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A partnership between science and industry for a monitoring of anchovy & sardine in the Bay of Biscay: When fishermen are actors of science

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Abstract :

Anchovy and sardine are small pelagic species occupying similar geographic areas in the Bay of Biscay (North-East Atlantic). Their biomass is strongly dependent on recruitment, making the annual assessment of TAC (Total Allowable Catch) a risky strategy due to uncertainty in predicting the magnitude of recruitment. Monitoring these resources more often and throughout their life cycle could allow management strategies to be adjusted based on observations which indicate the level of recruitment. In order to achieve a more frequent monitoring, an innovative data collection strategy involving a partnership between fishermen and scientists, was developed in 2009 and 2010 called "pilot sentinel surveys". This paper details the partnership, the information such a partnership can provide and how it can be useful for adaptively managing such resources. The method was based on short surveys undertaken by commercial vessels several times per year, in two spatially limited "key areas" known to be potential recruitment habitats. Acoustic surveys and fishing operations enabling biological sampling, were combined in each key area. Only one scientist was on board and an ad hoc sampling strategy was adopted during each survey by the Captain–Scientist team depending on the local conditions. This partnership allowed scientists to benefit from fishermen's experience and therefore adopt a sampling strategy which was optimized in time and space. The sentinel survey data were complemented with data collected during annual spring acoustic surveys carried out by the research vessel (RV) Thalassa. The RV was accompanied by commercial vessels allowing additional fishing operations and acoustic echo interpretation to be performed. This experiment showed that the sentinel observations in limited areas cannot provide reliable abundance indices, but are adequate to provide significant biological information on the seasonal progress of the life cycle of each species, such as growth, timing of in-coming recruitment and migration pattern. In addition, these "pilot sentinel surveys" significantly improved the mutual understanding between fishermen and scientists.

Highlights

► Fishermen were key players in a collaborative research on pelagic species monitoring. ► Sporadic surveys in key areas are relevant to monitor anchovy recruitment arrivals. ► Fishermen can collect acoustic and biological data to monitor small pelagic stocks.

Keywords : Sporadic acoustic surveys, Bay of Biscay, Small pelagic monitoring, Recruitment indicators, Fishermen's surveys

1. Introduction

Small pelagic species such as anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) constitute important fish resources in the Bay of Biscay (Fig. 1), mainly exploited by Spanish purse seiners and French pelagic pair trawlers. In this area, anchovy has been managed by TAC (Total Allowable Catch) since 1980 whereas there is no present or planned EU management for sardine. Anchovy biomass dynamics are strongly dependent on recruitment (which is defined as 1 year old for these species), which represents generally 70% of the stock (up to 90% in some years) for anchovy and 60 % for sardine (Silva et al., 2009).

Insert Fig. 1

In 2002, anchovy recruitment declined leading to a collapse of the stock biomass in 2003 and a closure of the fishery between 2005 and 2010 (ICES, 2013). Recruitment magnitude depends on summer larval drift and survival, and also winter juvenile survival. Until now, attempts to predict recruitment magnitude (age-1 in subsequent year) based on environmental conditions (Borja et al., 1996, 2008; Allain et al., 2001, 2007; Fernandes et al., 2010; Huret et al., 2010; Petitgas et al., 2011) have not been considered reliable enough by ICES to be used in management (ICES, 2007). The standing stock in the current year is assessed by ICES based on spring surveys at spawning time and on annual catches. ICES advises in the current year (t) on a TAC for year (t+1) based on the assessment of the current standing stock and an estimation of possible recruitment magnitudes for year (t+1). Juvenile acoustic surveys (Boyra et al., 2013) in autumn have been used to adjust the TAC(t+1) at the end of year (t), but inaccuracy in estimating total juvenile abundance, as well as unpredictable winter juvenile survival can be problematic for recruitment prediction (ICES, 2006). Here, we consider another approach to “in season” monitoring of the resource’s biology throughout its life cycle in specific habitats. The approach is based on the idea that the state of the resource and the recruitment magnitude could be assessed by capturing the seasonal evolution of certain key biological indicators. For example, anchovy growth rate is a key parameter in determining the dynamics of the population as it regulates reproductive potential (Pecquerie et al., 2009). Another important parameter is the occupation of offshore habitats (Petitgas et al., 2012) and also potentially the migration pattern to summer/autumn feeding habitats located in northern Biscay (ICES, 2010). This approach is also applied to sardine, which occupies somewhat similar geographic areas as anchovy in Biscay (ICES, 2010). Sardine, however, has a larger spatial distribution than anchovy and a different management context.

The aim of this paper is to describe an innovative data collection strategy, which was carried out in partnership with fishermen. The strategy was designed to cover key areas and seasons using small targeted scientific investigations. These investigations were undertaken considering fishermen's local knowledge, taking advantage of their experience instead of relying on one single comprehensive scientific survey in spring. This pilot study called "sentinel surveys" was conducted between 2009 and 2010 as a proof of concept and consisted of acoustic surveys of two sites and collection of biological samples using commercial fishing vessels. This paper describes the approach and the data collected with some examples of results and proposals for indices which could be used to monitor recruitment and describe the condition of adults throughout the year. Such indices could be used to develop sustainable management options including harvest rules (e.g., spatial and/or temporal closures in sensitive areas).

2. Material and methods

Independent of annual scientific assessment surveys which are used to assess biomass, 5 short "sentinel surveys" were organized from April 2009 to September 2010 on board commercial vessels. Sentinel surveys were carried out in order to collect relevant, targeted data throughout the year about sardine and anchovy in the Bay of Biscay, thus avoiding full scientific surveys on board research vessels which are expensive and not easy to mobilize. The idea was to involve fishermen and to take advantage of their knowledge and know-how. Preliminary meetings revealed that some of them were already willing to volunteer for scientific investigations which could provide better knowledge about the exploitation of fishery resources and possible elements for management considerations. It was nevertheless necessary to collect data outside the period when they were involved in sardine or anchovy fishery. However, outside this period (mainly the spawning season) they were usually committed to other fisheries (involving different species, areas, and/or equipment). It was therefore necessary to provide financial compensation to retain volunteers. Onboard such ships the fishing gear was adequate for the research purposes, but the onboard echo-sounder was generally uncalibrated and had no data storage capacity. Therefore a scientific echo-sounder and operator were added. Finally, a sampling strategy was developed so that data could be collected, while giving the captain sufficient freedom to benefit from his knowledge and intuition.

Insert Table 1

2.1. Sampling strategy and data acquisition

The sentinel surveys were carried out for a total of 24 days (Table 1). Three different pair trawlers participated in the survey operations (Table 1) over the18 month duration of the sentinel project. The fishing vessels were 15 - 22 m long and their pelagic trawl vertical opening was between 15 and 30 m depending on fishing conditions. The mesh size in the cod end was 12 mm, allowing them to catch small fish in good condition.

In the Bay of Biscay, spawning sites of anchovy and sardine are spatially distinct (Bellier et al., 2007). Anchovy spawning habitats are located in coastal waters, associated with river plumes (in front of the Gironde and Adour estuaries), and sometimes occur at the shelf break (Motos et al., 1996; Bellier et al., 2007; Planques et al., 2007; Petitgas et al., 2013). In contrast, sardine spawning sites are frequently fragmented and cover a larger area than for anchovy (Bellier et al., 2007). Thus, two key areas were selected according to the anchovy life cycle: i) an area off the Gironde estuary close to 45°30’N 1°30’W which is a recurrent spawning and nursery area observed during PELGAS surveys in spring and ii) a coastal area in southern Brittany close to 47°30’N and 3°30’W where the major commercial fishery takes place in autumn (Fig. 1). The commercial vessels visited both sites at least 5 times a year to check for the presence of anchovy and/or sardine and to assess their biological state.

For each sentinel survey, the commercial fishing vessel was equipped with a Simrad (Kongsberg Simrad AS, Kongsberg, Norway) EK60 split-beam echosounder of 70 kHz, operated by a scientific observer to guarantee the quality of data acquisition. The transducer was installed looking vertically downwards in a towed body and attached to the side of the vessel. The ping rate was adjusted for the bottom depth from 0.3 s to 0.5 s between 20 m and 100 m depth. The equipment was previously calibrated in a tank in the laboratory using standard procedures (Foote et al., 1987).

The strategy of the sentinel surveys was based on making best use of the knowledge of fishermen about their traditional fishing areas, fishing seasons, likelihood of fish presence and their behavior. This was combined with historical scientific knowledge. Within the target areas, the sampling strategy was opportunistic. The captain would locate aggregations of fish based on his best judgment. The scientist onboard would then set up a small grid of transects perpendicular to the coast and separated by 10 nautical miles (Fig. 1). This area would then be surveyed acoustically based on this design. Biological samples would be taken from trawl hauls identifying any important echotraces while on transect.

To complete the series, the research surveys PELGAS, conducted in spring on board RV Thalassa, were also taken into account in May 2009, 2010 and 2011 (Table 1). Commercial vessels played a role in the scientific surveys in a "consort" role. Pair trawlers accompanied RV Thalassa to increase fishing capacity and efficiency and thus identification of echotraces, in particular from the near surface and in shallow waters. The two key areas for the sentinel surveys are included in the PELGAS surveys which covered the entire French plateau, from the Spanish coast to 48°N and from the coast to the shelf break. The main objective of the PELGAS surveys is to provide an annual acoustic abundance index for anchovy and sardine (ICES, 2013). During the PELGAS surveys, acoustic data are only collected by RV Thalassa and biological samples are collected by Thalassa or the consort commercial vessels. The anchovy and sardine data of the sentinel surveys in spring can therefore be put in the larger context of their full distribution range as provided by the PELGAS consort surveys. The PELGAS survey used a grid of parallel transects separated by12 nautical miles perpendicular to the coast. PELGAS consort commercial vessels sailed the transects at 8 knots and carried out fishing operations on request. Their pelagic trawl had often a higher vertical opening (up to 35 m) but the cod end mesh size was similar to that used on RV Thalassa (12 mm).

2.2. Data analysis

For acoustic data, the same analysis was applied to the PELGAS and sentinel survey data. The echo energies were expressed as nautical area scattering coefficients (NASC, $m^2.nm^{-2}$) per elementary sampling distance unit (ESDU) (MacLennan et al., 2002). For processing, the ESDU size was fixed to one nautical mile. Echotraces were ascribed to species based on pelagic trawl hauls. The combination of the acoustic data with biological data allows us to convert acoustic backscatter into fish abundance by species (Simmonds and MacLennan, 2005; Doray et al., 2010). The resulting data are density of fish in weight per square nautical mile. These processed data were plotted on maps using ArcView GIS to examine the spatial occupation of anchovy and sardine within studied areas.

For biological data, a random sample of each species was measured to determine the length distribution in 0.5 cm classes for anchovy and sardine and up to 5 otoliths were collected by length class for age determination. In addition, annual growth increments between winter rings were measured using a digital camera installed on the binocular and using the image analysis software Visilog (V. 5.4.). Growth increments were measured along the major (longitudinal) axis of the otolith from the nucleus to winter rings. Increments corresponding to the growth of fish between birth and the first winter were measured and noted R1 for age 1 fish. For age 2 fish, increments between birth and second winter were noted R2 and, R2-R1 represented the growth of fish between the first and the second winter (Petitgas et al., 2012).

Fish were grouped into size categories (40 individuals): 3 for anchovy ("small" when length was less than 100 mm, "medium" between 100 and 140 mm, and "large" when length was more than 140 mm) and 4 for sardine, (the same than for anchovy for the 2 smallest and "large" between 140 and 180 mm and "very large" when length was more than 180 mm). Four parameters were estimated for each individual: length L (mm), wet mass M_W (g), dry mass M_D (g) and age. To get dry mass, the fish were oven-dried at 85°C to near constant mass (24-72h).

Fish condition was estimated from individual length/weight measurements. Many authors define an animal's condition as the energy capital accumulated in the body (i.e. fat reserves) and it refers to an animal's health, quality or vigour and fitness (Peig and Green, 2009; McPherson et al., 2011). Many relevant studies have used several morphometric or energetic indices as proxies of the condition of the fish without consensus on the best option (Jones et al., 1999; Froese, 2006; Peig and Green, 2010; McPherson et al., 2011; Kotrschal et al., 2011). In this study, two metrics were used to define the fish condition:

i) a morphometric index, called the "Scaled mass index" ($\widehat{M}_i$) (Peig and Green 2009, 2010**)**. Recently used for fish (Maceda-Veiga et al., 2014), this index standardizes mass to a specific fixed body length based on the scaling relationship between mass and length using the equation:

$$\widehat{M}_i = M_{Wi} \left[\frac{L_0}{L_i}\right]^{b_{SMA}} (1)$$

where M_{wi} is the wet body mass (g) and L_i the total length L (mm) of individual *i*; b_{SMA} is the scaling exponent obtained by the standardised major axis (SMA) regression on ln-transformed weight and length values. Model II Regression in R 3.0.3 was used to determine the slope of the fitted line (i.e b_{SMA}) (Legendre, 2008). L_0 was an arbitrary value of L (e.g. the arithmetic mean value for the population under study) (Peig and Green, 2009).

ii) a bioenergetic index, the "energy content" (E_D)**,** often used to measure fish growth and food consumption (Hartman and Brandt, 1995; Wuenschel et al., 2006; Tirelli et al., 2006; Dubreuil et Petitgas, 2009; Zhang et al., 2011; Rosa et al., 2010) to understand the energy allocation strategies of species. Dubreuil et al. (2009) established the relationship between the energy density (E_D kJ wet mass^{-1}) and the fish dry mass (M_D) expressed as a percentage ($\%M_D = 100\ M_D\ M_W^{-1}$) for anchovy of the Bay of Biscay:

$$E_D\ (\mathrm{kJ\ g^{-1}} M_W) = 0.41 \times \%M_D - 4.94\ (2)$$

No such relationship is available for sardine in the Bay of Biscay. Yet, as energy density is correlated to $\%M_D$ and $\%M_D$ is inverse of $\%M_C$ (water content in %), $\%M_D$ or $\%M_C$ both alike can be considered as proxy of energy density for sardine.

Samples for energy content were available from the sentinel surveys only. To test for significant differences in the biological parameters across seasons and areas we used a Kruskal Wallis test (0.05) followed by a multiple comparison test (Kruskal et Wallis, 1952).

Insert Fig. 2

3. Results

3.1 abundance and spatial distribution

Density per ESDU maps (Fig. 2) were produced for both species in the two key areas from the sentinel surveys, and from the PELGAS surveys. They corresponded to eight successive snapshots of the geographic distributions and relative density from May 2009 to May 2011. No survey was organized in February 2010 due to bad weather conditions. Additional information was considered with two indices (Table 2). The first one (AI, in tons) is the sum of densities per ESDU which can be considered as an abundance index, representative of the abundance of fish observed in the key area at the time of the survey. The second index (n+) is the number of ESDUs where the fish were observed. It can be considered as a distribution index (dispersion/concentration) of the fish in the key area. These indices are very variable from one survey to the other. Table 2 shows for instance that anchovy was more abundant but more dispersed in April 2010 than in July (from 981 to 230 tons) in Gironde area (from 148 to 111 for n+). Anchovy was also abundant in coastal waters of the southern Brittany area in July. Therefore, these two indices cannot be representative of the total stock abundance, but only of the presence/absence in the key area at the survey period.

Insert Table 2 and Fig. 3

However, it is possible from the observations to describe the seasonal movement patterns for each species, their schooling behavior, and their life history stage (age, sexual maturity, growth or condition). The densest aggregations of anchovy were observed in the Gironde area (Fig. 2), in shallow waters (from 20 to 50 m of bottom depth) and organized in small schools (less than 5 m high) 15 m above the bottom (Fig. 3(a)). Anchovy were often mixed with other pelagic species and were observed as thick and dense layers of small schools (Fig. 3(b)). In winter, anchovy seemed to be located further offshore beyond the 60 m isobath (Fig. 2) partly mixed with sardine (Fig. 3(a)). On the echograms, sardine schools appeared dense more than 5 m high (Fig. 3(a)). Further investigations of shoal characterization would be required to quantify size, shape and vertical distribution of aggregations but these structures are very similar to that observed by Massé et al. (1996).

3.2. Monitoring of recruitment

From length and age distribution

Among the 8 surveys (3 PELGAS surveys and 5 sentinel surveys), 2879 individual anchovies and 2308 individual sardines were sampled for length and age determination.

The biological materials collected allowed the monitoring of length distributions (Fig. 4(a) and Fig. 5(a)) and demographic structures (Fig. 4(b) and Fig. 5(b)) of anchovy and sardine in the two key areas. Proportion of age 0 and 1 in each area and their respective length modes allowed us to depict the settlement of year class strength in the two areas.

Insert Fig. 4 and Fig. 5

In the case of anchovy for instance, small fish (length from 7.5 and 13 cm) are always predominant in Gironde area whereas large individuals (from 14 to 19 cm) appear each year in summer and autumn in southern Brittany (Fig 4(a)). Looking at age distribution (Fig 4(b)), age 0 appears in the 2 areas in December 2009 and can be monitored during the 3 following surveys as age 1. In 2010, there is no survey in winter, but age 0 can already be seen in September 2010.

Insert Table 3

In general, sardines are larger in southern Brittany in 2010 and smaller in the Gironde area (Fig. 5(a)), where smaller fish (mean length between 13.5 and 17.9 cm) were observed in December 2009, April, May and September 2010 and May 2011 (Table 3). These were mainly from the 0 and 1 groups (Fig. 5(b)). Nevertheless, the length and age distributions of sardine are more variable from one survey to another than for anchovy.

Insert Fig. 6

From otolith analysis

In spring (May), R1 values (growth at age-0 before first winter) are similar in both areas (Fig. 6). But in other seasons and in summer in particular, values for the southern Brittany area are systematically greater than those for the Gironde area, indicating that only those individuals which grew faster at the beginning of their life are located in the northern habitats. R2-R1 values (growth between first and second winter) confirm this pattern (Fig. 6).

Insert Table 4 and Table 5

3.3. Indices of condition

Three indices of condition are considered: i) the scaled mass index $\widehat{M}_i$, ii) the energy density E_D and iii) the percent dry mass $\%M_D$. The indices were estimated for anchovy and sardine specimens whose length ranged from 6.5 to 20 cm and from 7.5 to 25 cm, respectively. The indices differed significantly between surveys (Kruskal-Wallis, $p < 0.05$) with minimum value in winter for $\widehat{M}_i$ and in April for E_D and $\%M_D$ (Tables 3, 4, 5 and Fig. 7, Fig. 8). For these latter indices, higher values were detected during July and/or September 2010. A significant difference was also found between the two areas (Kruskal-Wallis, $p < 0.05$).

Insert Fig. 7 and Fig. 8

4. Discussion

The sentinel pilot study demonstrates that it is possible to conduct a scientifically sound research program, using the expertise of both fishermen and scientists. Fishermen were involved in each phase of the project; developing sampling protocol, locating fish aggregations and collecting biological data, making it a truly collaborative fisheries research program (Yochum et al., 2011; Johnson and van Densen, 2007).

The objective of this experiment was to see if it was possible to develop useful indicators to monitor sardine and anchovy populations. A secondary objective was to determine if this was feasible using an approach consisting of short and seasonally repeated surveys, in specific key target areas using commercial vessels, taking advantage of the skills and knowledge of the fishermen. Because of meteorological conditions, it was often necessary to adjust the schedule of these short surveys and acoustic data collection was sometimes challenging onboard such small vessels. Nevertheless, several indicators were successfully calculated: acoustic index of presence of each species by area and their length and age distributions, condition index and growth index.

Surveys on commercial vessels targeting specific key areas, using local fishermen's knowledge and supported by research acoustic systems and expertise, have been attempted previously for stock assessment (O'Driscoll and Macauley, 2005; Ressler et al., 2009; Barbeaux and Fraser, 2009; Honkalehto et al., 2011). Their studies demonstrated that such cooperation was a promising way of monitoring species abundance in small scale areas. In our case, the local abundance indices by area provided by sentinel surveys were not representative of the global stock abundance. Nevertheless, the sentinel surveys were well-suited for monitoring anchovy, in terms of the strength and arrival in coastal waters of the new year class strength. This monitoring showed that 0 group appearance progresses from Gironde to southern Brittany (in July and December, respectively), and is consistent with what is already known about the spawning season, which begins in the south of the Bay of Biscay and ends in southern Brittany (Bellier et al., 2007). The sentinel surveys were not as successful for monitoring sardine, which can be explained by the larger spatial distribution of sardine spawning compared to that of anchovy; a more appropriate key area and more surveys might be necessary for sardine. Also, unlike the anchovy spawning season, which is mainly concentrated in spring, the spawning season of sardine is spread over much of the year with two distinct peaks in spring and autumn (Arbault and Lacroix, 1971, 1977; Bellier et al., 2007).

The data collected by the sentinel surveys allowed us to monitor the seasonal evolution of biological parameters (growth, energy) as well as differences between northern and southern habitats. The measured values of the biological indices agreed with values already observed for anchovy and sardine in the Bay of Biscay and in the Mediterranean (Maceda-Veiga et al., 2014; Spitz et al., 2010; Dubreuil et Petitgas, 2009; Tirelli et al., 2006; Rosa et al., 2010). The sentinel surveys thus show potential to monitor the key biological processes, which determine population health, if not global abundance. To maximize the suitability of indicators, it would be necessary to target key seasons each year, such as summer (August - September) and winter (December to February) taking into account that scientific surveys already occur in spring and autumn.

Last but not least, exchanges between fishermen and scientists working together on the sentinel survey project increased and encouraged mutual understanding and interest in obtaining integrated knowledge on the biology of the resources and their management strategies.

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Fig. 1. The Bay of Biscay is located in North Atlantic along the west coast of France (overview map). The two key areas in this study are indicated on the map on the right along with the location of transects carried out during one of the five surveys.

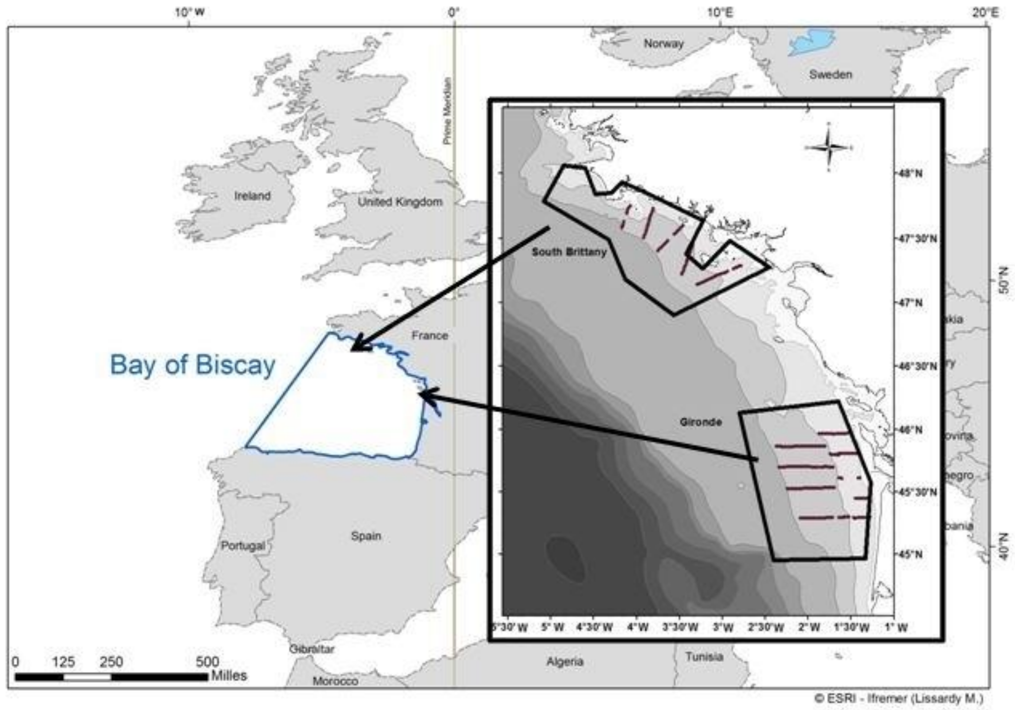


Fig. 2. Acoustic density of anchovy (green circles) .and sardine (blue circles) by survey in the two key areas (kg nm), where the letter "P" indicates a PELGAS survey and "S" a sentinel survey. For clarification, sardine circles were slightly shifted to avoid superimposition of symbols. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

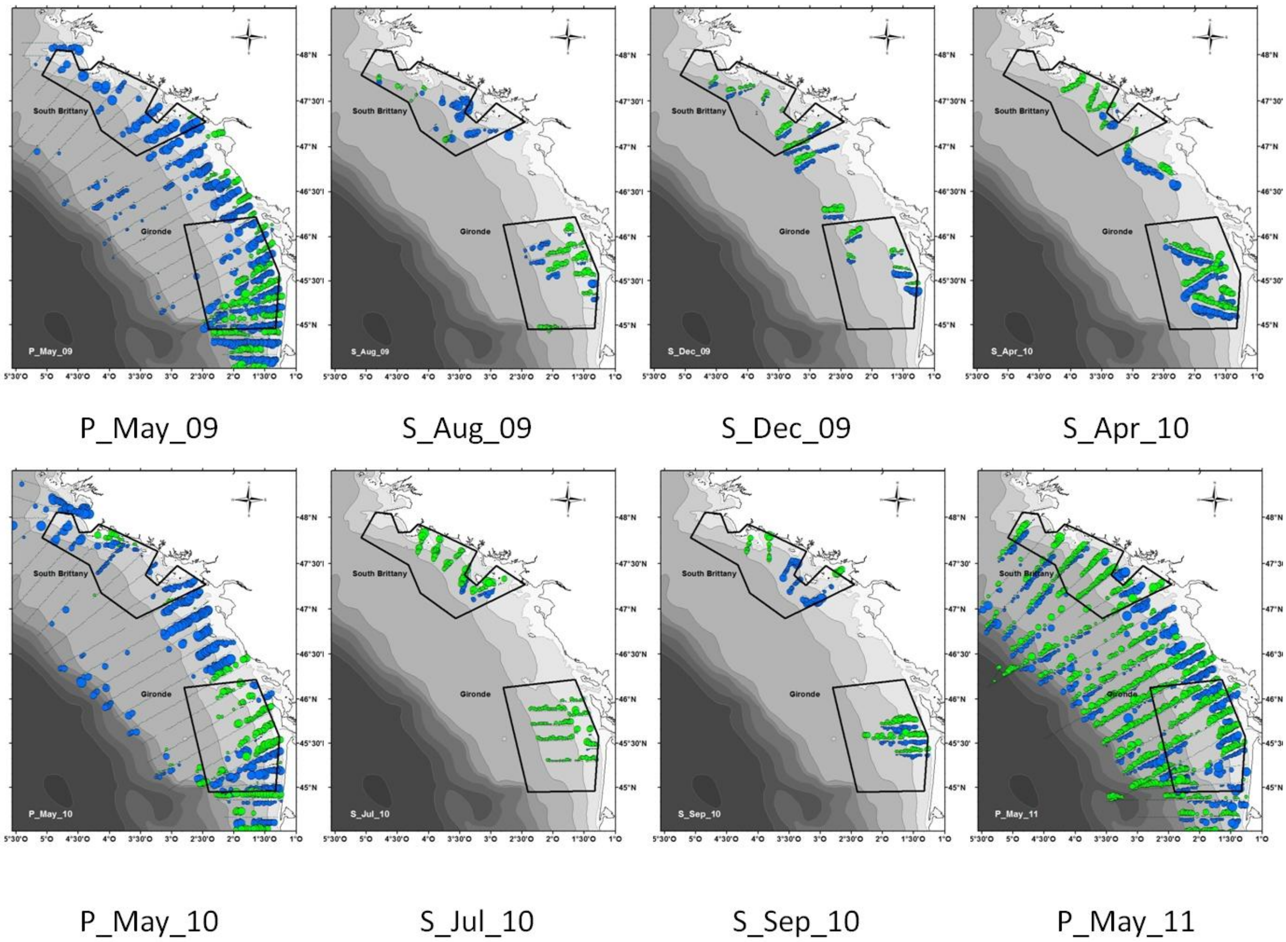
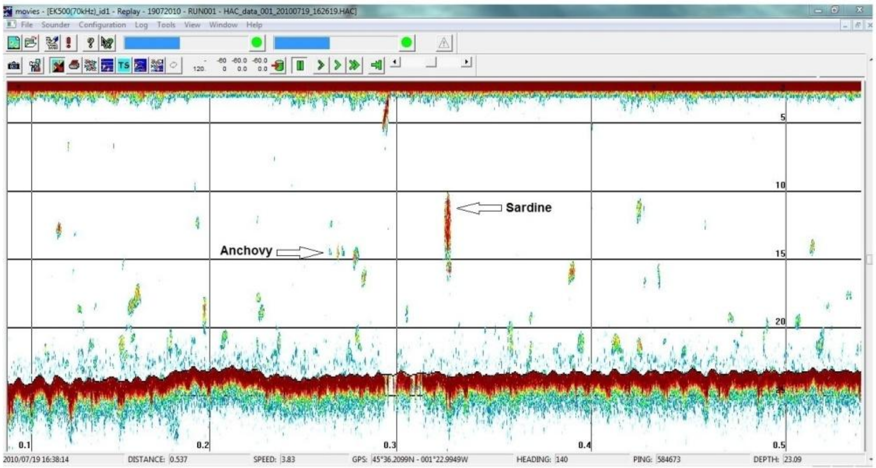


Fig. 3. Examples of echograms obtained during sentinel surveys (a) schools of anchovy and sardine in Gironde area during July 2010, (b) schools of mixed species in Gironde area during September 2010.

a)



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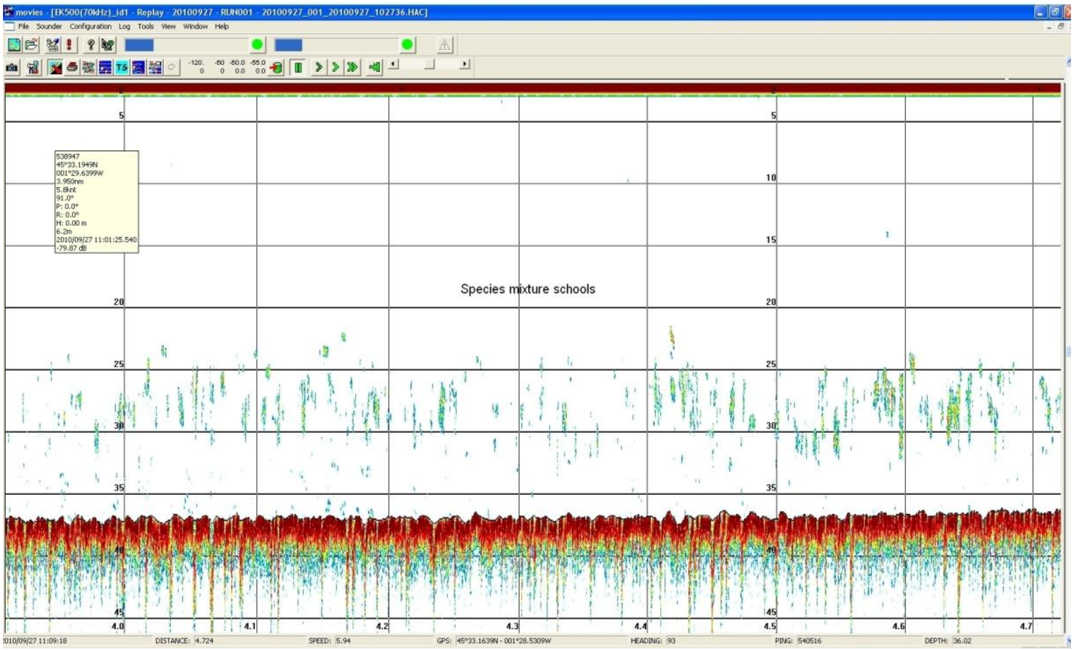

Fig. 4. Length distribution (a) and age distribution (b) of anchovy in% of total number for the PELGAS (P) and sentinel (S) surveys in southern Brittany (top) and Gironde (bottom) areas.

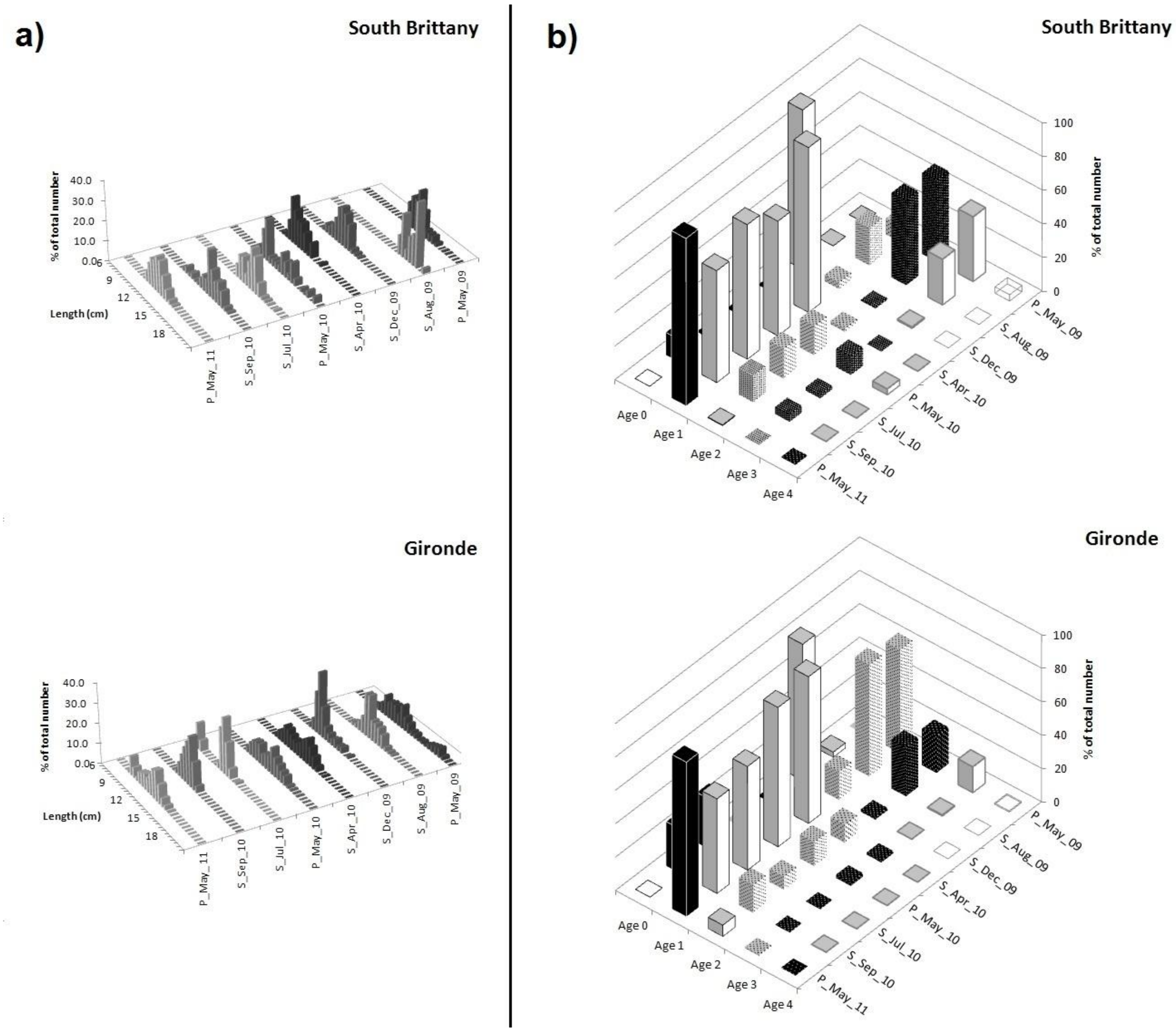

Fig. 5. Length distribution (a) and age distribution (b) of sardine in% of total number for the PELGAS (P) and sentinel (S) surveys in southern Brittany (top) and south Gironde (bottom) areas.

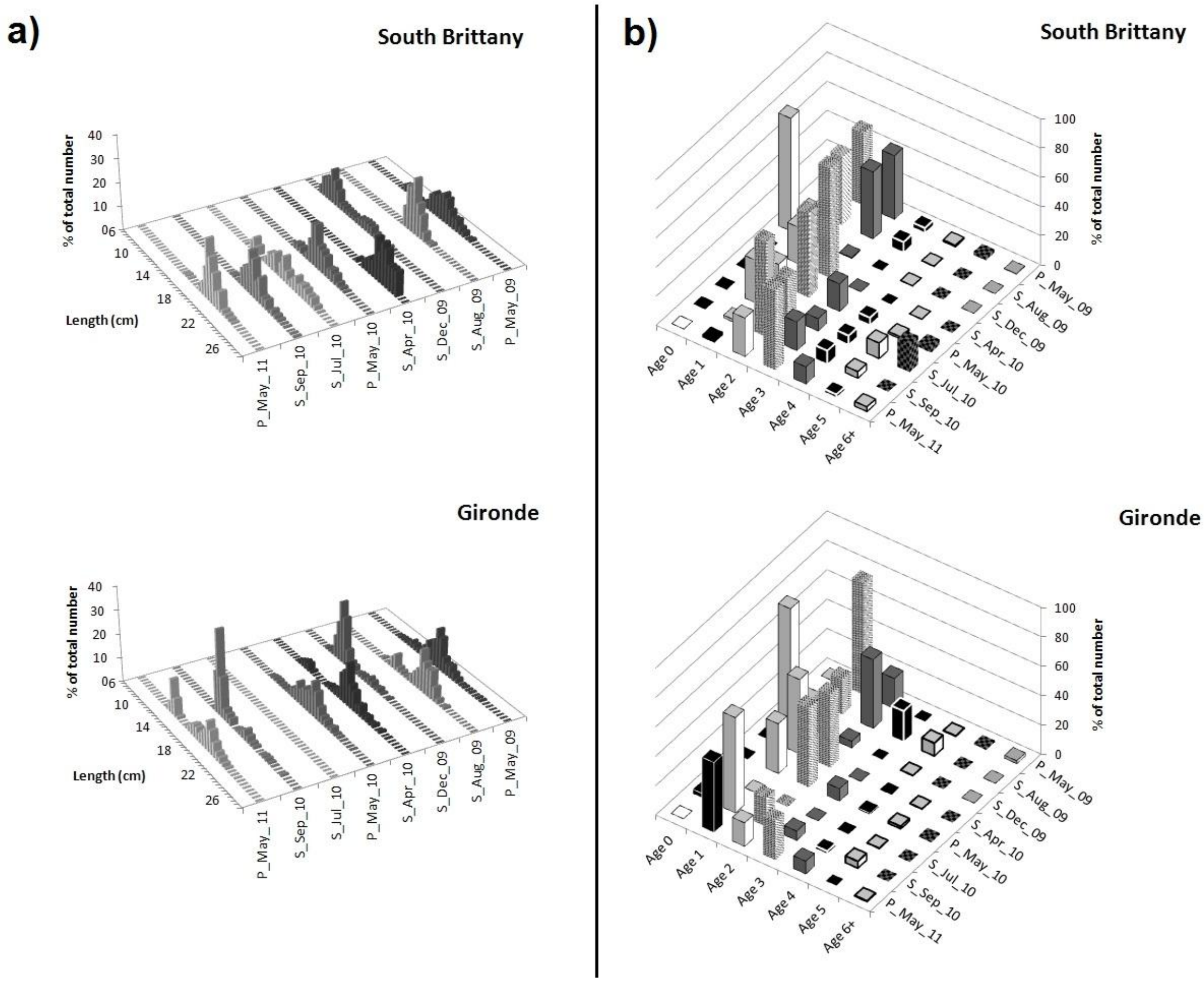

Fig. 6. Mean growth of anchovy between the first and the second winter measured on age 2 fish. R1 is indicator of the growth during the first spring/summer period and R2-R1 is indicator of the growth between the first and the second winter.

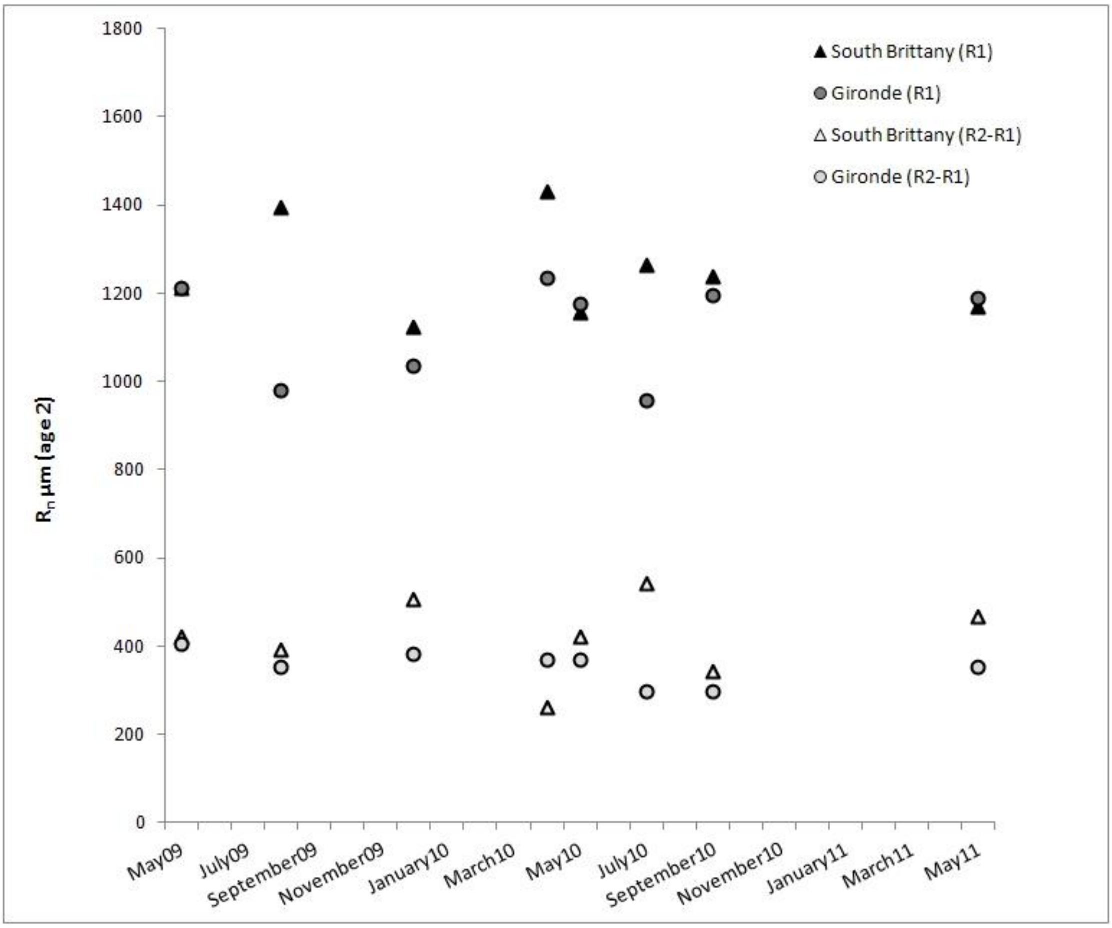

Fig. 7. Box plots of the scaled mass index (SMI, g) for anchovy (top) and sardine (bottom) throughout the year from PELGAS and sentinel surveys in the southern Brittany and Gironde areas.

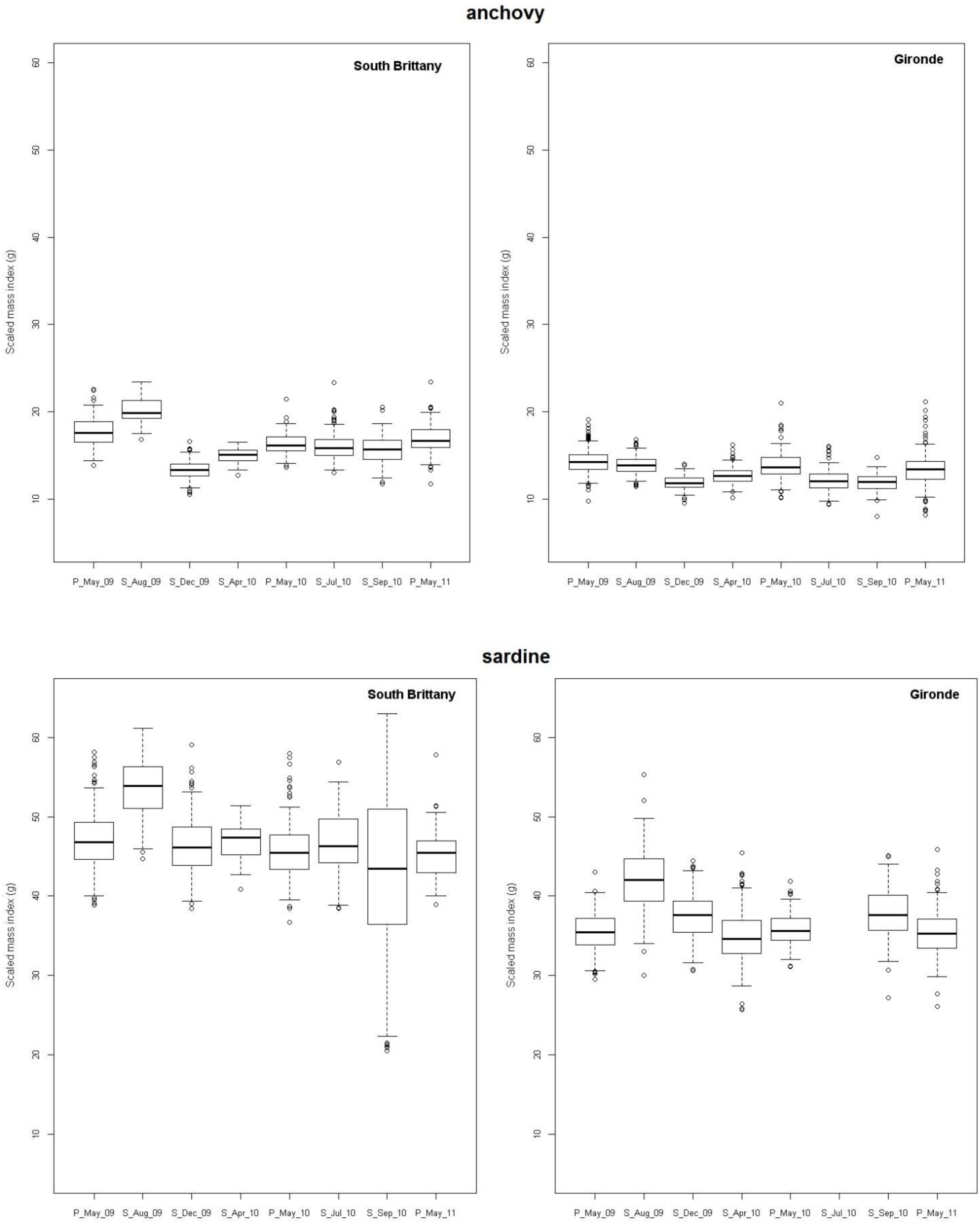

Fig. 8. Boxplot of the energy content (E kJ g^{-1}) for anchovy (top) and the percent dry mass (%M_D) for sardine (bottom) sampled during sentinel surveys in the southern Brittany and Gironde areas.

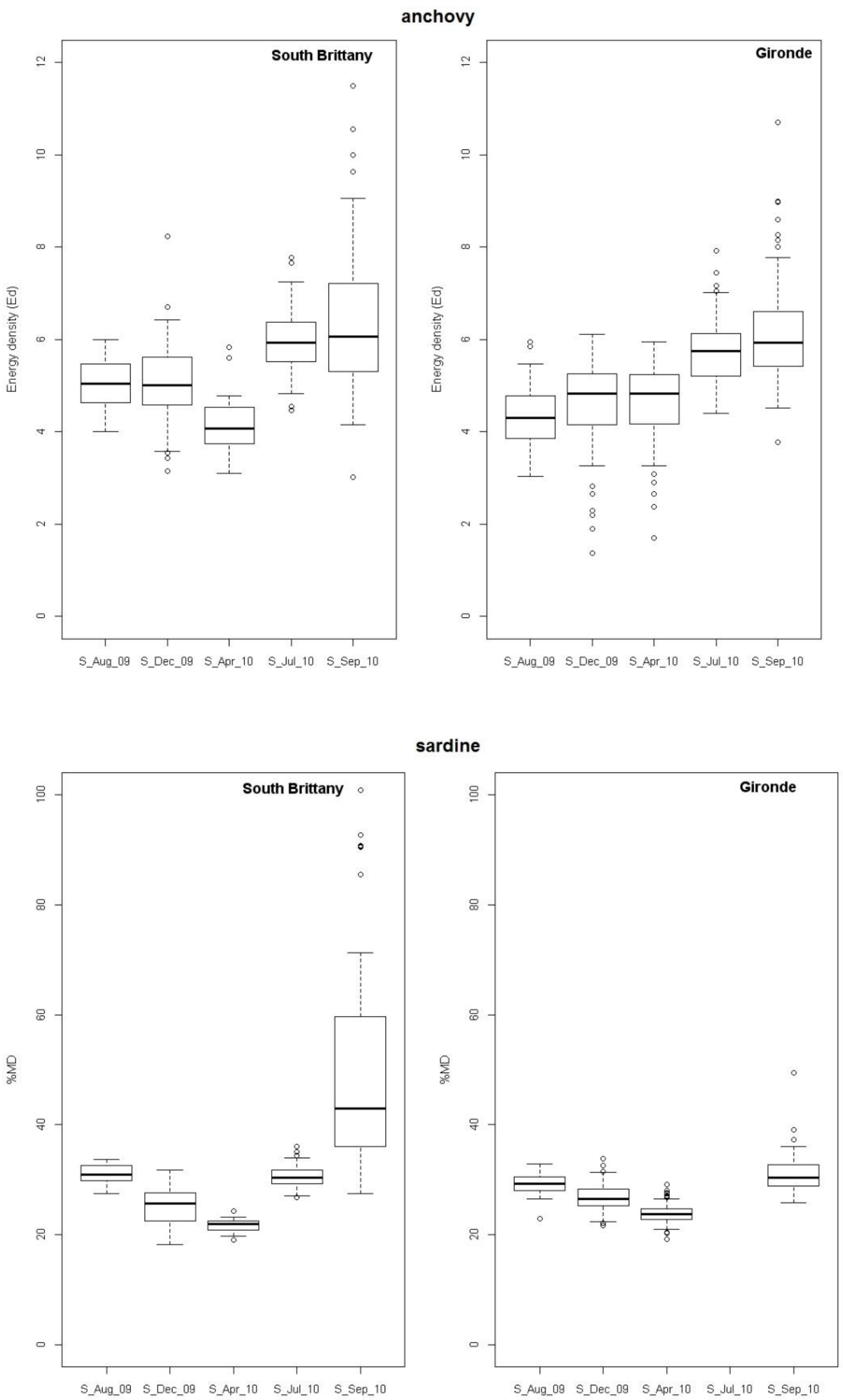

Table 1. Calendar of surveys.

Survey	Codification survey	Commercial fishing vessel (size) Fishing harbour	Season	Days at sea	Number of hauls
Consort PELGAS	P_May_09	Zéphyr and Carla Eglantine (size: 17.5 m & 17.8 m) La Turballe	26/04/2009 to 06/05/2009	11	55
		Magayant and Mary Christo (size: 22.8 m & 20.6 m) La Turballe	07/05/2009 to 16/05/2009	10	
Sentinel	S_Aug_09	Cintharth and Marilude 2 (size: 23.3 m & 20.2 m) La Turballe	10/08/2009 to 14/08/2009	5	12
Sentinel	S_Dec_09		15/12/2009 to 19/12/2009	5	11
Sentinel	S_Apr_10	Jérémi-Simon and Prométhée (size:20 m & 20 m) St Gilles Croix de vie	05/04/2010 to 10/04/2010	5	9
Consort PELGAS	P_May_10	Tangaroa and Magayant (size: 20.6 m & 22.8 m) La Turballe	26/04/2010to 06/05/2010	11	46
		Morgan and Virginie (size: 19.5 m & 19.5 m) Lorient	07/05/2010 to 17/05/2010	11	
Sentinel	S_Jul_10	Joker and ArRaok 2 (size: 16.1 m & 15.9 m) La Turballe	18/07/2010 to 23/07/2010	5	10
Sentinel	S_Sep_10		26/09/2010 to 30/09/2010	4	9
Consort PELGAS	P_May_11	Arlequin 2 and Colombine (size: 19.8 m & 22.6 m) La Turballe	27/04/2011to 08/05/2011	13	61
		Jérémi-Simon and Prométhée (size:20 m & 20 m) St Gilles Croix de vie	10/05/2011 to 18/05/2011	9	

Table 2. Statistics of anchovy and sardine density per esdu (kg per square nautical mile) for each area during sentinel surveys. n = number of ESDUs, mean=average (kg. nm^{-2}), s.e. = standard error, sum = abundance index (in tons), n+ = number of positive ESDUs, max = maximum density value (kg. nm^{-2}).

Species/Area		Aug_09	Dec_09	Apr_10	Jul_10	Sep_10
Anchovy/Gironde	n	187	62	115	153	81
	Mean ± s.e.	2019 ± 494	3134 ± 833	8538 ± 1259	1507 ± 354	6195 ± 1311
	Sum	377	194	981	230	501
	n_+	94	62	111	148	79
	Max	377482	194324	981857	230642	501821
Anchovy/South Brittany	n	110	106	128	77	83
	Mean ± s.e.	302 ± 129	2070 ± 397	2592 ± 547	13029 ± 3234	6302 ± 4210
	Sum	33	219	331	1000	523
	n_+	23	85	74	66	24
	Max	10978	30829	37321	145693	344392
Sardine/Gironde	n	187	62	115	153	81
	Mean ± s.e.	1116 ± 410	6287 ± 1682	25196 ± 4181	1 ± 1	1484 ± 336
	Sum	208	389	2900	184	120
	n_+	57	62	111	10	72
	Max	54276	75862	244595	76	19020
Sardine/South Brittany	n	110	106	128	77	83
	Mean ± s.e.	7835 ± 1892	927 ± 135	7560 ± 1883	729 ± 268	11317 ± 3448
	Sum	861	98	967	56	939
	n_+	58	106	39	27	48
	Max	128885	11071	116181	16486	176205

Table 3. Mean body length (L mm), weight (M_W g), scaled mass index (SMI g) and estimation of the scaling exponent by the SMA regression of M_W on L for each survey and area with the 95% confidence intervals. SD: standard deviation; n: sample number. L_0 used were: 128.3 mm (n = 2151) for Gironde anchovy, 133.9 mm (n = 843) for South Brittany anchovy, 167.3 mm (n = 1174) for Gironde sardine and 178.1 mm (n = 1156) for South Brittany sardine.

Survey	**Species**	**Area**	**n**	**L ± SD (mm)**	**M_W± SD (g)**	**SMI ± SD (g)**	**b_{SMA}**	**b_{SMA} (CI 95%)**
P_May_09	Anchovy	Gironde	466	144.4 ± 29.2	24.0 ± 15.0	14.3 ± 1.3	3.23	3.19 – 3.27
	Sardine		208	167 ± 30.7	38.6 ± 20.4	35.5 ± 2.4	2.96	2.91 – 3.01
	Anchovy	South	85	141.9 ± 15.9	22.4 ± 8.6	17.7 ± 1.7	3.31	3.13 – 3.50
	Sardine	Brittany	232	196.3 ± 24.6	65.6 ± 22.3	47.1 ± 3.6	2.99	2.92 – 3.07
S_Aug_09	Anchovy	Gironde	226	131.2 ± 15.8	15.6 ± 5.9	13.9 ± 1.0	3.16	3.08 – 3.24
	Sardine		120	183.0 ± 22.4	56.8 ± 18.8	42.1 ± 4.1	2.95	2.81 – 3.09
	Anchovy	South	40	176 ± 10.8	40.0 ± 6.1	20.1 ± 1.5	2.50	2.14 – 2.93
	Sardine	Brittany	139	177.8 ± 9.0	53.8 ± 10.3	53.6 ± 3.9	3.70	3.47 – 3.95
S_Dec_09	Anchovy	Gironde	130	107.6 ± 19.6	7.4 ± 4.0	11.8 ± 0.9	3.28	3.21 – 3.34
	Sardine		146	135.8 ± 26.0	21.6 ± 16.4	37.6 ± 3.0	3.31	3.24 – 3.38
	Anchovy	South	200	123.6 ± 14.8	10.8 ± 4.2	13.4 ± 1.0	3.38	3.30 – 3.47
	Sardine	Brittany	236	123.3 ± 29.9	16.7 ± 13.5	46.3 ± 3.5	3.36	3.32 – 3.40
S_Apr_10	Anchovy	Gironde	250	131.0 ± 17.7	14.5 ± 6.3	12.7 ± 0.9	3.42	3.36 – 3.49
	Sardine		240	179.5 ± 33.1	49.3 ± 23.1	35.0 ± 3.2	3.34	3.28 – 3.39
	Anchovy	South	40	120.4 ± 13.2	11.2 ± 4.2	15.0 ± 0.9	3.14	2.97 – 3.33
	Sardine	Brittany	40	227.9 ± 12.7	99.2 ± 16.3	46.9 ± 2.4	3.01	2.73 – 3.32
P_May_10	Anchovy	Gironde	427	129.8 ±16.1	15.1 ± 6.6	13.8 ± 1.3	3.21	3.14 – 3.28
	Sardine		157	171.2 ± 29	41.9 ± 19.9	35.8 ± 2.0	3.11	3.06 – 3.16
	Anchovy	South	78	139.2 ± 21.2	19.8 ± 9.6	16.3 ± 1.5	3.14	3.01 – 3.28
	Sardine	Brittany	228	194.5 ± 26.5	61.8 ± 23.6	45.7 ± 3.4	2.91	2.84 – 2.98
S_Jul_10	Anchovy	Gironde	124	109.4 ± 21.2	8.2 ± 3.5	12.1 ± 1.4	3.07	2.98 – 3.15
	Sardine		0	-	-	-	-	-
	Anchovy	South	133	146 ± 13.3	22.1 ± 6.7	16.1 ± 1.6	3.38	3.20 – 3.57
	Sardine	Brittany	86	188.7 ± 30.4	59.8 ± 28.1	46.7 ± 4.0	3.00	2.89 – 3.11
S_Sep_10	Anchovy	Gironde	139	115.2 ± 11.0	8.7 ± 2.7	11.9 ± 1.0	3.20	3.05 – 3.35
	Sardine		118	142.5 ± 26.8	25.5 ± 17.7	37.8 ± 3.2	3.22	3.13 – 3.32
	Anchovy	South	76	141.1 ± 16.4	19.7 ± 7.4	15.7 ± 1.7	3.40	3.20 – 3.61
	Sardine	Brittany	85	182.3 ± 16.6	48.8 ± 16.4	42.5 ± 11.0	5.06	4.42 – 5.79
P_May_11	Anchovy	Gironde	389	121.5 ± 17.4	11.8 ± 5.1	13.4 ± 1.9	3.55	3.45 – 3.65
	Sardine		185	178.6 ± 29.0	47.2 ± 21.7	47.2 ± 21.7	3.17	3.10 – 3.24
	Anchovy	South	191	121.9 ± 12.6	12.8 ± 4.3	17.1 ± 1.8	3.50	3.36 – 3.65
	Sardine	Brittany	110	193.7 ± 21.0	59.8 ± 18.0	45.3 ± 3.0	2.94	2.83 – 3.05

Table 4. *Engraulis encrasicolus* samples analyzed for water content (% M_C) and energy density (E_D) by size class. Mean ± S.D.

Size class	Codification survey	Season	Water content (% Mc)	Energy density E_D (kJ g^{-1} Mw)	Sample number n
Small	S_Aug_09	Summer 2009	79.65 ± 0.35	3.40 ± 0.14	3
L_T< 100 mm	S_Dec_09	Winter 2009	78.56 ± 2.08	3.85 ± 1.22	27
	S_Apr_10	Spring 2010	79.49 ± 2.04	3.47 ± 0.83	7
	S_Jul_10	Summer 2010	74.29 ± 1.87	5.60 ± 0.77	8
	S_Sep_10	Autumn 2010	76.76 ± 1.73	4.59 ± 0.71	3
Medium	S_Aug_09	Summer 2009	77.67 ± 1.37	4.21 ± 0.56	43
100 <L_T< 140 mm	S_Dec_09	Winter 2009	75.78 ± 2.01	4.99 ± 0.82	93
	S_Apr_10	Spring 2010	77.51 ± 1.64	4.28 ± 0.67	80
	S_Jul_10	Summer 2010	73.89 ± 1.89	5.77 ± 0.78	58
	S_Sep_10	Autumn 2010	72.98 ± 2.82	6.14 ± 1.16	68
Large	S_Aug_09	Summer 2009	76.30 ± 1.61	4.78 ± 0.66	53
L_T> 140 mm	S_Dec_09	Winter 2009	75.11 ± 1.61	5.26 ± 0.66	25
	S_Apr_10	Spring 2010	75.32 ± 1.13	5.18 ± 0.46	56
	S_Jul_10	Summer 2010	72.97 ± 1.70	6.14 ± 0.70	48
	S_Sep_10	Autumn 2010	70.64 ± 5.08	7.10 ± 2.08	24

Table 5. *Sardina pilchardus* samples analyzed for dry mass (%M_D) and water content (%M_C). Mean ± S.D.

Size class	**Codification survey**	**Season**	**Dry mass %M_D (Water content %M_C)**	**Sample number n**
Small	S_Aug_09	Summer 2009	-	-
L_T< 100 mm	S_Dec_09	Winter 2009	21.17 ± 1.29 (78.83)	18
	S_Apr_10	Spring 2010	-	-
	S_Jul_10	Summer 2010	-	-
	S_Sep_10	Autumn 2010	-	-
Medium	S_Aug_09	Summer 2009	-	
100 <L_T< 140 mm	S_Dec_09	Winter 2009	24.79 ± 2.22 (75.21)	65
	S_Apr_10	Spring 2010	23.58 ± 1.62 (76.42)	19
	S_Jul_10	Summer 2010	30.00 ± 0.39 (70.00)	2
	S_Sep_10	Autumn 2010	37.23 ± 19.04 (62.77)	39
Large	S_Aug_09	Summer 2009	30.06 ± 1.66 (69.94)	29
140 <L_T< 180 mm	S_Dec_09	Winter 2009	27.66 ± 2.36 (72.34)	61
	S_Apr_10	Spring 2010	24.65 ± 1.70 (75.45)	24
	S_Jul_10	Summer 2010	30.81 ± 2.12 (69.19)	15
	S_Sep_10	Autumn 2010	37.19 ± 11.56 (62.81)	44
Very Large	S_Aug_09	Summer 2009	30.02 ± 2.30 (69.98)	35
L_T> 180 mm	S_Dec_09	Winter 2009	28.79 ± 1.98 (71.21)	15
	S_Apr_10	Spring 2010	23.10 ± 1.75 (76.90)	85
	S_Jul_10	Summer 2010	30.60 ± 2.18 (69.40)	30
	S_Sep_10	Autumn 2010	42.91 ± 16.15 (57.09)	30