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The PELGAS survey: ship-based integrated monitoring of the Bay of Biscay pelagic ecosystem

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Abstract

The Pélagiques Gascogne (PELGAS) integrated survey has been developed since 2000 by a multidisciplinary team of Ifremer and La Rochelle University scientists, joined in 2007 by commercial fishermen. Its initial focus was to assess the biomass and predict the recruitment success of anchovy in the 15 Bay of Biscay in spring. Taking advantage of the space and versatility of R/V Thalassa II, sampling has been progressively extended to other ecosystem components, and PELGAS has pursued the second objective of monitoring and studying the dynamic and diverse Biscay pelagic ecosystem in springtime. The PELGAS survey model has allowed for the collection of long-term series of spatially-explicit data in the Bay of Biscay pelagic ecosystem main components: hydrology, phytoplankton, mesozooplankton, fish and megafauna since 20 2000. The survey now provides two main ecosystem products: standard raster maps of ecosystem parameters, and time series of indicators of the Bay of Biscay pelagic ecosystem state, informing fish stock and ecosystem-based management, and supporting ecosystem science. This paper introduces the PELGAS survey, as a practical example of integrated, vessel-based, ecosystem survey. The evolution of the PELGAS scientific team and sampling protocols are presented and analysed, to outline the survey critical success

25 factors. Data and results derived from PELGAS surveys are reviewed, to provide examples of scientific questions that can be tackled with integrated ecosystem survey data. The survey advantages and limitations are further discussed, before suggesting perspectives for marine ecosystem surveys in the context of the European Marine Strategy Framework Directive and Common Fisheries Policy.

Introduction

30 The Pélagiques Gascogne (PELGAS, Doray et al., 2000) survey aims at monitoring the Bay of Biscay pelagic ecosystem in springtime, to inform fisheries and ecosystem management, and to study pelagic ecosystem functioning on the continental shelf and upper-slope. PELGAS has been conducted by Ifremer, in collaboration with La Rochelle University and CNRS since 2000. As for other long term, multidisciplinary, ecosystem surveys such as CalCofi (CalCOFI, 2011), CCAMLR Ecosystem Monitoring Program (Agnew,
35 1997) or the Norwegian Barents Sea ecosystem survey (Eriksen, 2014; Eriksen et al., this volume) the initial aim of PELGAS was the provision of scientific information for fishery management. PELGAS initial objective was to provide springtime biomass estimates of the Bay of Biscay anchovy (*Engraulis encrasicolus*) population to the ICES stock assessment group in charge of this commercially important species.

40 The Bay of Biscay is an open oceanic bay delimited by the west-east oriented Spanish coast in the southern part, and the north-south oriented French coast in the eastern part (Figure 1). It is part of the subtropical/boreal transition subprovince of the biogeographic Lusitanian province (OSPAR Commission, 2000), where mixing between faunal groups of boreal and subtropical origin occurs. The southern or northern limits of many fish species distributions are namely located in the Bay of Biscay (Poulard and
45 Blanchard, 2005). Environmental conditions are quite variable in springtime in Biscay, depending on the onset and magnitude of post-winter phytoplanktonic blooms, seasonal water warming and stratification setup, coastal upwellings, as well as cumulated intensity of winter river discharge and plume spreading over the shelf (Koutsikopoulos and Le Cann, 1996; Huret et al., this volume). The PELGAS survey hence takes place in a dynamic and biologically diverse pelagic ecosystem, located in a subtropical/boreal transition
50 zone.

The diversity and dynamic nature of the Bay of Biscay pelagic ecosystem largely influences anchovy population dynamics, exemplifying the views of the fisheries science founding fathers, who had early on acknowledged the "complex interactions of the (marine) living beings" (Lankester, 1884) and the importance of recruitment in small pelagic fish population dynamics (Hjort, 1914). PELGAS was then designed as an
55 integrated ecosystem survey, which required extensive sampling of several ecosystem components, to improve the odds of understanding the target species population dynamics, in the context of the ecosystem approach to fisheries (EAF, Garcia et al., 2003).

This paper introduces the PELGAS survey, as a practical example of integrated, vessel-based, ecosystem survey. The evolution of the PELGAS scientific team and sampling protocols are presented and analysed, to
60 outline the survey critical success factors. Data and results derived from PELGAS surveys are reviewed, to provide examples of scientific questions that can be tackled with data collected during an integrated ecosystem survey. We further discuss the survey advantages and limitations, and suggest some perspectives for marine ecosystem surveys in the context of the European Marine Strategy Framework Directive (MSFD, 2008/56/EC).

65 **From target species biomass assessment to multidisciplinary pelagic ecosystem monitoring**

The extensive pelagic ecosystem sampling conducted during PELGAS surveys has been made possible by technological and methodological progresses made in both small pelagic fish sampling techniques and research vessel engineering since the early 80's. On the sampling side, the development of fisheries acoustics
70 (Simmonds and MacLennan, 2005) and egg-based methods (Daily Egg Production Method, DEPM, Lasker, 1985; Continuous Underway Fish Egg Sampler, CUFES, Checkley Jr et al., 1997) allowed in the late 90's to accurately estimate the biomass and spatial distribution of small pelagic fish adults and eggs. In France, protocols and software (MOVIES software, Weill et al., 1993) for small pelagic fish biomass assessment by acoustic methods have been developed in the Bay of Biscay by Ifremer since the early eighties. Acoustic-
75 trawl surveys conducted in the Bay onboard R/V Thalassa I from 1989 to 1994 led to the definition of sampling strategies for estimating small pelagic fish abundance, based on acoustic and trawl data (Massé and

Retière, 1995). First acoustic biomass estimates of the Bay of Biscay anchovy population were provided to the ad-hoc ICES stock assessment group in 1989.

On the platform side, the commissioning in 1996 of R/V Thalassa II¹, a large (73 m long) research vessel,
80 (R/V) designed by Ifremer for multi-disciplinary research in the fields of fisheries science, biology and oceanography, opened new ecosystemic horizons. R/V Thalassa II, a noise reduced stern trawler, about 10 m longer than R/V Thalassa I, provided more space for accommodating large scientific teams and crews (25 people max. each) and multidisciplinary equipment: echosounders, fishing gears, fully equipped biological and oceanography laboratories, instrumented winches for probes and plankton nets... Since the onset of
85 oceanography in the XVIIIst century, vessel space available for scientific purposes has always been the factor limiting the development of multidisciplinary scientific studies at sea (Adler, 2014). A major reason of the success of the HMS Challenger voyage (1872–1876), frequently cited as the first oceanographic survey, was indeed the pioneering accommodation of shipboard science by modifications of vessel space (Adler, 2014).

90 As HMS Challenger contributed to the foundation of the modern science of oceanography, by providing for the first time dedicated vessel space and equipment to the scientific crew, R/V Thalassa II provided the space, cutting edge equipments and skilled crew to realise the new multidisciplinary pelagic ecosystem monitoring, that has been envisioned by the French research community since the early 90's. Trial surveys have been conducted by Ifremer in 1997 and 1998 in the Bay of Biscay in springtime onboard R/V Thalassa
95 II, to assess the new vessel capabilities, and develop protocols for holistic pelagic ecosystem sampling. Researchers from a consortium of French institutes and universities collaborating within EAF-oriented national research programs had been invited onboard, to determine how to conduct ecosystem sampling in practice. The PELGAS survey has been originally designed by this multidisciplinary consortium of scientists who sought two main objectives: i) routinely collecting data on the state of the Bay of Biscay pelagic
100 ecosystem, mainly to inform European Common Fisheries Policy Data Collection Framework (DCF), and ii) conducting additional process studies. The question posed at the onset of the PELGAS survey was: 'how to understand Biscay anchovy population dynamics, based on data collected during an annual ship-based survey?'. The strong a priori dependence of anchovy population dynamics on environmental changes, via

1 <http://flotte.ifremer.fr/fleet/Presentation-of-the-fleet/Vessels/Deep-sea-vessels/Thalassa>

recruitment success, led to the design of a sampling protocol that encompassed several ecosystem
105 components, and required multidisciplinary work.

The PELGAS survey area, timeframe and protocols were defined to match the anchovy life cycle: the
sampling scheme covers the Biscay continental shelf in May, as anchovy is known to concentrate in
springtime in this area to spawn (ICES, 2010). PELGAS fish acoustic biomass assessment was moreover
based on the observation of fish schools, both for accurate fish acoustic backscatter partitioning between
110 species, and selective identification fishing. As small pelagic fish schools generally expand and disrupt at
night (Blaxter and Hunter, 1982; Fréon and Misund, 1999), small pelagic fish sampling during night-time
was not deemed appropriate during PELGAS. Daytime had then been devoted to en-route small pelagic fish
acoustic and trawl sampling, and to other compatible sampling activities, whereas night-time was available
for observing other ecosystem components. Scientists who could adapt their protocols and questions to those
115 diel sampling constraints stayed in the PELGAS team, whereas others left to conduct specific surveys,
sometimes coordinated with PELGAS. As anchovy recruitment success was largely determined by
environmental conditions, fisheries oceanographers joined fisheries biologists on the same "floating
laboratory and observatory" (Adler, 2014), to perform hydrobiological sampling at fixed stations at night
during PELGAS. After initial adjustments in 2000 and 2001, the PELGAS multidisciplinary sampling of the
120 hydrology and small pelagic fish pelagic main ecosystem components had become a routinely performed
activity in 2002.

Observations made at the beginning of the survey series then revealed that: i) understanding Biscay anchovy
population dynamics would require complementary data on other ecosystem-components, to better
understand bottom up and top down controls on anchovy population, ii) standard protocols used to study
125 anchovy in its biotope could provide knowledge on other species and ecological processes. As in other small
pelagic fish-related long term surveys (e.g. Calcofi), PELGAS survey objectives have then switched from the
study of a single fish stock status to ecosystem monitoring, while continuing to provide fishery-independent
fish biomass estimates required for fish stock assessment. New standardised sampling protocols and process
studies implemented over the survey series are detailed in the next section.

130 PELGAS survey has been funded by Ifremer since 2000 and co-funded by the European (EU) Common

Fisheries Policy Data Collection Framework (DCF) since 2001. Those stable sources of funding have so far enabled the long-term integrated monitoring of the Bay of Biscay pelagic ecosystem using the PELGAS survey.

Integrated ecosystem data collection and analysis

135 ***Ecosystem sampling***

Methods used during PELGAS for collecting and processing acoustic, trawling and fish egg for small pelagic fish biomass assessment have been developed and adapted to the Bay of Biscay context within the framework of the European project PELASSES, (2000-2002, DGXIV n° 99.010). They are now reviewed and standardised at the international level within the ICES ACEGG working group (ICES, 2016).

140 PELGAS sampling operations are performed round the clock. The scientific contingent comprises 23 people, split into 4 teams. The acoustic team (~6 people) is in charge of the fisheries data collection and pre-processing; the fishing team (~6 people) processes the midwater trawl catches; the hydrobiology team (~7 people) operates a CUFES during daytime, and performs vertical profiles for water sampling, as well as mesozooplankton net casts during night-time; and the marine megafauna observer team (3 people) is in
145 charge of cetacean, turtle, large fish and seabird sightings during daytime. The vessel crew comprises 25 to 27 people.

The PELGAS sampling scheme (Figure 1) was designed in 2000, on the basis of the fisheries acoustic survey trials conducted since the mid 70s in the Bay of Biscay, and on contributions to the design of the sampling strategy from the CLUSTER European project (FAIR-CT-96..1799 ended in 1998). It has ever since been
150 completed. Successive improvements and sensor additions are summarised in Figure 2, and detailed below.

Acoustic survey

Acoustic data are collected during daytime (~06:00 to ~22:00) along systematic line transects perpendicular to the French coast (Figure 1), from Spain in the South to Brittany in the North, over a linear total distance of about 2000 nautical miles (NM, 1 NM = 1 852 m). Transects are uniformly spaced every 12 nautical miles
155 (22 km). The mean size of clusters of pelagic fish schools in the Bay of Biscay has been estimated to 8 km

(Petitgas, 2003). The inter-transect distance has been chosen to sample the largest number of clusters of schools within the survey time available. The nominal vessel speed is 10 knots (1 knot = 1.852 m.s⁻¹). It results from a compromise between vessel speed and radiated noise. Vessel speed is reduced to 3 knots on average during fishing operations. The survey design allows for the sampling of Biscay continental shelf (about 23 000 NM²), from 20 m depth to the shelf break (200 m depth), within 30 days, on average.

Acoustic data have been continuously recorded by R/V Thalassa's hull-mounted echosounders during daytime, since the beginning of the series. Night-time acoustic data have been systematically recorded since 2008, to study the diel cycle of zooplankton and micronekton sound scattering layers (SSLs). In 2000, R/V Thalassa was equipped with three OSSIAN500 vertical echosounders emitting at the 12, 38 and 200 kHz nominal frequencies, and one OSSIAN500 49kHz net sounder. OSSIAN echosounders had been developed by the French company Micrel in collaboration with Ifremer, to assess pelagic fish biomass and study fish school features. The ship was also equipped with three Simrad EK500 echosounders emitting at the 12, 38 and 120 kHz frequencies, that provided complementary information on single acoustic targets backscatters (target strength, TS). The innovative, calibrated, multibeam vertical echosounder Simrad ME70 (Trenkel et al., 2008), was developed by Simrad in collaboration with Ifremer, to overcome sampling bias and limitations identified in both vertical monobeam echosounders (range-dependent acoustic beam sampling volume, partial and biased sampling of fish schools, Diner; 2001, 2007) and multibeam sonars (interferences between beams in the water column). It was installed onboard R/V Thalassa in 2005, and has been routinely used during PELGAS surveys since 2008. The ME70 system has provided 3-dimensional (3D) views of the pelagic zone, that are used during PELGAS to better assess the fish school specific composition and density, based on their 3D shape, density and position. All this information has been used during PELGAS surveys to improve the fish target identification strategy (when to perform identification trawl hauls?), and the allocation of echo recordings to fish species during the scrutinising process. In 2006, R/V Thalassa echosounders were replaced by five new generation Simrad EK60 echosounders emitting at 18, 38, 70, 120, 200 kHz, that provided higher-quality target strength, target position, and volume backscattering strength measurements (Andersen, 2001). The EK60 transducers were installed close to each other to allow for multifrequency analysis (Korneliussen et al., 2008). A 333kHz Simrad EK60 echosounder was added in 2012, to study fluid-like mesozooplankton targets. The 18 kHz transducer has a 11° nominal two-ray beam

angle, other frequencies have a 7° beam opening. A Simrad ER60 120 kHz echosounder fitted with a side-
185 looking ellipsoidal transducer (Simrad ES2.5x10°) has been used in one of the vessel moon pools since 2009,
to assess the density of fish schools in the vertical echosounders blind zone (0-10 m depth). EK60
echosounders will be replaced by Simrad EK80 wide band echosounders during R/V Thalassa II's refit in
summer 2017. Their new broadband capabilities should help improving the multifrequency identification of
acoustic targets (see e.g. Stanton et al., 2010; Stanton et al., 2012). Echosounders used a 1.024 ms pulse
190 duration and were calibrated before or after each PELGAS survey using a standard method (Foote et al.,
1987). Transducers emissions are synchronised via a synchronisation board in order to avoid interferences
between echosounders transmitting and receiving in the same band of frequencies. Echosounders have been
manually operated before 2008, and via the Hermes software thereafter. The Hermes software was developed
by Ifremer to control the configuration and the emission of all echosounders (Trenkel et al., 2009). On the
195 continental shelf, the echosounders ping rate is automatically adjusted by the Hermes software, as a function
of the seabed depth, to avoid false bottom echoes in the water column (Renfree and Demer, 2016). In
offshore waters, ping rate is manually adjusted between 0.5 and 2 pings/s to avoid multiple bottom echoes
registrations in the 10-150 m layer.

Fish acoustic densities are scrutinised based on spatial and spectral signatures of schools, and associated to
200 trawl catches to produce small pelagic fish biomass estimates, according to the methodology described in
(Doray et al., 2010), using the dedicated R package EchoR (Doray et al., 2016b).

Fishing

Acoustic transects are adaptively interrupted to perform identification trawl hauls, to groundtruth acoustic
data, informing on the relative species composition of the fish schools, and to collect biological data (fish
205 length, weight, age...). Identification hauls were carried out using the R/V Thalassa 2 doors, headline: 76 m
foot rope: 70 m (or 57 m x 52 m at depths below 50 m) pelagic trawls. Since 2007, a consort survey has been
routinely organized with French pairs trawlers which accompanied R/V Thalassa during 20 days on average,
to conduct supplementary identification hauls (Massé et al., 2016). Rationale for performing an identification
haul include: i) observing numerous fish echotraces within 2 to 3 NM; ii) noticing changes in the echotrace
210 characteristics; iii) observing an echotrace fished on previous transects, but not on the current transect.

Accompanying commercial fishing vessels have been directed by PELGAS scientists toward echotraces to identify, according to the acoustic registrations recorded by R/V Thalassa's, and to the vessels' relative fishing efficiency (pair trawlers are more efficient near the surface and in coastal areas). The participation of commercial fishermen to PELGAS enabled to double the number of identification hauls (from 60 to 120 on average), hence increasing the precision of the fish echo recordings allocation to species. Trawl catches are sorted and analysed after each haul, to characterise the catch specific composition, length and mean weight distributions, and individual biological parameters for anchovy and sardine (age, length, weight, maturity..., see details in Doray et al., 2014). Catches made by the commercial fishermen are sorted by a trained scientific observer onboard fishing vessels. Anchovy and sardine samples are transferred and analysed onboard R/V Thalassa. Gelatinous macro-zooplankton in midwater trawl catch are recorded and analysed following MSFD protocol since 2016 (Aubert, 2017).

Hydrobiology

A hull-mounted Seabird SBE21 thermosalinometer, fitted with temperature, salinity and fluorescence sensors records surface hydrological conditions every 30 seconds during the survey. During daytime, the hydrobiology team operates the CUFES system mounted with a 315 μm mesh collector and providing pumped surface (5 m depth) seawater at an average rate of 570 $\text{L}\cdot\text{min}^{-1}$. A CUFES sample is collected every 3 nautical miles during acoustic sampling. At night, 3 to 4 hydrobiological stations are performed on every other transect, yielding on average a total of 80 stations per survey. The hydro-stations are ideally performed on a transect that was surveyed during the previous daytime period, to synoptically characterise the biophysical environment, and to allow for the adjustment of the stations locations, according to the hull-mounted thermosalinometer measurements for surface waters, as well as to the egg counts. PELGAS hydrobiological environment sampling scheme is summarized in Figures 1 and 2. Hydrobiological equipments routinely deployed at PELGAS stations include: i) a Conductivity-Temperature-Depth (CTD) probe fitted with auxiliary sensors including a fluorimeter, a turbidimeter and an O₂ sensor, a Laser Optical Particle Counter (LOPC, Herman, 2004) and 9 Niskin bottles, ii) a single frame fitted with three 57 cm diameter, 200 μm mesh WP2 nets equipped with a Hydrobios (back-run stop) mechanical flowmeter. CTD vertical profiles are first performed from the sea surface to 5 meter above the seabed, (downcast at

approximately $0.8 \text{ m}\cdot\text{s}^{-1}$), using a conducting cable that enables the real-time characterization of the water vertical structure during the downcast. Typically, three sets of three Niskin bottles are fired in stratified water conditions. Depending on the real-time observed CTD profile, bottles are fired when moving up the water column during the upcast to collect water: i) well below the pycnocline, ii) at the deep fluorescence maximum (DCM) (generally near the pycnocline), and iii) at the sea surface. NISKIN bottles content is filtered after deployment, to analyse phytoplankton and microzooplankton communities, chlorophyll a biomass, and suspended matter concentration for further analysis.

From 2003 to 2008, vertical WP2 net tows were exclusively performed in the anchovy core distribution area in southern Biscay. WP2 sampling has been carried out at all stations since 2009. The WP2 is shooted at 100 m depth maximum (downcast and upcast $0.5 \text{ m}\cdot\text{s}^{-1}$), or at 5 m above the seabed depth, if less than 100 m depth. A micrometers mesh-size 315 “filet Carré” (Bourriau, 1991) fitted with 315 or 500 μm mesh nets and a 315 μm mesh-size Multinet (Hydrobios) fitted with 5 nets have also been adaptively opportunistically deployed. The former has mainly been used for sampling fish eggs to perform density gradient columns for egg density measurements (Huret et al., 2016), or grazing experiments as well as for larval sampling, while the latter was towed for stratified sampling and vertical distribution analysis of ichthyoplankton larvae. The first WP2 sample and the CUFES samples have been preserved with 4% buffered formaldehyde (final concentration) and examined under microscope until 2014. Since 2015, the WP2 and CUFES samples have been imaged onboard, live, directly after collection prior preservation, with the ZooCAM flow imager (Colas et al., this volume). The ZooCAM is an in-flow imaging particle and plankton analyser that has been developed following a collaborative, trans-disciplinary work between Ifremer teams, initiated during PELGAS in 2013. It was applied to the semi-automatic processing and counting of anchovy and sardine eggs in CUFES samples, and to the gross taxonomic identification and measurement of mesozooplankton organisms in CUFES and WP2 samples. This hardware development, combined with ad-hoc image analysis software (Ecotaxa; Picheral et al., 2016), provided an image-based, time-efficient procedure to process ichthyo- and mesozooplankton samples at a lower taxonomic resolution than time consuming manual identification. The second WP2 sample is fractioned into 4 size classes (2000, 1000, 500 et 200 micrometers) and dried for dry biomass analysis. The third WP2 sample was devoted to other analysis required by ongoing research projects, such as isotopes, genetics or energy density analysis.

Megafauna

Marine megafauna (marine mammals, marine turtles, large fish, birds), macro-litters and ships are recorded during daytime, along acoustic transects, by two trained observers. Briefly, the data collection protocol follows standard line transect methodology for density estimation with distance sampling methods (Buckland et al., 2015). The precise GPS location of each sighting, and distance travelled (vessel speed > 8 knots) and observation conditions (glare, cloud cover, sea state, etc...) are recorded from dawn till dusk. Along a transect, a leg corresponds to a portion of effort prospected in the same observation conditions : whenever the latter changed (e.g. a change in ship activity or in sea state), and also when observers rotate, a new leg is initiated. Two observers, each operating on one side of the upper bridge (16 meters above sea level) or inside the bridge when outdoor conditions were foul (14 meters above sea level), searched for marine megafauna with naked eyes (binoculars were only used for species identification upon detection) within an angle of 90° from the side to the bow. Identification was carried out to the lowest possible taxonomic level. Pictures were taken to validate species identification for cetaceans, and for seabirds when in doubt. Every hour, one observer was relieved from duty by the third observer to prevent observer fatigue: a leg was thus at most one hour long and observation bouts for any observer lasted at most two hours followed by a one hour break. Effort was suspended during trawling operations, but birds following the ship were recorded during trawl hauling in and out. Detailed protocol can be found in Doray et al. (2014),

Ecosystem data management and analysis

Acoustic and CTD raw data are stored in the French national oceanographic data center SISMER². Pre-processed acoustic and fishing data, as well as PELGAS biomass assessment results are stored in the dedicated relational database EchoBase³. Mesozoo- and ichthyoplankton images are stored online in Ecotaxa (Picheral et al., 2016), a web application dedicated to the visual exploration and the taxonomic annotation of plankton images. Sighting data on marine megafauna collected since the onset of the PELGAS surveys have been deposited in the OBIS SEAMAP database⁴.

Since 2000, PELGAS data have been mostly analysed component per component, by respective experts.

2 http://www.ifremer.fr/sismer/index_EN.htm

3 <http://echobase.codelutin.com/v/latest/en/>

4 <http://seamap.env.duke.edu/dataset/1403>

PELGAS group members however felt in 2013 that new, transdisciplinary, analysis of data across ecosystem components was needed, to do justice to the data series, and further improve the comprehensive understanding of the Biscay pelagic ecosystem functioning. The first challenge faced at the onset of cross ecosystem component analysis was the disparity of sampling scales, that prevented direct data comparison across components (Levin, 1992). This difficulty was mitigated by the development in 2008 of a simple spatial smoothing procedure, the block averaging procedure (Petitgas et al., 2009; Petitgas et al., 2014), that was applied to produce standard raster maps of all parameters collected during PELGAS surveys. This method was developed to quickly spatially interpolate, while edge effects, large amounts of ecosystem data collected according to different sampling schemes, in an unsupervised way. The application of other, more supervised spatial interpolation techniques, such as geostatistics (see review in Chiles and Delfiner (1999)), to PELGAS ecosystem data, had indeed been deemed too time consuming, given the large amount of parameters to map every year. Taking advantage of the high spatial resolution of PELGAS discrete (hydrobiological stations) and continuous (acoustic, CUFES, marine megafauna) sampling, a common, reasonably fine ($0.25^\circ \times 0.25^\circ$) grid was defined. Hydrobiology being the ecosystem component sampled at the coarsest resolution, the compromise grid mesh was defined so as to ensure that at least one hydrobiological station was comprised in each grid cell. Grid maps proved to be an acceptable and convenient format for sharing ecosystem surveys data at the national and international levels (see e.g. ICES, 2016).

Multivariate ordination and clustering methods have been applied to series of grid maps, to identify stable correlation structures between ecosystem parameters describing map cells. Cells with comparable correlation structures across component descriptors displayed coherent spatial patterns, that were used to define sub-regions within the Biscay pelagic ecosystem. This map-based approach of the ecosystem complexity allowed to perform direct pairwise comparisons of ecosystem components spatio-temporal dynamics (Doray et al.-a, Lambert et al., this volume), or to define global pelagic seascapes (Petitgas et al., this volume). Those first attempts to perform cross ecosystem component analysis of PELGAS data confirmed the need for new methodologies to further analyse such complex ecosystem datasets.

The PELGAS model for integrated ecosystem data collection and analysis is summarised in Figure 2.

Advantages and limitations of the PELGAS model

Collaborative working

320 Conducting an integrated ecosystem survey requires collaboration between scientists from various disciplines, to avoid the mere juxtaposition of standard, independent data collection schemes on the same platform, and to ultimately answer a shared scientific question. In the case of PELGAS, scientists from different disciplines first joined forces to better understand anchovy recruitment success, which initiated the collaborations needed to conduct the PELGAS integrated ecosystem survey. However, developing effective
325 collaboration within the PELGAS group has not been straightforward, as scientists have a natural tendency to compete with one another for research resources, both during and after the voyage, since the early days of oceanography (Adler, 2014).

Three factors can be put forward to explain the development of collaborative working in the PELGAS group. The first one is the presence in the PELGAS scientific crew of technicians and engineers specialised in data
330 collection, but also of a majority of the researchers, PhD students and interns who would subsequently analyse the survey data. The annual gathering onboard R/V Thalassa of researchers from various fields for relatively long periods of time during PELGAS certainly helped building bridges between disciplines and laboratories, via informal interactions at sea. Secondly, besides close interactions during the survey, Ifremer and La Rochelle University researchers involved in the analysis of PELGAS data have met at least once a
335 year to share methodologies and results, and plan future surveys and analysis. Thirdly, informal collaborations initiated at sea or during PELGAS meetings were further developed within the framework of one national research program (PNEC Gascogne, 2000-2005) and eight international research projects that made use of data and concepts derived from the survey (PELASSES, 2000-2002; SIMFAMI, 2001-2005; UNCOVER, 2006-2010; RECLAIM 2006-2010; FACTS, 2010-2012; ATLANTOS, 2015-2019,
340 REPRODUCE, 2010-2012; SEAMAN, 2013-2015). This combination of informal interactions and formal collaborations within research projects, brought the scientists involved in the PELGAS group to progressively articulate their personal research interests around a broader and scientifically appealing objective: monitoring and understanding the Bay of Biscay pelagic ecosystem. This ambitious objective has

emerged, and was deemed achievable, due/thanks to the diversity of PELGAS community of scientists,
345 which regrouped the necessary expertise to interpret data collected in separate ecosystem components, as
well as concepts and methodologies to collate all the information, and derive results at the ecosystem scale.
Sharing knowledge on sampling and data analysis methods has been a powerful way to initiate cross
ecosystem components studies, either by applying methods used in one component to another (e.g. isotopic
methods initially applied to cetaceans and seabirds and thereafter to fish and mesozooplankton), or by re-
350 analysing archived data series with a different focus (e.g. analysis of multifrequency fisheries acoustics data
to derive new information on mesozooplankton and micronekton). The emergence of an "ecosystem of
scientists", used to multidisciplinary collaborative working at sea, and on land, has in this way enabled the
development of the ecosystem science produced by the PELGAS project. The PELGAS ecosystem has been
further enriched by the participation of commercial fishermen to the survey. Fishermen and scientists have
355 been jointly assessing the Biscay anchovy and sardine biomass since 2007, building a shared diagnostic of
the state of the stock, as well as mutual trust and good relationships (Massé et al 2016).

Ecosystem sampling

With the addition of top predators sightings in 2003, and the generalisation of mesozooplankton sampling at
all stations in 2009, all major Biscay pelagic ecosystem components have been routinely sampled in the
360 same area since 2009. After that, no shiptime was left to deploy additional sampling gears. PELGAS
sampling scheme was therefore optimised by: i) adding new sensors to existing gears deployed at fixed
stations (addition of LOPC, and oxygen, pH, and turbidity sensors to the CTD), and ii) collecting more
biological information from trawl sampling (e.g. application of MSFD protocol on gelatinous
mesozooplankton since 2016, fish stomach contents and energy density). In order to design meaningful
365 monitoring for the ecosystem approach (Kupschus et al., 2016), new sensors and protocols have been added
to the PELGAS survey to bridge knowledge gaps identified in data analysis and/or ecosystem modelling
studies. New sampling tools and technologies have been selected to comply with practical constraints
(funding, staff requirement, vessel space and time availability, maturity of technology). Vessel availability
for testing new protocols also appeared to be a crucial factor for validating enhancements of PELGAS
370 sampling strategy.

In the future, supplementary biological data such as micronekton species composition, isotopes and energy densities of fish and mesozooplankton, and stomach contents and contaminants of fish, could be obtained by training the fishing team to collect extra parameters on midwater trawl catches. In the multispecific context of the Bay of Biscay, fish sampling could not be passed completely over to the consort vessels, to free 375 valuable R/V *Thalassa* time. This would indeed decrease the precision of biomass indices, as the current trawl sampling rate is just sufficient to ascertain the specific composition of the main fish concentrations. Optical net systems could however be deployed on *Thalassa*'s midwater trawls to assess the species and size composition of fish and micronekton echotraces sampled acoustically (Zwolinski et al., 2014), within different depth strata. This would save *Thalassa* time, that could be re-allocated to other tasks. Due to the 380 lack of shiptime for extra gear deployment, future PELGAS sampling enhancements will also involve the development of en-route, semi-automatic observations. Fisheries acoustics have provided en-route, real time, high resolution acoustic views of the small pelagic fish horizontal and vertical distributions, since the beginning of the PELGAS series. Acoustic sampling revealed pelagic seascapes, that were adaptively sampled with midwater trawls during the survey. Acoustic multifrequency echograms moreover provides real 385 time information on sound scattering layers produced by large mesozooplankton and micronekton (Lavery et al., 2007), that might be further exploited to characterise these communities. Acoustic-guided, adaptive sampling could hence complement the traditional discrete sampling at fixed "observing stations" (Adler, 2014), carried out at night during PELGAS. Using ship or sonde-based broadband echosounders (Stanton et al., 2010; Stanton et al., 2012) should moreover allow for a more precise acoustic characterisation of 390 echotraces, and provide more taxonomic information on acoustic seascapes. Hull-mounted thermosalinometer and the CUFES/ZooCam combination actually provide en-route, high resolution data on the hydrology, chlorophyll-a, and the abundance of mesozoo- and ichthyo-plankton in the acoustic blind zone (0-10 m depth). Pelagic seascapes near the sea surface could be defined by applying Petitgas et al. (this volume) approach to series of standard raster maps of significant descriptors collected by the CUFES and the 395 thermosalinometer. Those hydrobiological pelagic seascapes could also be compared to SSLs and fish concentrations detected by vertical echosounders in the 10-30 m layer, or by the lateral echosounder in the 0-10 m depth layer, to further characterise the small pelagic fish habitats near the sea surface (see e.g. Doray et al., this volume-a). The installation of a FerryBox (Petersen, 2014) on R/V *Thalassa* in 2018 will provide

additional en-route data on oxygen, pH, coloured dissolved organic matter concentration (CDOM), and algae
400 groups by fluorescence spectroscopy. En route, in depth sampling of Biscay hydrology and plankton could be
eventually conducted by deploying an undulating towed body (Bruce and Aiken, 1975) equipped with CTDs
and optical or imaging particle and plankton counters (Herman, 2004). The rapid increase of satellite-based
bandwidth could eventually allow to remotely control some sampling or data processing operations onboard
research vessel or other platforms, freeing valuable vessel space for scientists conducting new sampling
405 (Zwolinski et al., 2014). Real time remote control and data fluxes management of several sampling platform
could also allow to adaptively combine vessel-borne sampling with observations realised on other platforms
(autonomous moving subsea platforms, drones, fixed platforms, buoys etc... cf. Godo et al., 2014), to
improve sampling coverage and/or resolution.

Development of en-route and/or semi-automatic systems enabling the extension of PELGAS sampling
410 coverage has generated new, voluminous, data fluxes that need to be securely archived and processed within
reasonable delay. New hardware and software have been developed to accommodate these new large
ecosystem data fluxes, with the common objective of processing onboard as much data as possible, to take
advantage of the availability and expertise of the scientific team during the survey (e.g. Zoocam).

Ecosystem data analysis

415 Biomass and abundance indices of chub mackerel (*Scomber colias*), Atlantic mackerel (*Scomber scombrus*),
horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), European anchovy
(*Engraulis encrasicolus*), European sardine (*Sardina pilchardus*) and sprat (*Sprattus sprattus*) have been
derived every year from PELGAS data since 2000 (Figure 3). Anchovy and sardine biomass and abundance
at age have also been routinely computed. PELGAS has provided the ICES HANSA stock assessment group
420 with a relative estimate of the springtime Biscay anchovy adult biomass since 2000. The PELGAS biomass
index has been combined in an analytical stock assessment model with the other survey indices and
commercial fishery landings, to assess the state of Biscay anchovy stock, and provide the European
Commission with an advice on Total Allowable Catch (ICES, 2015). A biomass estimate of the sardine stock
component present in Biscay in springtime has also been derived from PELGAS survey data since 2000
425 (Figure 3), and provided to the HANSA group. This index has been used to assess the state of the data

limited sardine stock in Biscay and the English Channel (ICES, 2015). PELGAS biomass estimates and size structures of Atlantic, horse mackerel, blue whiting and boarfish have been provided to the ad-hoc ICES WIDE stock assessment group since 2016. The precision and robustness of small pelagic fish biomass indices derived from acoustic-trawl PELGAS data have been investigated by: i) assessing parameters (fish
430 Target Strength, Doray et al., 2016a, and methods, Petitgas et al., 2003) used in the acoustic biomass estimation procedure, and ii) jointly analysing egg-based and acoustic-based fish biomass estimates, to identify potential annual sampling bias in both methods (Petitgas et al., 2006; Petitgas et al., 2009).

The PELGAS survey model moreover allowed for the collection of long-term series of spatially-explicit data in the main the Bay of Biscay pelagic ecosystem components: hydrology, phytoplankton, mesozooplankton,
435 fish and megafauna. Standard mapping procedures defined by the PELGAS consortium allowed to routinely produce maps of parameters collected in the ecosystem main components, in addition to biomass indices for fish stock assessments (Figure 2). Numerical ecologists and fisheries oceanographers have collaborated since the onset of the PELGAS survey to apply statistical and mechanistic models to ecosystem data collected during the survey. PELGAS data have hence contributed to the publication of more than 70 peer-reviewed
440 articles and 9 PhD thesis over the 2000-2017 period.

Statistical models have been applied to study the interannual variability of spatial distributions, and in particular to the definition of habitats, i.e. the environmental conditions that are favourable for an organism presence or prevalence (Petitgas et al., 2014). PELGAS georeferenced ecosystem data have hence been used to study statistical relationships between ecosystem components, in a spatial context. The interannual
445 variability of the spatial distributions of various ecosystem variables have been modelled: hydrological parameters, to define typical "hydrological landscapes" (Planque et al., 2006); plankton and fish spatial abundance, to explore relations between the trophic state of the system, planktonic community structure, and fish distributions (Petitgas et al., 2006); Vandromme et al., 2014); small pelagic fish egg density, to assess temporal changes in spawning (Bellier et al., 2007); adult pelagic fish densities, to characterise nested
450 aggregative structures (Petitgas 2003), "acoustic populations" (Petitgas et al., 2003), spatial segregation in size and species (Petitgas et al., 2011; Certain et al., 2011), and relationships between recruitment and adult spatial patterns (Petitgas et al., 2014); cetacean and seabirds abundance, to define habitats (Certain et al.,

2008), and to investigate predator-prey interactions (Certain et al., 2011) and vulnerability to pressure (Certain et al., 2015).

455 Data and concepts derived from PELGAS surveys have been incorporated/tested in mechanistic models of Biscay pelagic ecosystem processes since the onset of the series. In addition to contributions to the study of surface circulation (Charria et al., 2013; Reverdin et al., 2013) and toxic algae blooms (Batifoulier et al., 2013) in the Bay of Biscay, PELGAS hydrological data have served to partly groundtruth the MARS3D hydrodynamic model (Lazure et al., 2009) of the Bay of Biscay, and its ecosystem extension, ECOMARS
460 (Huret et al., 2013). A biophysical Individual Based Model of the growth and survival of anchovy larvae and juveniles was developed based on PELGAS data (Allain et al., 2003; Huret et al., 2010), to investigate larval dispersal and survival (Allain et al., 2007b; Huret et al., 2010), predict anchovy recruitment, and test the effect of climate scenarii on anchovy larval dispersal (Lett et al., 2010), based on MARS3D model outputs (Allain et al., 2007a). PELGAS data (Dubreuil and Petitgas, 2009) were used to calibrate a bioenergetic
465 model of Biscay anchovy (Pecquerie et al., 2009; Gatti et al., 2017) and sardine (Gatti et al., 2017). This model was implemented to complement earlier studies (Bellier et al., 2007) aiming at predicting anchovy spawning potential habitats (Pecquerie et al., 2009), and to explore spawning migrations, based on ECOMARS model outputs (Politikos et al., 2015). Knowledge and data on Biscay small pelagic fish life cycles from PELGAS surveys have been compiled in a review of the North-East Atlantic small pelagic fish
470 life cycles (ICES, 2010) and used to investigate the recent expansion of anchovy populations in the North Sea (Petitgas et al., 2012). The PELGAS survey has shed light on Biscay pelagic ecosystem global functioning, generally through the analysis of trophic interactions between components. Modelling studies using PELGAS data have investigated the carbon transfer from low to high trophic levels in the Bay of Biscay (Marquis et al., 2007; Marquis et al., 2011; Lassalle et al., 2011). Effects of mesozooplankton
475 productivity on anchovy population have been studied using biochemical markers from PELGAS samples (Bergeron and Massé, 2011; Bergeron et al., 2013). PELGAS has provided biological samples to assess the energy content of cetacean preys (Spitz et al., 2010; Spitz and Jouma'a, 2013) and the isotopic signature of consumers in spring in Biscay (Chouvelon et al., 2012; Chouvelon et al., 2014; Chouvelon et al., 2015). PELGAS data have been used to calibrate the ISIS-FISH fishery simulation model (Lehuta et al., 2013) to
480 assess the efficiency of Biscay anchovy fisheries management scenarii (Lehuta et al., 2010). Potential

impacts of fisheries on cetacean populations in the Bay of Biscay have been assessed using trophic network models including PELGAS data (Lassalle et al., 2012). Hydrodynamic and later complex ecosystem models hence allowed to extrapolate the time restricted observations realised during the survey into a larger, seasonal or inter-annual context, and to test hypothesis on ecological processes and global change effects on the
485 ecosystem.

Papers presented in this volume provide new insights on ecological processes taking place in single components of the Bay of Biscay pelagic ecosystem. Perrot et al. (this volume) showed how water samples collected during the PELGAS2016 survey can be used to groundtruth the results of an ocean color algorithm aiming at detecting phytoplanktonic coccolithophores. Dessier et al. (this volume) provided new insights on
490 mesozooplankton spatio-temporal distribution and energy content in southern Biscay. Gatti et al. (this volume) presented new results on adult anchovy and sardine energy content along a latitudinal gradient, and across ages. Authier et al. (this volume) documented patterns of change in marine megafauna relative abundance at the community level, based on a decade of PELGAS data (2004-2016). Huret et al. (this volume) proposed to correct the actual dates of the annual survey with respect to a climatology of the
495 seasonal evolution of surface temperature, allowing for a better interpretation of the observed interannual spawning. Cross-ecosystem component studies resulting from new collaborative work were also presented in the present volume. Most are based on the standard raster maps of ecosystem parameters collected during PELGAS (Figure 2). Doray et al. (this volume-a) have defined spring habitats of small pelagic fish communities in the Bay of Biscay, and assessed their variability over a decade. Lambert et al. (this volume)
500 have explored the variations in habitat preferences exhibited by five mobile top predators species within the Bay of Biscay. Spitz (this volume) has studied the predation of cetaceans on small pelagic fish based on stomach content analysis. Petitgas et al. (this volume) have combined the standard maps of parameters collected in the main components of the Biscay pelagic ecosystem over the 2009-2014 period, to define a map of ecosystem seascapes that are consistent over the years, together with a map of their inter-annual
505 variability. Doray et al. (this volume-b) have selected series of potential pelagic ecosystem indicators derived from the PELGAS survey, to identify the main ecological processes that have been at work in the Bay of Biscay since 2000, and to test the effects of external forcing on the ecosystem dynamics.

Limitations and challenges

PELGAS has been evaluated against the "ideal" integrated survey for ecosystem approach defined by ICES
510 (ICES, 2012). According to this evaluation, the main step that would be required for the PELGAS survey to
move from its current state to the ideal ecosystem survey would be to extend its coverage to the demersal
ecosystem (ICES, 2012). The main actual limitation of PELGAS being R/V Thalassa vessel time, it would
not be possible to monitor both pelagic and demersal ecosystems in Biscay in spring, without chartering
another vessel, or doubling the survey duration. As Biscay demersal resources are assessed in autumn, during
515 the EU DCF funded EVHOE bottom trawl survey (Mahé, 1987), duplicating this coverage in spring during
PELGAS is likely not top priority.

Even if process studies have been opportunistically carried during PELGAS surveys to bridge knowledge
gaps on e.g. phytoplankton production, zooplankton grazing, vertical distribution of eggs and larvae, fish
Target Strength variation with depth, identification of sound scattering layers or identification of satellite
520 detected blooms..., one of the major limitation of the PELGAS survey is the absence of long-term sampling
effort dedicated to process studies. In spite of the fact the survey has been designed by researchers and has
always been integrated into national ecology programs, the standard data collection over the survey grid has
been disconnected from process understanding. Conducting process studies alongside standard data
collection during a survey is however a daunting task, as sharing vessel space and time, and harmonising
525 sampling coverage over all ecosystem components for maintaining standard data collection remain the major
challenges faced during PELGAS. Recent outbreaks of mesozooplankton or micronekton organisms have
e.g. been qualitatively observed during PELGAS surveys (salps in 2014, 2015, pteropods and to a lesser
extent euphausiids in 2016, unpublished data). These observations suggest that extending PELGAS sampling
to cover those poorly known, but potentially ecologically and biogeochemically important (Banse, 1995;
530 Lehodey et al., 2015) intermediate trophic levels could be crucial to better understand pelagic ecosystem
functioning, especially in the context of climate change (Richardson, 2008). En-route multifrequency
acoustic data routinely collected during PELGAS could potentially inform on intermediate trophic levels
dynamics, but their interpretation still requires extra gear deployments for thorough groundtruthing (Mair et
al., 2005), that are not compatible with the survey schedule. More detailed data on phytoplankton diversity

535 should ideally be collected, as well as information on organisms that are known to play major roles in marine ecosystem such as bacteria, viruses and parasites (e.g. of fishes).

However, extending sampling activities cannot be carried out endlessly without compromising data quality (Shephard et al., 2015). Choosing between maintaining standard data series for fulfilling new MSFD and DCF requirements, or conducting process-based studies might become in a near future a dilemma faced by
540 most groups running integrated ecosystem surveys. This is why regular survey protocol evaluation and adaptation (cf. Kupschus et al., 2016) during WGACEGG and PELGAS annual meetings, as well as sampling automation, will be crucial to keep improving integrated ecosystem survey coverage, without compromising the quality of the existing long term data series.

Perspectives for ship-based ecosystem monitoring

545 The PELGAS survey has been demonstrating since 2000 that the integrated collection of data on other ecosystem components during a target-species fish biomass assessment survey was possible, and useful, in the context of an EAF. PELGAS ecosystem approach has inspired some European scientists promoting other surveys, in a general move from target-species fish biomass assessment to wider ecosystem approach. Following PELGAS example, hydrobiological sampling and cetacean and seabird sightings have been added
550 to the bottom trawl surveys conducted by Ifremer on R/V Thalassa in the Bay of Biscay and Celtic Sea (EVHOE, Mahé, 1987), and in the English Channel and North Sea (French contribution to IBTS, Vérin, 1992). PELACUS, PELGAS' Spanish counterpart survey aiming at assessing small pelagic fish biomass in Cantabrian and Galician waters by acoustic-trawl method, has been conducted on R/V Thalassa from 1997 to 2012. Conducting coordinated surveys on the same platform permitted to pursue the exchanges between
555 French and Spanish scientists initiated during the PELASSES project, to benefit from the same equipments, and to develop ecosystem sampling during both PELACUS and PELGAS surveys. Other fisheries acoustic surveys coordinated since 2002 within the ICES ACEGG working group have also been inspired by the PELGAS' ecosystem approach: PELAGO (Portugal), JUVENA (Spain, Boyra et al., 2013), and PELTIC (United Kingdom, ICES, 2016, p. 331).

560 The adoption of MSFD in 2008 has renewed the interest in ecosystem surveys in Europe, as they could become the backbone of ecosystem data collection in the offshore areas covered by the directive. MSFD

aims to achieve Good Environmental Status (GES) in European Union waters by 2020 (MSFD, 2008/56/EC), through the monitoring of supporting state indicators. PELGAS has in a way anticipated MSFD requirements by collecting observations and deriving potential indicators of the state of Biscay pelagic ecosystem in spring since 2000. Table 1 presents a list of potential ecosystem indicators that have been derived from PELGAS data, including spatial indices proposed by Woillez et al. (2007). An example of the combination and synthesis of PELGAS indicators series to study the Biscay pelagic ecosystem dynamics over time is presented in Doray et al. (this volume-b). The PELGAS group intends to keep developing new potential indicators of pelagic ecosystem state, and indicators combination methods, to contribute to the operationalisation of ecosystem management. Whereas ambitious marine ecosystem management objectives have been adopted in Europe within the MSFD framework, the tension between the economic cost of MSFD Monitoring Programs and the need to produce data to derive supporting state indicators has been outlined (Shephard et al., 2015; Borja and Elliott, 2013). Ecosystem surveys being logistically complex and expensive to run, the EU DCF funding of PELGAS has been essential for developing and maintaining this long term ecosystem survey. The future of PELGAS and other ecosystem surveys in Europe will hence likely depends on member states willingness to provide sufficient funding for developing and maintaining Monitoring Programs up to the challenge of MSFD objectives.

Conclusions

PELGAS has been developed as an integrated ecosystem survey, aiming at assessing adult anchovy biomass and predicting recruitment success in the Bay of Biscay in spring, in the context of an EAF. Sampling has been progressively extended to other ecosystem components, and the PELGAS survey focus has shifted to an evermore efficient and holistic monitoring of the Bay of Biscay pelagic ecosystem, while conserving its initial target species biomass assessment objective. The PELGAS survey has hence confirmed that acoustic-trawl survey could be the backbone for development of pelagic ecosystem survey (Zwolinski et al. 2014). PELGAS data have been analysed using statistical models to improve knowledge on single ecosystem components, but also to compare data from different components or sampling tools. This cross component/data source approach was used to control for sampling bias, and to investigate not only

ecosystem change, but also its causes. Deterministic modelling has been used to integrate ecosystem knowledge, and test hypothesis on ecological process since the beginning of the series. Each new PELGAS survey is however the definitive crash-test for ecological hypothesis, as the diverse and dynamic Biscay spring pelagic ecosystem is often full of surprise. Biscay anchovy stock biomass has e.g. largely varied since 2000, due to dramatic variations in recruitment (Figure 3). The stock biomass has dropped in 2002, leading to the fishery closure from 2005 to 2010. Anchovy biomass remained low due to recruitment failure until 2010. The fishery was re-opened in 2010, based on the relatively high survey biomass indices. Biscay anchovy stock biomass has remained high since 2010, following the implementation of more conservative Harvest Control Rules in 2009 (COM, 2009). Despite the new knowledge on Bay of Biscay anchovy population dynamics derived from the PELGAS survey (cf. Ecosystem data analysis section), the recruitment success of this species remains unpredictable. Anchovy recruitment variability was found to be correlated with several environmental parameters (spring coastal upwelling along the French and Spanish coasts, Borja et al., 1998; summer water-column stratification breakdowns under west – southwest summer storms, Allain et al., 2001). But these correlations have thereafter failed to be predictive (ICES, 2010). An end-to-end model of Biscay anchovy life cycle, integrating PELGAS data on eggs, larvae, mesozooplankton and predators, is currently under development, to further investigate the ecological processes driving the anchovy population dynamics and recruitment success.

In the MSFD context, PELGAS time series of potential indices on Biscay pelagic ecosystem state (Table 1) could contribute to inform forthcoming ecosystem based management of European waters. However, all the data that would be needed to integrate all ecosystem components will probably never be collected during a single PELGAS survey. The integration of PELGAS products within larger scale ecosystem programs should hence be pursued. PELGAS can e.g. serve as a data collection platform for operational oceanography, by providing near real time groundtruthing data for satellite imaging products (see e.g. Perrot et al., this volume). International survey coordination within the ICES ACEGG group now allows for the monitoring of small pelagic fish resources and of some of the key features of their environment from Gibraltar to Ireland, in spring and autumn (Massé et al., In press).

The PELGAS survey should however be included in a larger ecosystem monitoring program, integrating

615 operational oceanography products, and data fluxes from seabed observatories, buoys, drifters and ships of
opportunity (e.g. Dexter and Summerhayes, 2010; Godo et al., 2014), to build efficient MSFD-targeted Joint
Monitoring Programs (Shephard et al., 2015). Such joint monitoring programs could hence resolve
multiscale ecosystem dynamics, by e.g. combining mesoscale snapshots provided by vessel-based surveys,
with continuous variations collected at restricted locations by instrumented fixed observatories. In any case,
620 the recent trend toward operationalisation of marine ecosystem management in a changing world reinforces
the need for PELGAS-like ecosystem surveys, to serve as efficient providers of data and concepts for
ecosystem management and research.

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630 References

- Adler, A., 2014. The Ship as Laboratory: Making Space for Field Science at Sea. *J. Hist. Biol.* 47, 333–362. doi:10.1007/s10739-013-9367-7
- Agnew, D.J., 1997. The CCAMLR Ecosystem Monitoring Programme. *Antarct. Sci.* 9. doi:10.1017/S095410209700031X
- Ahl, V., Allen, T., 1996. *Hierarchy Theory: a Vision, Vocabulary and Epistemology*. Columbia University Press, New York.
- Allain, G., Petitgas, P., Grellier, P., Lazure, P., 2003. The selection process from larval to juvenile stages of anchovy (*Engraulis encrasicolus*) in the Bay of Biscay investigated by Lagrangian simulations and comparative otolith growth. *Fish Ocean.* 12, 407–418.
- Allain, G., Petitgas, P., Lazure, P., 2007a. The influence of environment and spawning distribution on the survival of anchovy (*Engraulis encrasicolus*) larvae in the Bay of Biscay (NE Atlantic) investigated by biophysical simulations. *Fish Ocean.* 16, 506–514.
- Allain, G., Petitgas, P., Lazure, P., Grellier, P., 2007b. Biophysical modelling of larval drift, growth and survival for the prediction of anchovy (*Engraulis encrasicolus*) recruitment in the Bay of Biscay (NE Atlantic). *Fish Ocean.* 16, 489–505.
- Andersen, L.N., 2001. The new Simrad EK60 scientific echosounder system. *J Acoust Soc Am* 109,

- Aubert, A., 2017. Protocole DCSMM d'échantillonnage macro- et méga- zooplancton gélatineux pour campagnes halieutiques IFREMER (Programme de Surveillance DCSMM).
- Banse, K., 1995. Zooplankton: Pivotal role in the control of ocean production. *ICES J. Mar. Sci.* 52, 265–277. doi:10.1016/1054-3139(95)80043-3
- Batifoulier, F., Lazure, P., Velo-Suarez, L., Maurer, D., Bonneton, P., Charria, G., Dupuy, C., Gentien, P., 2013. Distribution of Dinophysis species in the Bay of Biscay and possible transport pathways to Arcachon Bay. *J. Mar. Syst.* 109–110, S273–S283. doi:10.1016/j.jmarsys.2011.12.007
- Bellier, E., Planque, B., Petitgas, P., 2007. Historical fluctuations in spawning location of anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) in the Bay of Biscay during 1967–73 and 2000–2004. *Fish Ocean.* 16, 1–15.
- Bergeron, J.-P., Koueta, N., Massé, J., 2013. Interannual fluctuations in spring pelagic ecosystem productivity in the Bay of Biscay (northeast Atlantic) measured by mesozooplankton aspartate transcarbamylase activity and relationships with anchovy population dynamics. *Fish. Res.* 143, 184–190. doi:10.1016/j.fishres.2013.02.006
- Bergeron, J.-P., Massé, J., 2011. Change in the shoaling behaviour and nutritional condition of anchovies (*Engraulis encrasicolus* L.) during a wind-induced water column disturbance: a natural event test of a general hypothesis. *Mar. Freshw. Behav. Physiol.* 44, 93–107. doi:10.1080/10236244.2011.568600
- Blaxter, J.H.S., Hunter, J.R., 1982. The Biology of the Clupeoid Fishes, in: *Advances in Marine Biology*. Elsevier, pp. 1–223. doi:10.1016/S0065-2881(08)60140-6
- Borja, Á., Elliott, M., 2013. Marine monitoring during an economic crisis: The cure is worse than the disease. *Mar. Pollut. Bull.* 68, 1–3. doi:10.1016/j.marpolbul.2013.01.041
- Bourriau, P., 1991. The “Carré Net.” *ICES CM.*
- Boyra, G., Martinez, U., Cotano, U., Santos, M., Irigoien, X., 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 J. Mar. Sci.* 70, 1354–1368. doi:10.1093/icesjms/fst096
- Bruce, R.H., Aiken, J., 1975. The undulating oceanographic recorder ? A new instrument system for sampling plankton and recording physical variables in the euphotic zone from a ship underway. *Mar. Biol.* 32, 85–97. doi:10.1007/BF00395162
- Buckland, S.T., Rexstad, E.A., Marques, T.A., Oedekoven, C.S., 2015. *Distance Sampling: Methods and Applications*, *Methods in Statistical Ecology*. Springer International Publishing, Cham. doi:10.1007/978-3-319-19219-2
- CalCOFI, 2011. State of the California Current 2010–2011: Regional Variable Responses to a Strong (But Fleeting?) La Niña. *CalCOFI Report No.* 52.
- Certain, G., Jorgensen, L.L., Christel, I., Planque, B., Bretagnolle, V., 2015. Mapping the vulnerability of animal community to pressure in marine systems: disentangling pressure types and integrating their impact from the individual to the community level. *ICES J. Mar. Sci.* 72, 1470–1482. doi:10.1093/icesjms/fsv003
- Certain, G., Massé, J., Van Canneyt, O., Petitgas, P., Doremus, G., Santos, M.B., Ridoux, V., 2011. Investigating the coupling between small pelagic fish and marine top predators using data collected from ecosystem-based surveys. *Mar. Ecol. Prog. Ser.* 422, 23–39.
- Certain, G., Ridoux, V., van Canneyt, O., Bretagnolle, V., 2008. Delphinid spatial distribution and abundance estimates over the shelf of the Bay of Biscay. *ICES J Mar Sci* 65, 656–666.
- Charria, G., Lazure, P., Le Cann, B., Serpette, A., Reverdin, G., Louazel, S., Batifoulier, F., Dumas, F., Pichon, A., Morel, Y., 2013. Surface layer circulation derived from Lagrangian drifters in the Bay of Biscay. *J. Mar. Syst.* 109–110, S60–S76. doi:10.1016/j.jmarsys.2011.09.015
- Checkley Jr, D.M., Ortner, P.B., Settle, L.R., Cummings, S.R., 1997. A continuous, underway fish

- egg sampler. Fish. Oceanogr. 6, 58–73. doi:10.1046/j.1365-2419.1997.00030.x
- Chiles, J., Delfiner, P., 1999. Geostatistics: Modeling Spatial Uncertainty. Wiley, New York (USA).
- Chouvelon, T., Chappuis, A., Bustamante, P., Lefebvre, S., Mornet, F., Guillou, G., Violamer, L., Dupuy, C., 2014. Trophic ecology of European sardine *Sardina pilchardus* and European anchovy *Engraulis encrasicolus* in the Bay of Biscay (north-east Atlantic) inferred from $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of fish and identified mesozooplanktonic organisms. J. Sea Res. 85, 277–291.
- Chouvelon, T., Spitz, J., Caurant, F., Mèndez-Fernandez, P., Chappuis, A., Laugier, F., Le Goff, E., Bustamante, P., 2012. Revisiting the use of $\delta^{15}\text{N}$ in meso-scale studies of marine food webs by considering spatio-temporal variations in stable isotopic signatures – The case of an open ecosystem: The Bay of Biscay (North-East Atlantic). Prog. Oceanogr. 101, 92–105. doi:10.1016/j.pocean.2012.01.004
- Chouvelon, T., Violamer, L., Dessier, A., Bustamante, P., Mornet, F., Pignon-Mussaïd, C., Dupuy, C., 2015. Small pelagic fish feeding patterns in relation to food resource variability: an isotopic investigation for *Sardina pilchardus* and *Engraulis encrasicolus* from the Bay of Biscay (north-east Atlantic). Mar. Biol. 162, 15–37. doi:10.1007/s00227-014-2577-5
- COM, 399 final, 2009. Proposal for a COUNCIL REGULATION establishing a long term plan for the anchovy stock in the Bay of Biscay and the fisheries exploiting that stock (SEC(2009) No. 1076 final).
- Dexter, P., Summerhayes, C.P., 2010. Ocean Observations - the Global Ocean Observing System (GOOS), in: Pugh, D., Holland, G. (Eds.), Troubled Waters: Ocean Science and Governance. CUP, Cambridge, pp. 161–178.
- Diner, N., 2007. Evaluating uncertainty in measurements of fish shoal aggregate backscattering cross-section caused by small shoal size relative to beam width. Aquat Living Resour 20, 117–121.
- Diner, N., 2001. Correction on school geometry and density: approach based on acoustic image simulation. Aquat Living Resour 14, 211–222.
- Doray, M., Badts, V., Massé, J., Duhamel, E., Huret, M., Doremus, G., Petitgas, P., 2014. Manual of fisheries survey protocols. PELGAS surveys (PELAGiques GAScogne). Manuel des protocoles de campagne halieutique Ifremer No. 30259.
- Doray, M., Berger, L., Le Bouffant, N., Coail, J.Y., Vacherot, J.P., de La Bernardie, X., Morinière, P., Lys, E., Schwab, R., Petitgas, P., 2016a. A method for controlled target strength measurements of pelagic fish, with application to European anchovy (*Engraulis encrasicolus*). ICES J. Mar. Sci. J. Cons. 73, 1987–1997. doi:10.1093/icesjms/fsw084
- Doray, M., Duhamel, E., Huret, M., Petitgas, P., Massé, J., 2000. PELGAS. <http://dx.doi.org/10.18142/18>
- Doray, M., Massé, J., Petitgas, P., 2010. Pelagic fish stock assessment by acoustic methods at Ifremer. Rapp Int Ifremer DOP/DCN/EMH 10-02, 1–17. <http://archimer.ifremer.fr/doc/00003/11446/7996.pdf>
- Doray, M., Petitgas, P., Saraux, C., Cornou, A.S., 2016b. EchoR: R package for computing indices of the state of fish population and communities, based on fisheries acoustic data, R package.
- Doray, M., Petitgas, P., Huret, M., this volume-a. Spring habitats of small pelagic fish communities in the Bay of Biscay. Prog. Oceanogr.
- Doray, M., Petitgas, P., Huret, M., Duhamel, E., Romagnan, J.B., Authier, M., Dupuy, C., Spitz, J., this volume-b. Monitoring small pelagic fish in the Bay of Biscay ecosystem, using indicators from integrated survey. Prog. Oceanogr.
- Dubreuil, J., Petitgas, P., 2009. Energy density of anchovy *Engraulis encrasicolus* in the Bay of Biscay. J Fish Biol 74, 521–534.
- Eriksen (Ed.), 2014. Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters, August-October 2014, IMR/PINRO Joint Report Series.

- Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., Simmonds, E.J., 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Coop Res Rep 144, 57.
- Fréon, P., Misund, O., 1999. Dynamics of Pelagic Fish Distribution and Behaviour: Effects on Fisheries and Stock Assessment. Blackwell Science, London.
- Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G., 2003. The ecosystem approach to fisheries. FAO Fisheries Technical Paper No. 443. FAO, Rome.
- Gatti, P., Petitgas, P., Huret, M., 2017. Comparing biological traits of anchovy and sardine in the Bay of Biscay: A modelling approach with the Dynamic Energy Budget. *Ecol. Model.* 348, 93–109. doi:10.1016/j.ecolmodel.2016.12.018
- Godo, O.R., Handegard, N.O., Browman, H.I., Macaulay, G.J., Kaartvedt, S., Giske, J., Ona, E., Huse, G., Johnsen, E., 2014. Marine ecosystem acoustics (MEA): quantifying processes in the sea at the spatio-temporal scales on which they occur. *ICES J. Mar. Sci.* 71, 2357–2369. doi:10.1093/icesjms/fsu116
- Herman, A.W., 2004. The next generation of Optical Plankton Counter: the Laser-OPC. *J. Plankton Res.* 26, 1135–1145. doi:10.1093/plankt/fbh095
- Hjort, J., 1914. Fluctuations in the great fisheries of Northern Europe viewed in the light of biological research. *Rapp. Procès Verbaux CIEM* 20, 227.
- Huret, M., Bourriau, P., Gatti, P., Dumas, F., Petitgas, P., 2016. Size, permeability and buoyancy of anchovy (*Engraulis Encrasicolus*) and sardine (*Sardina Pilchardus*) eggs in relation to their physical environment in the Bay of Biscay. *Fish. Oceanogr.* 25, 582–597. doi:10.1111/fog.12174
- Huret, M., Petitgas, P., Woillez, M., 2010. Dispersal kernels and their drivers captured with a hydrodynamic model and spatial indices: A case study on anchovy (*Engraulis encrasicolus*) early life stages in the Bay of Biscay. *Prog. Oceanogr.* 87, 6–17. doi:10.1016/j.pocean.2010.09.023
- Huret, M., Sourisseau, M., Petitgas, P., Struski, C., Léger, F., Lazure, P., 2013. A multi-decadal hindcast of a physical–biogeochemical model and derived oceanographic indices in the Bay of Biscay. *J. Mar. Syst.* 109–110, S77–S94. doi:10.1016/j.jmarsys.2012.02.009
- ICES, 2016. Second Interim report of the Working Group on Acoustic and Egg Surveys for Sardine and Anchovy in ICES Areas VII, VIII and IX (WGACEGG), in: ICES CM 2015/SSGIEOM:31. 16-20 November 2015, Lowestoft, UK., p. 396 pp.
- ICES, 2015. Report of the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA). ICES CM 2015/ACOM:16. Lisbon, Portugal.
- ICES, 2012. Report of the Workshop on Evaluation of current ecosystem surveys (WKECES). 20-22 November 2012, Bergen, Norway. ICES CM 59.
- ICES, 2010. Life cycle spatial patterns of small pelagic fish in the Northeast Atlantic. ICES Coop. Res. Rep. 93.
- Korneliussen, R.J., Diner, N., Ona, E., Berger, L., Fernandes, P.G., 2008. Proposals for the collection of multifrequency acoustic data. *ICES J. Mar. Sci.* 65, 982–994. doi:10.1093/icesjms/fsn052
- Koutsikopoulos, C., Le Cann, B., 1996. Physical processes and hydrological structures related to the Bay of Biscay anchovy. *Sci. Mar.* 60, 9–19.
- Kupschus, S., Schratzberger, M., Righton, D., 2016. Practical implementation of ecosystem monitoring for the ecosystem approach to management. *J. Appl. Ecol.* 53, 1236–1247. doi:10.1111/1365-2664.12648
- Lankester, E.R., 1884. The scientific results of the exhibition. *Fish. Exhib. Lit.* 4, 405–45.
- Lasker, R. (Ed.), 1985. An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy (*Engraulis mordax*), U.S. Dep. Commer. ed, NOAA Tech. Rep. NMFS.

- Lassalle, G., Gascuel, D., Le Loc'h, F., Lobry, J., Pierce, G.J., Ridoux, V., Santos, M.B., Spitz, J., Niquil, N., 2012. An ecosystem approach for the assessment of fisheries impacts on marine top predators: the Bay of Biscay case study. *ICES J. Mar. Sci.* 69, 925–938. doi:10.1093/icesjms/fss049
- Lassalle, G., Lobry, J., Le Loc'h, F., Bustamante, P., Certain, G., Delmas, D., Dupuy, C., Hily, C., Labry, C., Le Pape, O., Marquis, E., Petitgas, P., Pusineri, C., Ridoux, V., Spitz, J., Niquil, N., 2011. Lower trophic levels and detrital biomass control the Bay of Biscay continental shelf food web: Implications for ecosystem management. *Prog. Oceanogr.* 91, 561–575. doi:10.1016/j.pocean.2011.09.002
- Lavery, A.C., Wiebe, P.H., Stanton, T.K., Lawson, G.L., Benfield, M.C., Copley, N., 2007. Determining dominant scatterers of sound in mixed zooplankton populations. *J. Acoust. Soc. Am.* 122, 3304–3326.
- Lazure, P., Garnier, V., Dumas, F., Herry, C., Chifflet, M., 2009. Development of a hydrodynamic model of the Bay of Biscay. Validation of hydrology. *Cont. Shelf Res.* 29, 985–997. doi:10.1016/j.csr.2008.12.017
- Lehodey, P., Conchon, A., Senina, I., Domokos, R., Calmettes, B., Jouanno, J., Hernandez, O., Kloser, R., 2015. Optimization of a micronekton model with acoustic data. *ICES J. Mar. Sci.* 72, 1399–1412. doi:10.1093/icesjms/fsu233
- Lehuta, S., Mahevas, S., Petitgas, P., Pelletier, D., 2010. Combining sensitivity and uncertainty analysis to evaluate the impact of management measures with ISIS-Fish: marine protected areas for the Bay of Biscay anchovy (*Engraulis encrasicolus*) fishery. *ICES J. Mar. Sci.* 67, 1063–1075. doi:10.1093/icesjms/fsq002
- Lehuta, S., Petitgas, P., Mahévas, S., Huret, M., Vermard, Y., Uriarte, A., Record, N.R., 2013. Selection and validation of a complex fishery model using an uncertainty hierarchy. *Fish. Res.* 143, 57–66. doi:10.1016/j.fishres.2013.01.008
- Lett, C., Ayata, S.-D., Huret, M., Irisson, J.-O., 2010. Biophysical modelling to investigate the effects of climate change on marine population dispersal and connectivity. *Prog. Oceanogr.* 87, 106–113. doi:10.1016/j.pocean.2010.09.005
- Levin, S., 1992. The problem of pattern and scale in ecology. *Ecology* 73, 1943–1967.
- Mahé, J.-C., 1987. EVHOE EVALUATION HALIEUTIQUE DE L'OUEST DE L'EUROPE. <http://dx.doi.org/10.18142/8>
- Mair, A., Fernandes, P., Lebourges-Dhaussy, A., Brierley, A., 2005. An investigation into the zooplankton composition of a prominent 38-kHz scattering layer in the North Sea. *J. Plankton Res* 27, 623–633.
- Marquis, E., Niquil, N., Delmas, D., Hartmann, H.J., Bonnet, D., Carlotti, F., Herbland, A., Labry, C., Sautour, B., Laborde, P., Vézina, A., Dupuy, C., 2007. Inverse analysis of the planktonic food web dynamics related to phytoplankton bloom development on the continental shelf of the Bay of Biscay, French coast. *Estuar. Coast. Shelf Sci.* 73, 223–235. doi:10.1016/j.ecss.2007.01.003
- Marquis, E., Niquil, N., Vezina, A.F., Petitgas, P., Dupuy, C., 2011. Influence of planktonic foodweb structure on a system's capacity to support pelagic production: an inverse analysis approach. *ICES J. Mar. Sci.* 68, 803–812. doi:10.1093/icesjms/fsr027
- Massé, J., Retière, N., 1995. Effect of number of transects and identification hauls on acoustic biomass estimates under mixed species conditions. *Aquat. Living Resour.* 8, 195–199. doi:10.1051/alr:1995017
- Massé, J., Sanchez, F., Delaunay, D., Robert, J.M., Petitgas, P., 2016. A partnership between science and industry for a monitoring of anchovy and sardine in the Bay of Biscay: When fishermen are actors of science. *Fish. Res.* 178, 26–38. doi:10.1016/j.fishres.2015.11.018
- Massé, J., Uriarte, A., Angelico, M.M., Carrera, P., In press. Pelagic survey series for sardine and anchovy in ICES subareas 8 and 9 (WGACEGG) – Towards an ecosystem approach. ICES

Coop. Res. Rep. 332.

- OSPAR Commission, 2000. Quality Status Report 2000: Region IV e Bay of Biscay and Iberian (OSPAR Commission report).
- Pecquerie, L., Petitgas, P., Kooijman, S.A.L.M., 2009. Modeling fish growth and reproduction in the context of the Dynamic Energy Budget theory to predict environmental impact on anchovy spawning duration. *J. Sea Res.* 62, 93–105. doi:10.1016/j.seares.2009.06.002
- Petersen, W., 2014. FerryBox systems: State-of-the-art in Europe and future development. *J. Mar. Syst.* 140, 4–12. doi:10.1016/j.jmarsys.2014.07.003
- Petitgas, P., 2003. A method for the identification and characterization of clusters of schools along the transect lines of fisheries-acoustic surveys. *ICES J Mar Sci* 60, 872–884.
- Petitgas, P., Alheit, J., Peck, M., Raab, K., Irigoien, X., Huret, M., van der Kooij, J., Pohlmann, T., Wagner, C., Zarraonaindia, I., Dickey-Collas, M., 2012. Anchovy population expansion in the North Sea. *Mar. Ecol. Prog. Ser.* 444, 1–13. doi:10.3354/meps09451
- Petitgas, P., Doray, M., Huret, M., Massé, J., Woillez, M., 2014. Modelling the variability in fish spatial distributions over time with empirical orthogonal functions: anchovy in the Bay of Biscay. *ICES J. Mar. Sci.* 71, 2379–2389. doi:10.1093/icesjms/fsu111
- Petitgas, P., Doray, M., Massé, J., Grellier, P., 2011. Spatially explicit estimation of fish length histograms, with application to anchovy habitats in the Bay of Biscay. *ICES J. Mar. Sci. J. Cons.* doi:10.1093/icesjms/fsr139
- Petitgas, P., Goarant, A., Massé, J., Bourriau, P., 2009. Combining acoustic and CUFES data for the quality control of fish-stock survey estimates. *ICES J Mar Sci* 66, 1384–1390.
- Petitgas, Pierre, Magri, S., Lazure, P., 2006. One-dimensional biophysical modelling of fish egg vertical distributions in shelf seas. *Fish. Oceanogr.* 15, 413–428. doi:10.1111/j.1365-2419.2006.00409.x
- Petitgas, P., Massé, J., Beillois, P., Lebarbier, E., Le Cann, A., 2003. Sampling variance of species identification in fisheries-acoustic surveys based on automated procedures associating acoustic images and trawl hauls. *ICES J Mar Sci* 60, 437–445.
- Petitgas, P., Massé, J., Bourriau, P., Beillois, P., Delmas, D., Herbland, A., Koueta, N., Froidefond, J., Santos, M., 2006. Hydro-plankton characteristics and their relationship with sardine and anchovy distributions on the French shelf of the Bay of Biscay. *Sci Mar* 70S1, 161–172.
- Picheral, M., Colin, S., Irisson, J.-O., 2016. EcoTaxa, a tool for the taxonomic classification of images.
- Planque, B., Lazure, P., Jegou, A., 2006. Typology of hydrological structures modelled and observed over the Bay of Biscay shelf. *Sci. Mar.* 70S1, 43–50.
- Politikos, D.V., Huret, M., Petitgas, P., 2015. A coupled movement and bioenergetics model to explore the spawning migration of anchovy in the Bay of Biscay. *Ecol. Model.* 313, 212–222. doi:10.1016/j.ecolmodel.2015.06.036
- Poulard, J., Blanchard, F., 2005. The impact of climate change on the fish community structure of the eastern continental shelf of the Bay of Biscay. *ICES J. Mar. Sci.* 62, 1436–1443. doi:10.1016/j.icesjms.2005.04.017
- Renfree, J.S., Demer, D.A., 2016. Optimizing transmit interval and logging range while avoiding aliased seabed echoes. *ICES J. Mar. Sci. J. Cons.* 73, 1955–1964. doi:10.1093/icesjms/fsw055
- Reverdin, G., Marié, L., Lazure, P., d'Ovidio, F., Boutin, J., Testor, P., Martin, N., Lourenco, A., Gaillard, F., Lavin, A., Rodriguez, C., Somavilla, R., Mader, J., Rubio, A., Blouch, P., Rolland, J., Bozec, Y., Charria, G., Batifoulier, F., Dumas, F., Louazel, S., Chanut, J., 2013. Freshwater from the Bay of Biscay shelves in 2009. *J. Mar. Syst.* 109–110, S134–S143. doi:10.1016/j.jmarsys.2011.09.017
- Richardson, A., 2008. In hot water: zooplankton and climate change. *ICES J Mar Sci* 65, 279–295.
- Shephard, S., van Hal, R., de Boois, I., Birchenough, S.N.R., Foden, J., O'Connor, J., Geelhoed,

- S.C.V., Van Hoey, G., Marco-Rius, F., Reid, D.G., Schaber, M., 2015. Making progress towards integration of existing sampling activities to establish Joint Monitoring Programmes in support of the MSFD. *Mar. Policy* 59, 105–111. doi:10.1016/j.marpol.2015.06.004
- Simmonds, E.J., MacLennan, D.N., 2005. *Fisheries Acoustics. Theory and Practice*. Blackwell publishing, Oxford, UK.
- Spitz, J., Jouma'a, J., 2013. Variability in energy density of forage fishes from the Bay of Biscay (north-east Atlantic Ocean): reliability of functional grouping based on prey quality: variability in energy density of forage fishes. *J. Fish Biol.* 82, 2147–2152. doi:10.1111/jfb.12142
- Spitz, J., Mourocq, E., Schoen, V., Ridoux, V., 2010. Proximate composition and energy content of forage species from the Bay of Biscay: high- or low-quality food? *ICES J. Mar. Sci.* 67, 909–915.
- Stanton, T.K., Chu, D.Z., Jech, J.M., 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 J Mar Sci* 67, 365–378.
- Stanton, T.K., Sellers, C.J., Jech, J.M., 2012. Resonance classification of mixed assemblages of fish with swimbladders using a modified commercial broadband acoustic echosounder at 1–6 kHz. *Can. J. Fish. Aquat. Sci.* 69, 854–868. doi:10.1139/f2012-013
- Trenkel, V., Mazauric, V., Berger, L., 2008. The new fisheries multibeam echosounder ME70: description and expected contribution to fisheries research. *ICES J Mar Sci* 65, 645–655.
- Trenkel, V.M., Berger, L., Bourguignon, S., Doray, M., Fablet, R., Massé, J., Mazauric, V., Poncelet, C., Quemener, G., Scalabrin, C., Villalobos, H., 2009. Overview of recent progress in fisheries acoustics made by Ifremer with examples from the Bay of Biscay. *Aquat Living Res* 22.
- Vandromme, P., Nogueira, E., Huret, M., Lopez-Urrutia, Á., González-Nuevo González, G., Sourisseau, M., Petitgas, P., 2014. Springtime zooplankton size structure over the continental shelf of the Bay of Biscay. *Ocean Sci* 10, 821–835. doi:10.5194/os-10-821-2014
- Vérin, Y., 1992. IBTS INTERNATIONAL BOTTOM TRAWL SURVEY (IBTS). <http://dx.doi.org/10.18142/17>
- Weill, A., Scalabrin, C., Diner, N., 1993. MOVIES-B: An acoustic detection description software. Application to shoal species' classification. *Aquat Living Resour* 6, 255–267.
- Wuillez, M., Poulard, J.C., Rivoirard, J., Petitgas, P., 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 J Mar Sci* 64, 537–550.
- Zwolinski, J.P., Demer, D.A., Cutter Jr., G.R., Stierhoff, K., Macewicz, B.J., 2014. Building on Fisheries Acoustics for Marine Ecosystem Surveys. *Oceanography* 27, 68–79.

Annex 1: Acronym Glossary

- ATLANTOS: “Atlantic Ocean Observing System” European Union’s Horizon 2020 research and innovation programme project (2015-2019, Project no. 633211)
- CDOM: coloured dissolved organic matter concentration
- 635 CLUSTER: “Aggregation patterns of pelagic commercial fish under different stock situations and their impact on exploitation and assessment” European project (1996-1998, FAIR CT96-1799).
- CTD: Conductivity-Temperature-Depth sonde
- CUFES: Continuous Underway Fish Egg Sampler
- DCF: European Common Fisheries Policy Data Collection Framework
- 640 DCM: Deep Chlorophyll Maximum
- DEPM: Daily Egg Production Method
- EAF: Ecosystem Approach to Fisheries
- EVHOE: “Evaluation Halieutique de l'Ouest de L'Europe” bottom trawl survey
- FACTS: “Forage Fish Interactions” European Commission’s Seventh Framework Programme small project
- 645 (2010-2012, Project no. 244966)
- GES: Good Ecological Status
- IBTS: International Bottom Trawl Survey
- ICES: International Council for the Exploration of the Sea
- JUVENA: acoustic surveying of anchovy Juveniles in the Bay of Biscay
- 650 LOPC: Laser Optical Particle Counter
- MSFD: European Marine Strategy Framework Directive
- NM: nautical mile (1852 m)
- PELACUS: Multidisciplinary acoustic-trawl survey

- 655 PELAGO: Spring Acoustics Survey in Atlantic Iberian waters of ICES area 9a (Cabo Trafalgar to River Minho)
- PELASSES, “Direct abundance estimation and distribution of pelagic fish species in North East Atlantic waters” European project. (2000-2002, DGXIV n° 99.010)
- PELGAS: “Pélagiques Gascogne” integrated survey
- PELTIC: Pelagic ecosystem survey in western Channel and eastern Celtic Sea
- 660 RECLAIM: “REsolving CLimAtic IMpacts on fish stocks” European Commission’s Sixth Framework Programme project (2006-2010, Project no. 044133 (SSP8))
- REPRODUCE: “Understanding REcruitment PROcesses Using Coupled biophysical models of the pelagic Ecosystem” European Commission’s Seventh Framework Programme MariFish EraNet’s project (2010-2012)
- 665 SEAMAN: “Spatially resolved Ecosystem models and their Application to Marine MANagement” European Commission’s Seventh Framework Programme SeaSera EraNet’s project (2013-2015)
- UNCOVER: “Understanding the Mechanisms of Stock Recovery” European Commission’s Sixth Framework Programme project (2006-2010, Project no. 022717 (SSP 8))
- 670 WGACEGG: ICES Working Group on Acoustic and Egg Surveys for Sardine and Anchovy in ICES areas VII, VIII and IX
- WGHANSA: ICES Working Group on Southern Horse Mackerel, Anchovy, and Sardine
- WP2: UNESCO Working Party 2 mesozooplankton netSIMFAMI: “Species Identification Methods From Acoustic Multi-frequency Information” European Commission’s Fifth Framework Programme project (2001-2005, Q5RS-2001-02054)

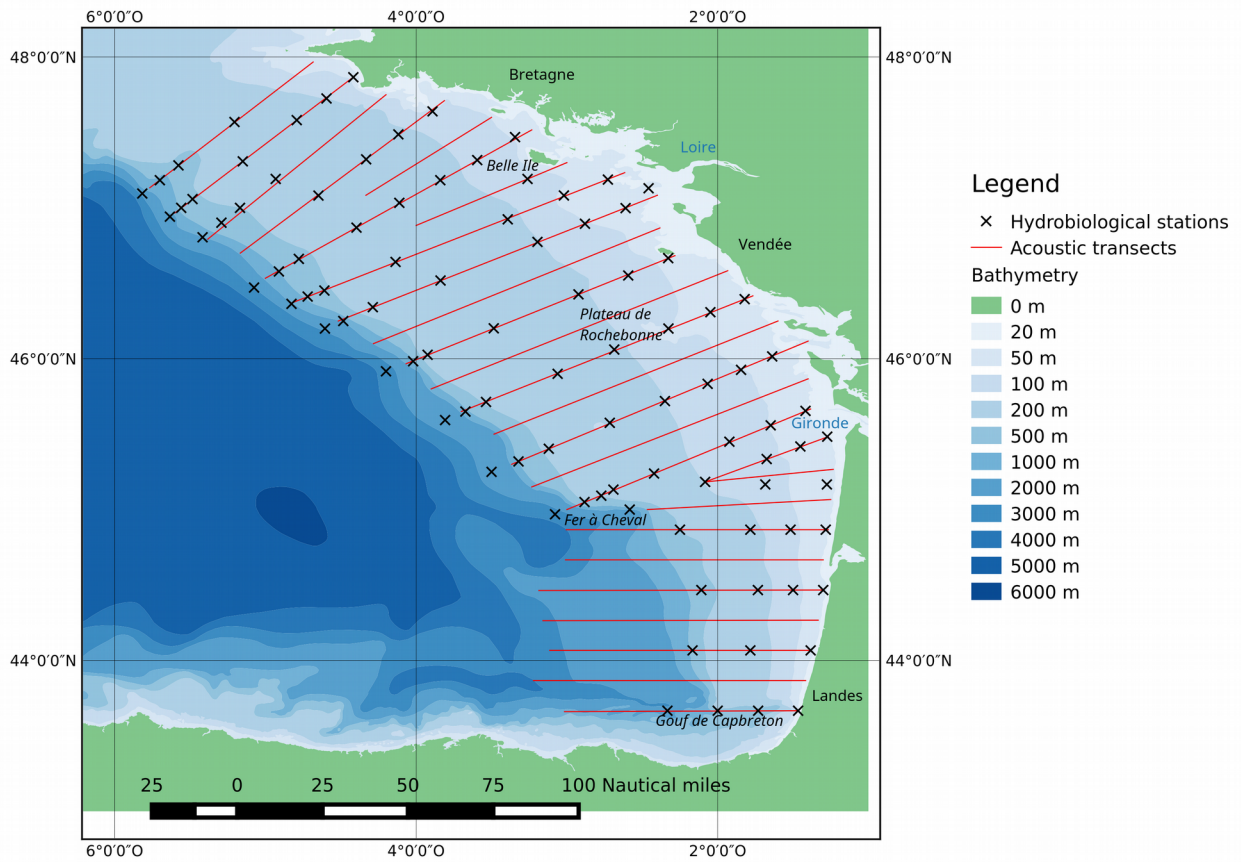
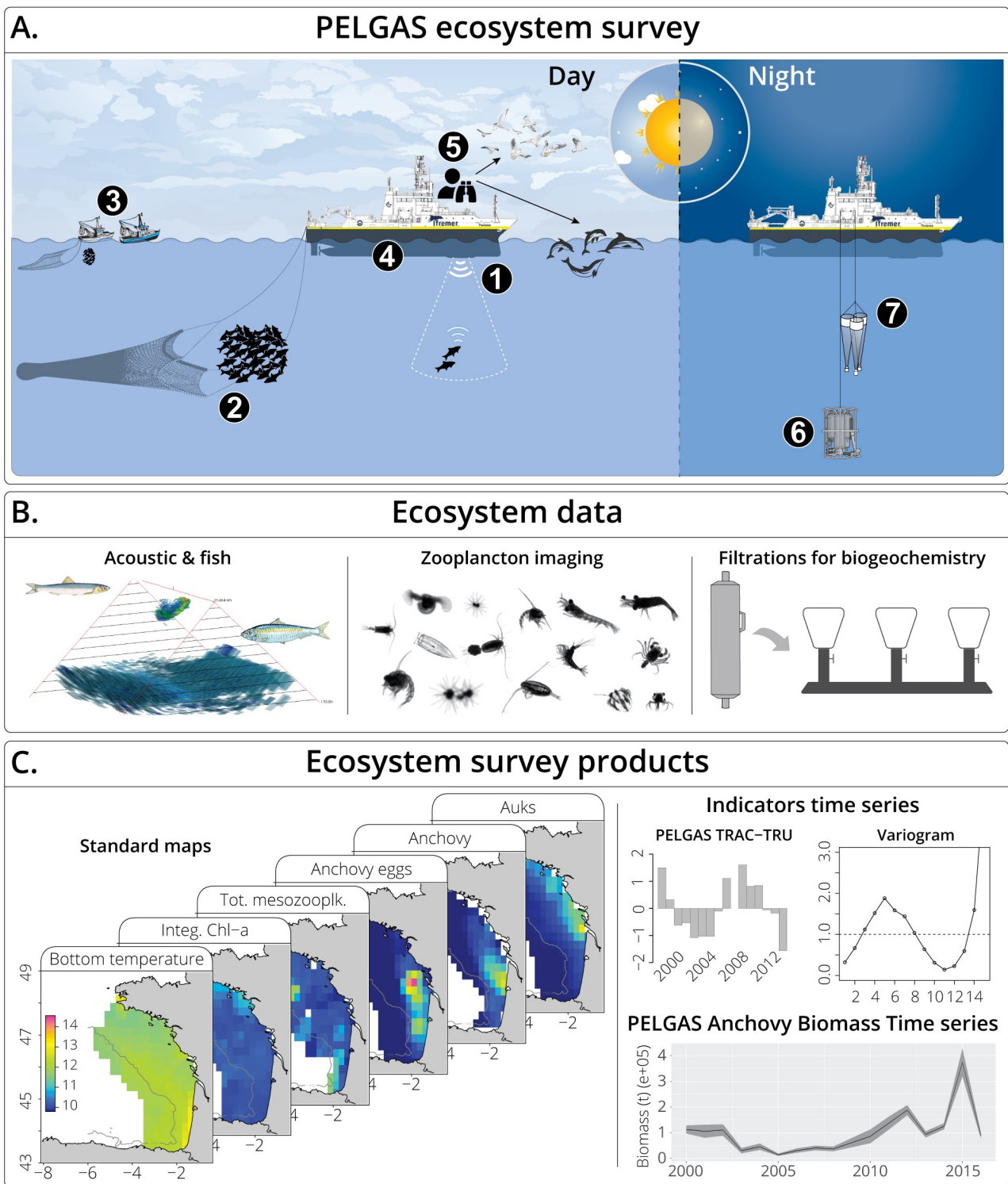


Figure 1. PELGAS survey sampling scheme. Coastal regions names are in black, main rivers names in blue, and main bathymetric features names in black italic.



680 Figure 2. The PELGAS survey model. A. Ecosystem data collection in spring in the Bay of Biscay. During daytime, along line transects: 1. fisheries acoustics, 2. R/V *Thalassa* midwater trawling, 3. consort commercial pair trawlers fishing, 4. hull-mounted thermosalinometer, 5. cetaceans and seabird sightings. During night-time, at fixed stations: 6. sonde-based hydrobiological sampling, 7. meso-zooplankton nets. B. Onboard ecosystem data pre-processing: acoustic data scrutinising, midwater trawl catch sorting, biological

685 parameters recording, zoo and ichthyoplankton imaging, seawater filtrations for biogeochemistry. C. Ecosystem products: standard raster maps of parameters in all pelagic ecosystem compartments, time series of indicators of the state of Biscay pelagic ecosystem, including commercial fish stocks.

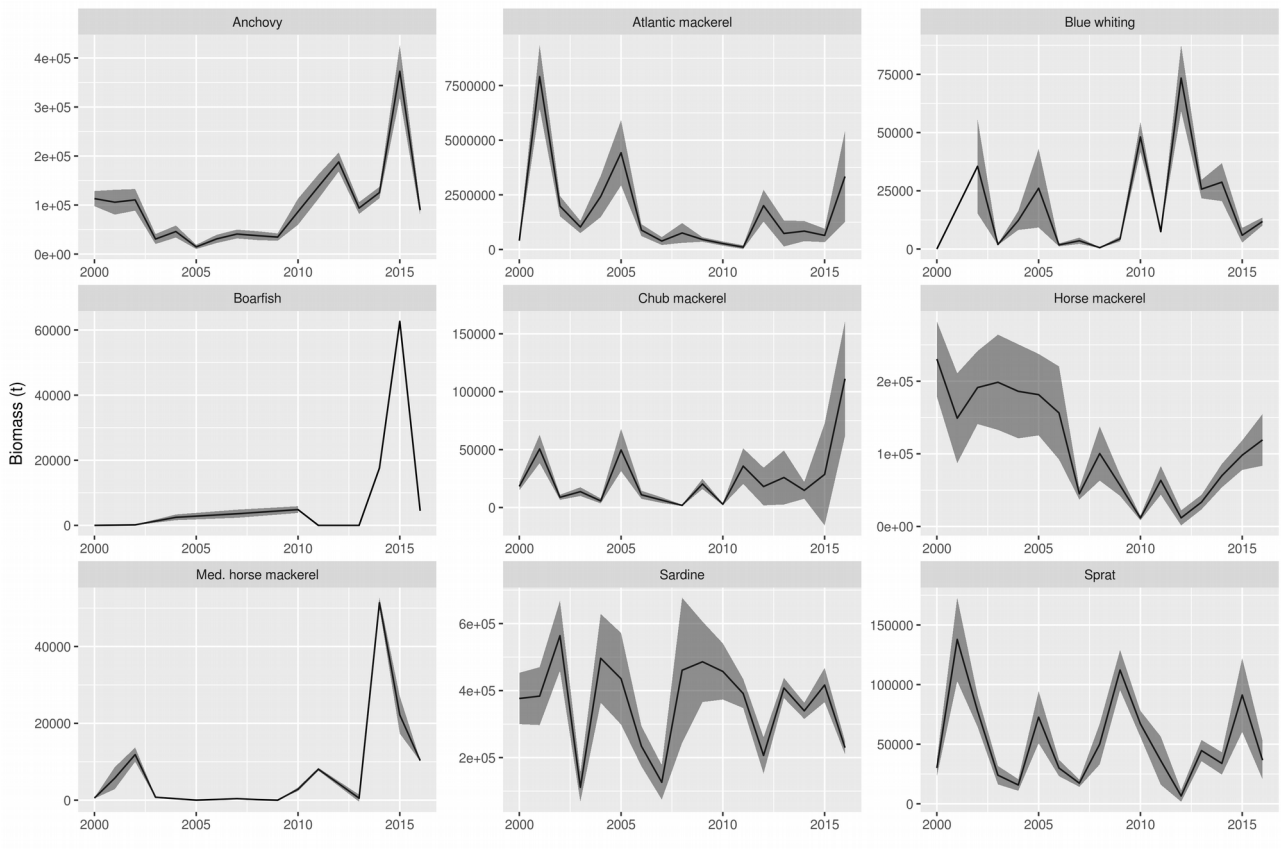


Figure 3. Small pelagic biomass estimates series (in metric tons) derived from the PELGAS survey acoustic and trawl data: boarfish, *Capros aper*; Mediterranean horse mackerel, *Trachurus mediterraneus*; blue whiting, *Micromesistius poutassou*; anchovy, *Engraulis encrasicolus*; sardine, *Sardina pilchardus*; chub mackerel, *Scomber colias*; Atlantic mackerel, *Scomber scombrus*; sprat, *Sprattus sprattus*; horse mackerel, *Trachurus trachurus*.

Table

695

Table 1. Potential indicators of the state of the Bay of Biscay pelagic ecosystem derived from the PELGAsurvey. Mesozooplankton and small pelagic fish indicators can be provided for all species, or per species and/or size. Cetaceans and seabirds indicators can be provided for all species, or per species or group of species. Distributional pattern indicators are computed based on Woillez et al. (2007).

Descriptor	Attribute	Criteria	Indicators	
Biodiversity	Species: zooplankton (>20µm, 2006-2016), small pelagic fish (adults and eggs, 2000-2016), cetaceans (adults, 2003-2016), seabirds (adults, 2003-2016).	Population size	Acoustic total biomass&abundance estimates, along with estimation error	
		Population condition	Acoustic biomass&abundance estimates per size/age	
		Species distribution	Distributional range	Surface area
				Centre of gravity
			Distributional pattern (survey scale)	Spatial patches
				Inertia
				Isotropy
				Positive area
				Spreading area
				Equivalent area
	Community condition	Habitats	Gini index	
			Coefficient of variation of strictly positive densities	
			Microstructure	
			Mean biomass	
Community (small pelagic fish 2000-2016, cetaceans and seabirds 2003-2016)	Habitats	Habitat condition		
		Percentage of total area occupied		
Commercial fish	Reproductive capacity	Acoustic Spawning Stock Biomass (SSB) estimate		
	Age and size distribution	95% percentile of the population length distribution Proportion of fish larger than L50		
Marine litter in the marine environment	Amount, composition and source of litter floating at sea, in the water column and on the sea floor		Floating litter	