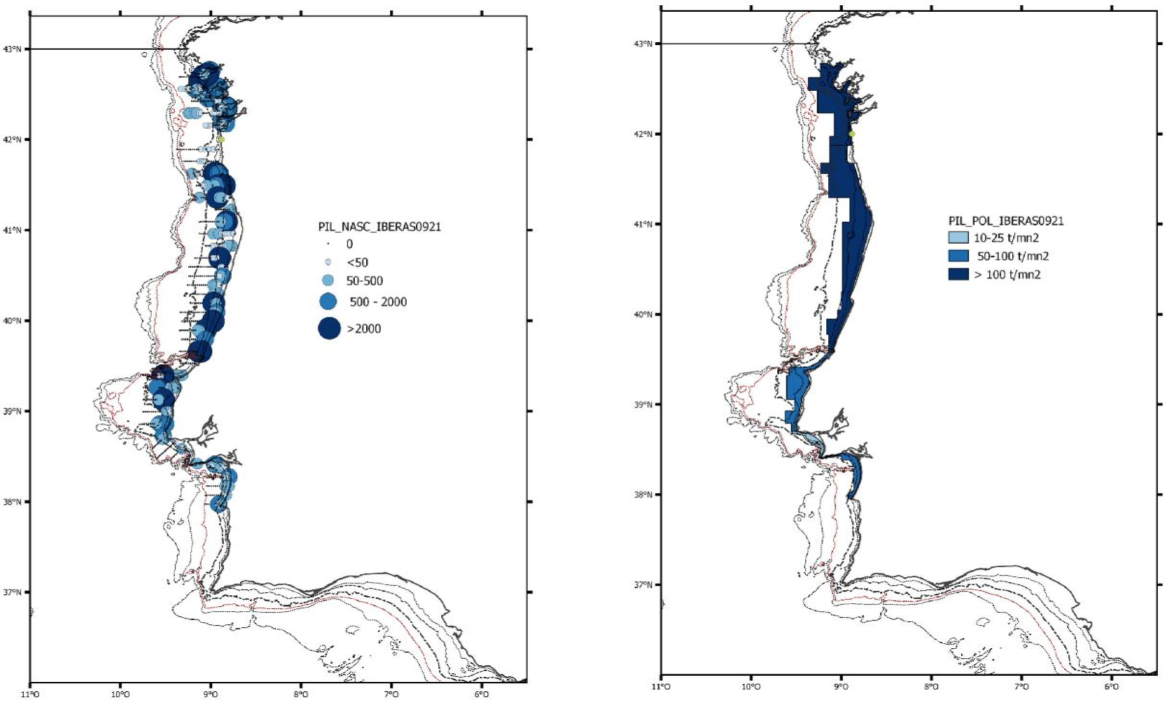


Figure 18 Sardine spatial distribution in IBERAS0921. Left: bubble plot which represent NASC values attributed to sardine (size proportional to abundance). Right: Sardine strata together with the relative density (t/nm²).

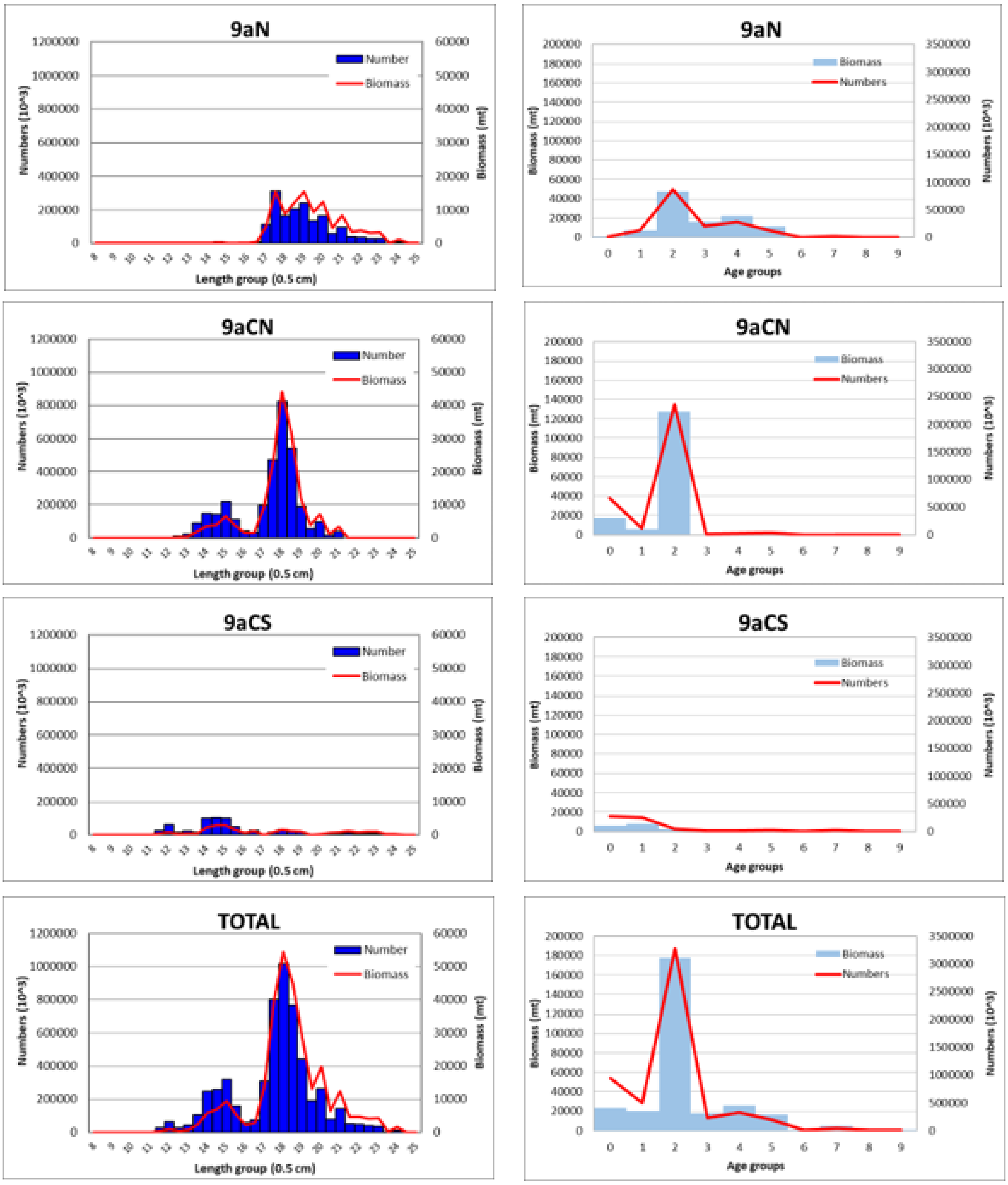


Figure 19 Sardine biomass and abundance estimates by ICES sub-division and the total for the whole area. Left panels in length classes, right panels in age groups

4.3.1.1 Sardine stock indicators

The sardine indicators below are a series of metrics comparing results from years 2018 to 2021 (whole IBERAS data series). However, for result comparison, it should be noted that there is a two-month gap between the 2018 survey (November/December) and the surveys carried out in 2019, 2020, and 2021 (September/October).

Spatial distribution

The center of gravity calculated for sardine was located in subdivision 9aCN. The main distribution in the present survey is in the same subdivision but northern than in previous years, when it was stable around Figueira da a Foz. The mean depth was around 20 m in the previous years, and deeper this year when the mean depth was almost 60 m (Figure 20).

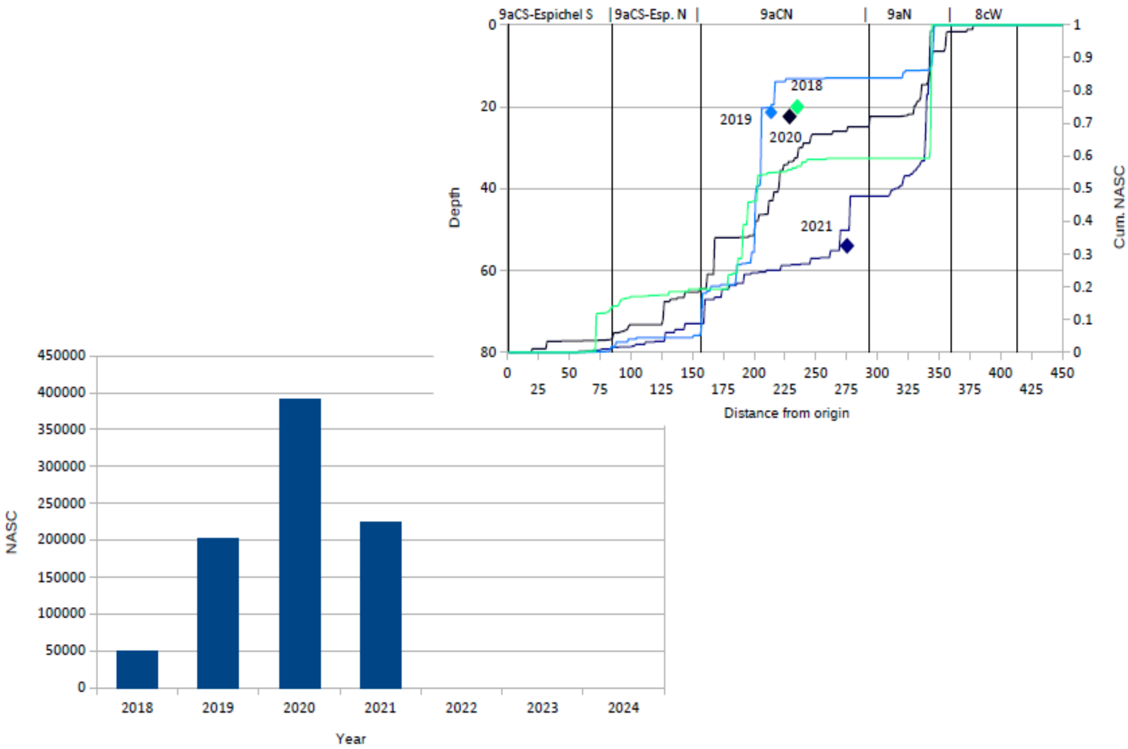
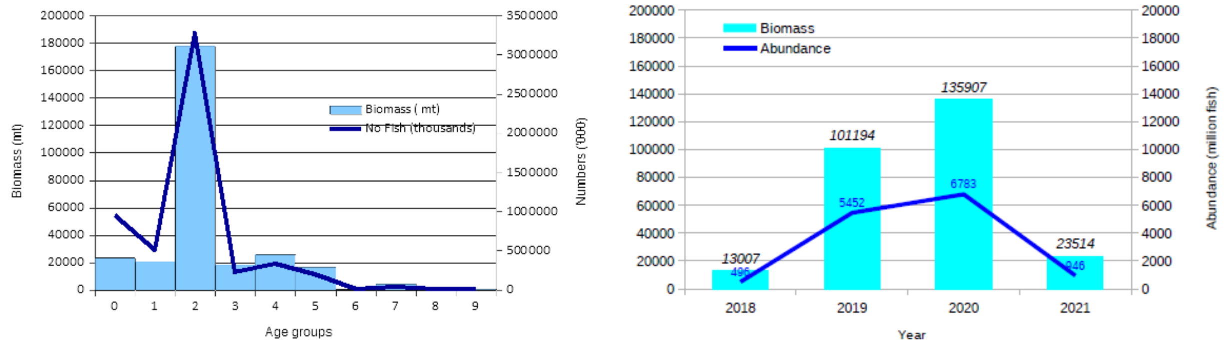


Figure 20 Relative cumulative NASC values of sardine along the coast (from south to north) and center of gravity (above right) and the total backscattering energy attributed to sardine (below left). Numbers in the cumulative plot correspond to the ICES sub-divisions.

Recruitment index (2018-2021)

The recruitment index for this was of $23*10^3$ metric tonnes and $0.9*10^9$ fish. Those values are lower than those found in 2019 and 2020 and confirm the 2019 cohort ($178*10^3$ mt, $3.2*10^9$ fish) (*Figure 21*).



year. The same pattern was observed in the mean weight. Through the years, the length anomaly for age class 0 was negative until last year, and this year showed a positive increase: On the contrary, The weight anomaly is in a decreasing trend (Figure 22).

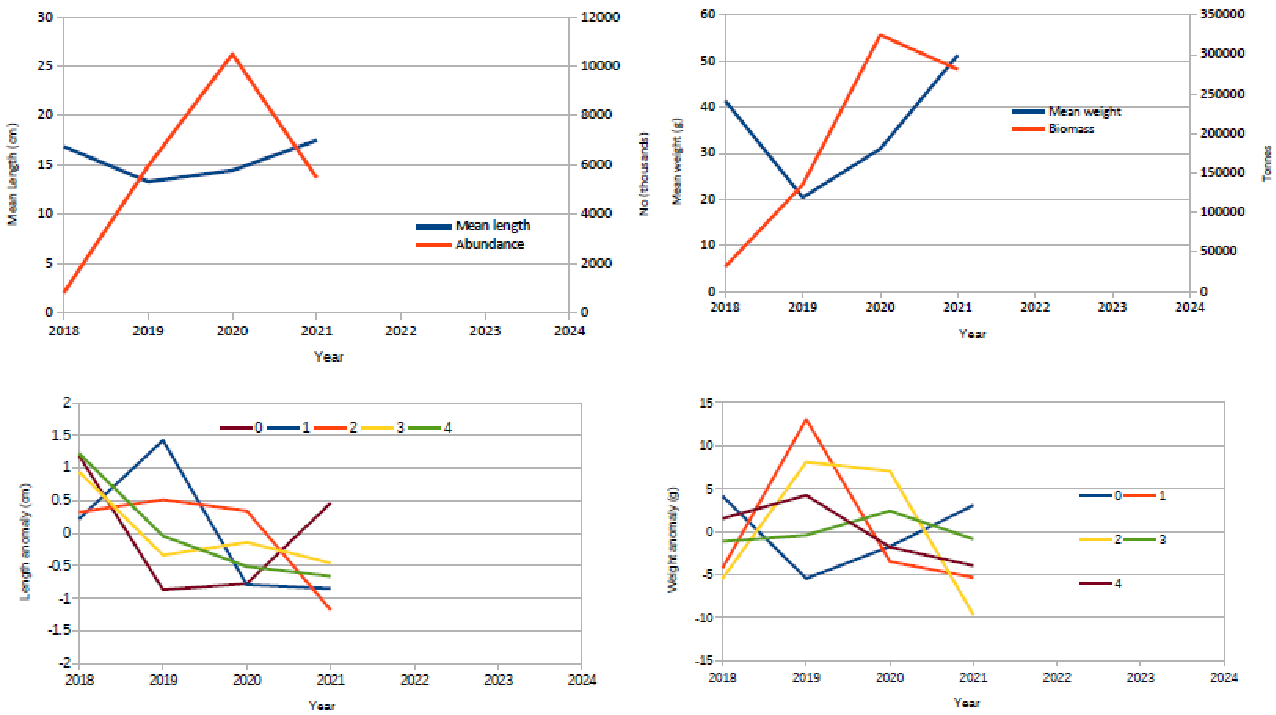


Figure 22 Mean length(cm) and mean weight (g) by year (upper plots). Length anomality (cm) and weight anomality (g) by years and age class (lower plots).

4.3.2 Anchovy assessment

In 2021, anchovy was assessed as one category. Anchovies this year were concentrated in the north, with almost no individuals in the rest of the surveyed area (Figure 23). The estimated biomass for anchovy in 2021 was 31236 tonnes, corresponding to 1431 million fish (Table 8).

Table 8 Summary of the anchovy assessment, with the name of the strata, number of positive nmi, mean NASC value (m^2 nmi^{-2}), Surface (nmi^2), fishing station used for the estimation and number and biomass estimated.

Zone	Area	No	Mean	Area	Fishing st.	PDF	No (million fish)	Biomass (tonnes)	Density (Tn/nmi-2)
		SURVEY:	IBERAS0921 ANCHOVY						
9aCS	Ericeira	54	0.65	339	P14	S01	2	29	0
	Total	***54***	***0.65***	***339***			***2***	***29***	***0***
9aCN	9aCN	161	167.86	1282	P14	S01	1429	31206	24
	Total	***161***	***167.86***	***1282***			***1429***	***31206***	***24***
	Portugal	***215***	***126***	***1620***			***1431***	***31236***	***19***
	TOTAL	**215**	***125.86***	**1620**			**1431**	**31236**	**19**

The predominant age of anchovy this year was age 1, with 156*10^3 metric tonnes estimated biomass and 6.0*10^8 fish, confirming good recruitment found last year (*Figure 24*).

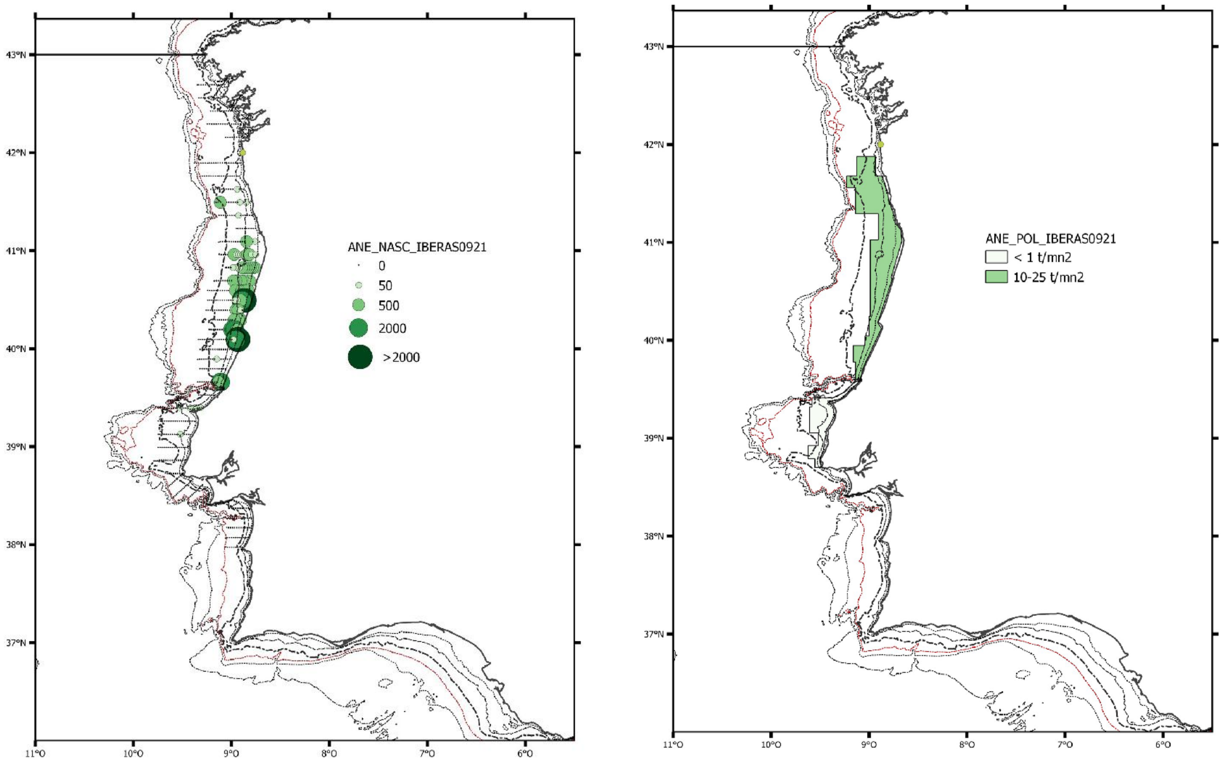


Figure 23 Anchovy spatial distribution in IBERAS 0921. Map on the left: bubble plots which represent the NASC values attributed to anchovy (size proportional to abundance). Map on the right: strata used together with the relative density.

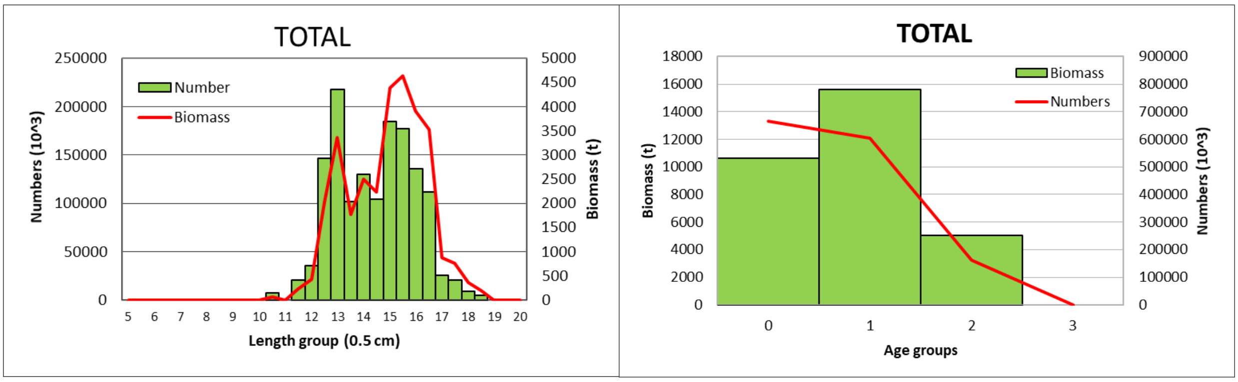


Figure 24 Anchovy biomass and abundance estimates for the whole area. Left panel in length classes, right panel in age groups.

4.3.2.1 Anchovy stock indicators

The anchovy indicators shown are a series of metrics comparing results from years 2018 to 2021 (whole IBERAS data series). However, for result comparison, it should be considered a two-month gap between the years 2018 and 2019/2020/2021.

Spatial distribution

The center of gravity calculated for anchovy, and as in previous years was stable around Figueira da Foz (area 9aCN). The mean depth was around the 20 m depth in all years analysed, except year 2020 where the mean depth was around 60 m depth, due to the presence of offshore schools (Figure 25).

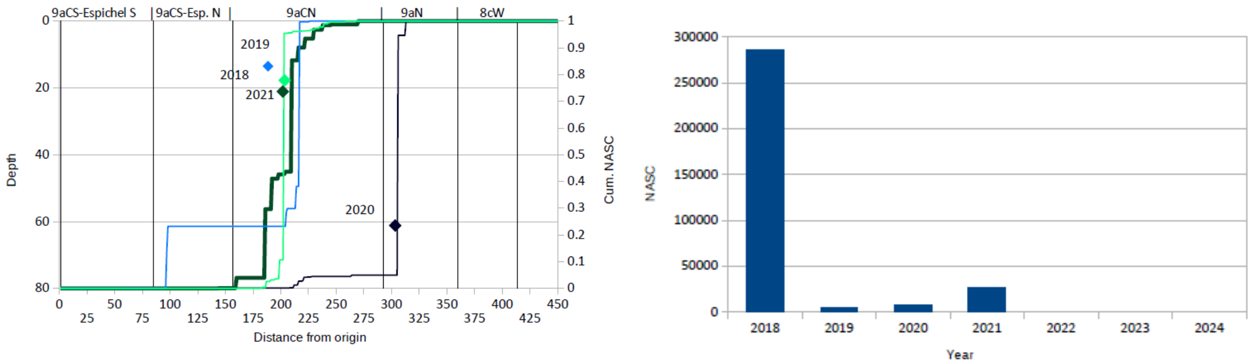


Figure 25 Relative cumulative NASC values of anchovy along the coast (from south to north) and center of gravity (left) and the total backscattering energy attributed to anchovy along the IBERAS time series (right). Numbers in the cumulative plot correspond to the ICES sub-divisions.

Recruitment index (2018-2021)

The recruitment index for this was quite low when compared with previous years. $10*10^3$ metric tonnes and $6.65*10^8$ fish.

Length and weight evolution (2018-2021)

The anchovy mean length through the years showed a maximum in 2019, and a decrease ever since. Regarding mean weight, a maximum was also observed in 2019, following by a big decrease last year and a significant recovery this year. Through the years, the length and weight anomaly for age class 0 was negative until this year, that showed a positive increase (Figure 26).

Figure 26 Mean length(cm) and mean weight (g) by year (upper plots). Length anomality (cm) and weight anomality (g) by years and age class (lower plots).

5. DISCUSSION AND CONCLUSIONS

This year, the survey reached its fourth year of performance. The survey coverage was lower than previous years, due to the interruption provoked by the explosion of the La Palma volcano. Nevertheless, IBERAS0921 managed to cover the probable distribution of the Iberoatlantic stock of sardine and anchovy (e.g prime objective).

Sardine schools were observed close to the bottom this year. As main result, biomass estimates for sardine achieved of $289*10^3$ metric tonnes that corresponds to $5.6*10^9$ fish. The most representative was age group 2, which accounted for $177*10^3$ metric tonnes ($3.28*10^9$ fish), confirming the strength of the 2019 cohort. This year recruitment was quite low (age 0; $23*10^3$ metric tonnes, $0.9*10^9$ fish), when compared with the last biggest recruitment in 2019 ($178*10^3$ mt, $3.2*10^9$ fish). The center of gravity was found around Figueira da Foz, with a large dispersion.

Biomass estimates for anchovy was 31236 metric tonnes that corresponds to 1431 million fish. Age group 0 counted with $10*10^3$ metric tonnes ($6.65*10^8$ fish), age group 1 was predominant with $156*10^3$ metric tonnes ($6.0*10^8$ fish). Anchovy was mostly found in the Northern part (9aCN). As is usual, the center of gravity was found also in 9aCN area.

This year the assessment of other important pelagic species in the community, such as chub mackerel, horse mackerel and mackerel were not carried out.

Overall IBERAS is providing a good indicator of the strength of the sardine recruitment for the iberoatlantic stock. The index estimates have been oscillating in the last 4 years, with the first three years with an exponential increase, then a low recruitment found this year (2021).

6. ACKNOWLEDGEMENT

We would like to thank the captain and the crew of R/V Ramón Margalef for this great cooperation, especially the boatswain who made possible the dinghy navigations. We also thank the Spanish and Portuguese scientific team that participated in the surveys and to other colleagues from IEO and IPMA which participated in the post possessing of survey samples and data.

IBERAS is a new acoustic-trawl survey developed in cooperation between the Instituto Português do Mar e da Atmosfera (IPMA) and the Instituto Español de Oceanografía (IEO).

7. CONSULTED BIBLIOGRAPHY

Barange, M., Hampton, I. And Soule, M. 1996 Empirical determination of in situ target strength of three loosely aggregated pelagic fish species. ICES Journal of Marine Science, 53: 225-232.

Barange, M., and Hampton, I. 1997. Spatial structure of co-occurring anchovy and sardine populations from acoustic data: implications for the survey design. FisheriesOceanography, 6(2): 94-108.

Boyra, G., Martínez, U., Cotano, U., Santos, M., Irigoien, X., and Uriarte, A. 2013. Acoustic surveys for juvenile anchovy in the Bay of Biscay: abundance estimate as an indicator of the next year's recruitment and spatial distribution patterns. ICES Journal of Marine Science. doi.10.1093/icesjms/fst096.

Carrera, P. and Porteiro, C. 2003. Stock dynamic of the Iberian sardine (Sardinapilchardus, W.) and its implication on the fishery off Galicia. Scientia Marina., 67 (Suppl. 1): 245-258.

Carrera, P., Churnside, J. H., Boyra, G., Marques, V., Scalabrin, C., and Uriarte, A. 2006.Comparison of airborne lidar with echosounders: a case study in the coastal Atlantic waters of southern Europe. ICES Journal of Marine Science, 63: 1736-1750.

Cochran, W.G. (1977). Sampling Techniques (third edition). John Wiley and Sons, New York, 428 pp.

Coetzee, J. 2000. Use of a shoal analysis and patch estimation system (SHAPES) to characterise sardine schools. Aquat. Living Resour., 13, 1-10.

Coetzee, J. C., Misund, O. A., and Oechslin, G.2001. Variable spatial structure of schooling pelagic fish off Namibia: implications for acoustic surveys. African Journal of Marine Science, 23 (1): 99–109.

De Robertis, A., McKelvey, D. R., and Ressler, P. H. 2010. Development and application of an empirical multifrequency method for backscatter classification. Canadian Journal of Fisheries and Aquatic Sciences, 67: 1459–1474.

Diner,N., Weill, A., Coail, J. Y., and Coudeville, J. M. 1989. INES-MOVIES: a new acoustic data acquisition and processing system. ICES CM 1989/B:45. 11pp.

Dragesund, O. and Olsen, S. 1965. On the possibility of estimating year-class strength by measuring echo-abundance of 0-group fish. Fiskeridir. Skr. Havundersøk., 13:47-75.

Dressel, S. H., and Norcross, B. L. 2005. Using poststratification to improve abundance estimates from multispecies surveys: a study of juvenile flatfishes. Fish. Bull. 103:469-488.

Edwards, J. I., F. Armstrong. 1984. Herring, mackerel and sprat target strength experiments with behavioural observations. ICES CM 1984/B:34. 21 pp.

Fässler, S. M. M. 2008. target strength variability in atlantic herring (clupeaharengus) and its effect on acoustic Abundance estimates. Ph. Thesis. University of St. Andrews. http://hdl.handle.net/10023/1703. 277 pp.

Fässler, S. M. M., O'Donnell, C., and Jech, J.M. 2013. Boarfish (Caprosaper) target strength modelled from magnetic resonance imaging (MRI) scans of its swimbladder. ICES Journal of Marine Science, 70: 1451–1459.

Foote, K. G., Aglen, A., and Nakken,O. 1986. Measurement of fish target strength with a split-beam echo sounder. J. Acoust. Soc. Am. 80 (2), 612-621.

Foote K.G., 1987. Fish target strengths for use in echo integrator surveys. J. Acoust. Soc. Am., 82: pp. 981-987.

Frouzova, J., Kubecka, J., Balk, H., and Frouz, J. 2005. Target strength of some European fish species and its dependence on fish bodi parameters. Fisheries Research, 75: 86-89.

Georgakarakos, S., Trygonis, V., and Haralabous, J. 2011. Accuracy of Acoustic Methods in Fish Stock Assessment Surveys. Sonar Systems, Prof. Nikolai Kolev (Ed.), ISBN: 978-953-307-345-3, InTech. Pp 275-298.

Gorska, N., Korneliussen, R. J., and Ona, E. 2007. Acoustic backscatter by schools of adult Atlantic mackerel. – ICES Journal of Marine Science, 64: 1145–1151.

Gutiérrez, M., y MacLennan, D. N., 1998. Resultados preliminares de las mediciones de Fuerza de Blanco in situ de las principales especies pelágicas. Crucero BIC Humboldt 9803-05 ded Tumbes a Tacna. Inf. Inst. Mar Perú, no. 135:16-19.

Halldórsson, O. and Reynisson, P. 1983. Target strength measurements of herring and capelin "in situ" at lceland. FAO Fish. Rep. 300: 78-84.

Hannachi, M.S., Ben Abdallah, L., and Marrakchi, O. 2005. Acoustic identification of small pelagic fish species: target strength analysis and school descriptor classification, MedSudMed Technical Documents 5: 90–99.

Henderson, M. J. 2005. The influence of orientation on the target strength of pacific hake (Merlucciusproductus). Master Thesis. University of Washington.

Henderson, M. J., Horne, J. K., and Towler, R. H. 2007. The influence of beam position and swimming direction on fish target strength. ICES Journal of Marine Science, 65: 226–237.

Henderson M. J., and Horne J. K. 2007. Comparison of in situ, ex situ, and backscatter model estimates of Pacific hake (Merlucciusproductus) target strength. Canadian Journal of Fisheries and Aquatic Sciences, 64: 1781–1794.

Huse, I. and Ona, E. 1996. Tilt angle distribution and swimming speed of overwinteringNorwegian spring-spawning herring. – ICES Journal of Marine Science, 53:863–873.

Korneliussen, R. J., and Ona, E. 2003. Synthetic echograms generated from the relative frequency response. ICES Journal of Marine Science, 60: 636–640.

Korneliussen, R. J., Diner, N., Ona, E., Berger, L., and Fernandes, P. 2008. Proposals for the collection of multifrequency acoustic data. ICES Journal of Marine Science. 65: 982-994.

Korneliussen, R. J., Heggelund, Y., Eliassen, I. K., and Johansen, G. O. 2009. Acoustic species identification of schooling fish. ICES Journal of Marine Science, 66: 1111–1118.

Lillo S., Cordova J. &Paillaman A., 1996. Target-strength measurements of hake and jack mackerel. ICES Journal of Marine Science, 53: pp. 267-272.

MacCall, A. D. (1990). The dynamic geography of marine fish populations. In Recruitment fishery oceanography. (Washington Sea Grant, University of Washington Press, Seattle, 153 pp).

Machias, A. and Tsimenides, N. Anatomical and physiological factors affecting the swim-bladder cross-section of the sardine Sardinapilchardus. Canadian Journal of Fisheries and Aquatic Science, 53:280-287.

Martins, M. M., Skagen, D., Marques, V., Zwolinski, J., and Silva, A. 2013. Changes in the abundance and spatial distribution of the Atlantic chub mackerel (Scombercolias) in the pelagic ecosystem and fisheries off Portugal. Scientia Marina 77(4) December 2013, 551-563.

McClatchie, S., Thorne, R. E., Grimes, P. &Hanchet, S. 2000. Ground truth and target identification for fisheries acoustics. Fisheries Research, 47, 173-191.

Muiño, R., Carrera, P., Petitgas, P., Beare, D. J., Georgakarakos, S., Haralambous, J., Iglesias, M., Liorzou, B., Massé, J., and Reid, D. G. 2003. Consistency in the correlation of school parameters across years and stocks. ICES Journal of Marine Science, 60: 164–175.

Muiño, R., Carrera, P., and Iglesias, M. 2003. The characterization of sardine (SardinapilchardusWalbaum) schools off the Spanish-Atlantic coast. – ICES Journal of Marine Science, 60: 1361–1372.

Nakken, O. and Dommasnes A. 1975. The application for an echo integration system in investigations on the stock strength of the Barents Sea capelin (Mallotusvillosus, Müller) 1971-74. ICES CM 1975/B:25.

Nakken O. &Dommasnes A., 1977. Acoustic estimates of the Barents Sea capelin stock 1971–1976. ICES CM, 1977/H:35.

Ona, E. 1990. Physiological factors causing natural variations in acoustic target strength of fish. J. mar. biol. Ass. U.K., 70: 107-127.

Patti, B., Mazzola, S.; Calise, L., Bonanno, A., Buscaino, G., and Cosimi, G. 2000. Echo-survey estimates and distribution of small pelagic fish concentrations in the Strait of Sicily during June 1998. GFCM/ SAC Working Group on Small Pelagics, Fuengirola, Spain, 1–3 March 2000. 8 pp.

Pedersen, G., Godø, O. R., Ona, E., and Macaulay, G. J. 2011. A revised target strength–length estimate for blue whiting (Micromesistiuspoutassou): implications for biomass estimates. ICES Journal of Marine Science, 68: 2222–2228.

Petitgas, P., Massé, J., Beillois, P., Lebardier, E., and Le Cann, A. 2003. Sampling variance of species identification in fisheries-acoustic surveys based on automated procedures associating acoustic images and trawl hauls. ICES Journal of Marine Science, 60: 437-445.

Pitcher T. J. 1983. Heuristic definitions of shoaling behaviour. Anim. Behav., 31, 611-13.

Pitcher, T. J. 2001. Fish schooling: implications for pattern in the oceans and impacts on human fisheries. In: Encyclopedia of Ocean Sciences (Ed. By J. H. Steele, K. K. Turekian& S. A. Thorpe), pp. 975–987. London: Academic Press.

Porteiro, C., Carrera, P., and Miquel, J. 1996. Analysis of Spanish acoustic surveys for sardine, 1991-1993: abundance estimates and inter-annual variability. ICES Journal of Marine Science, 53: 429-433.

Reid, D. (ed.) 2000. Report on echo-trace classification. ICES Cooperative Research Report no 238, 107 pp.

Reid, D., Scalabrin, C., Petitgas, P., Massé, J., Aukland, R., Carrera, P., and Georgakarakos, S. 2000. Standard protocols for the analysis of school based data from echosounder surveys. Fisheries Research, 47: 125-136.

Scalabrin, C. 1997. Identification acoustique des espèces pélagiques à partir d'attributs discriminants des bancs de poissons monospécifiques. Thèse du Doctorat en Océanographie Biologique: Université de Brétagne Occidentale de Brest.

Simmonds, E. J., Williamson, N. J., Gerlotto, F., and Aglen, A. 1992 Acoustic survey design and analysis procedure: a comprehensive review of current practice. ICES Cooperative Research Report no 187. 127 pp.

Simmonds, E. J. & MacLennan, D. N. 2005. Data analysis. In Fisheries Acoustics: Theory and Practice.Oxford: Blackwell.

Simmonds E. J. and MacLennan, D. 2005. Survey design in Fisheries Acoustics. Theory and practice. 2nd edition. Blackwell Science.

Simmonds, E.J., Gutiérrez, M., Chipollini, A., Gerlotto, F., Woillez, M., and Bertrand, A. 2009. Optimizing the design of acoustic surveys of Peruvian anchoveta. ICES Journal of Marine Science, 66: 1341–1348.

Stanton, T. K., Chu, D., Jech, J. M., and Irish, J. D. 2010. New broadband methods for resonance classification and high-resolution imagery of fish with swimbladders using a modified commercial broadband echosounder. – ICES Journal of Marine Science, 67: 365–378.

Swain, D. P., Sinclair, A.F. 1994. Fish Distribution and Catchability: what is the appropriate measure of distribution?. Can. J. Fish. Aquat. Sci. 51:1046-1054.

Woillez, M., Poulard, J-C., Rivoirard, J., Petitgas, P., and Bez, N. 2007. Indices for capturing spatial patterns and their evolution in time, with application to European hake (*Merluccius merluccius*) in the Bay of Biscay. ICES Journal of Marine Science, 64: 537–550.

Woillez, M., Rivoirard, J., and Fernandes, P. G. 2009. Evaluating the uncertainty of abundance estimates from acoustic surveys using geostatistical simulations. ICES Journal of Marine Science, 66: 1377–1383.

Zar, J. H. (1984). Biostatistical Analysis. 2nd edition. Prentice-Hall, Inc.

Zwolinski, J. 2007. Estimação acústica da distribuição e abundância de sardinha, Sardina pilchardus. Tesis doctoral. Universidade de Aveiro. Departamento de Biologia. 147pp.

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