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Effect of environmental parameters on acoustic characterisation of pelagic biocenoses in ultra-shallow (5-30 m) coastal areas

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Introduction

The European Marine Strategy Framework Directive (MSFD) requires the achievement of good ecological status of the marine environment (Ministère de l'Écologie, du Développement durable et de l'Énergie, 2013) for all members of European Union. This directive concerns all the component of the marine environment, including fish. Up to now, fish are monitored mainly in offshore waters through acoustic programs such as PELGAS in Bay of Biscay (Doray et al., 2018) or PELMED (Bourdeix, 2018) in the Mediterranean. However, shallow and ultra-shallow coastal waters (< 30 m) are not fully covered because large conventional research vessel size and acoustic frequencies (38 Hz) usually used are not suited to insonify these shallow areas. Therefore, there is a lack of information from shallow waters, which is not consistent with MSFD.

Shallow waters are recognized to have an important role in ecosystem functioning, especially for juvenile fishes because of their role of nurseries (e.g. Blaber et al., 1989; Gunter, 1967; Lenanton, 1982; Nagelkerken et al., 2000) even if they are highly impacted by anthropic activities (e.g. fisheries, coastal urbanisation, pollutions). For all these reasons, it is important to develop methodologies to understand shallow water areas and monitor their biocenoses. The ACaPELA (ACoustic PELAGic) project (Thiriet et al., 2017b) takes place within this context and aims to better understand and monitor pelagic fish in coastal shallow water ecosystems (Champagnat et al., 2017; Thiriet et al., 2017a).

Fisheries acoustics is a non-intrusive tool, which allows increasing knowledge on marine systems (Brehmer, 2006; Simmonds and MacLennan, 2005), long-term monitoring of pelagic populations (Doray et al., 2018) and covering a large area with a high resolution. Fisheries acoustic is widely used to estimate stocks of commercial fishes (Misund, 1997). In this study, we adapt fisheries acoustics materials to use it on small vessels and be able to survey fish populations on shallow and ultra-shallow waters.

This survey is the first one of ACaPELA project whose main purpose was to validate the possibility to work on shallow coastal areas and assess the efficiency of the method to study the effect of environmental parameters on the pelagic fish communities. Fish shoals are analysed using acoustic, morphologic and spatial descriptors. To experience the efficiency of descriptors to discriminate ecosystems, a comparative analysis is conducted in three contrasted areas, which has been characterized using CTD stations.

Material and methods

Fisheries acoustic survey was carried out from Brest harbour in December 2019 and cover 53 nautical miles (nmi). The survey focus on shallow parts (5-30 m depth) in three areas: the Bay of Brest, the Iroise Sea and a turbulent transition area (Figure 1). Physico-chemical water profiles (temperature, salinity, oxygen) was recorded by a CTD (Conductivity Temperature Depth, model SBE19+V2) to compare water column characteristics. No vertical profiles have been realised in the turbulence area, due to high current and waves.

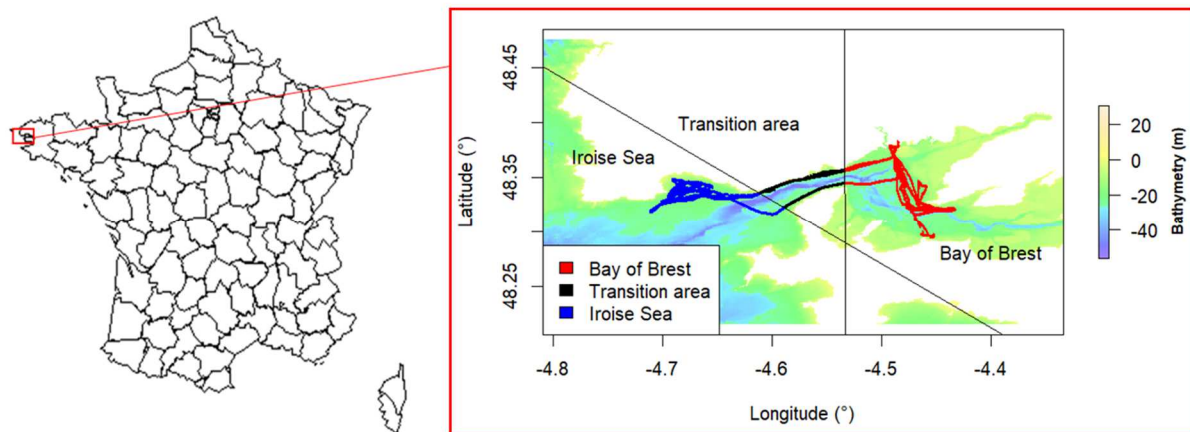


Figure 1. Study area and survey design. In red, data from the bay of Brest; in black, data from turbulent area; in blue, data from Iroise sea.

The vessel was equipped of an EK80 echosounder with three frequencies (70, 120 and 200 kHz). Transducers were set in a frame to beam vertically, as close as possible to maximize sampling volume overlap (Figure 2). Acoustic material was calibrated following constructor recommendations (Simrad, 2018) using a 38.1 mm tungstene calibration sphere (Demer et al., 2015). Acoustic heads were immersed at 1.25m depth and installed on the vessel “Albert Lucas”, from the “flotte océanographique française” (“Flotte océanographique française,” 2021) at Brest, France.

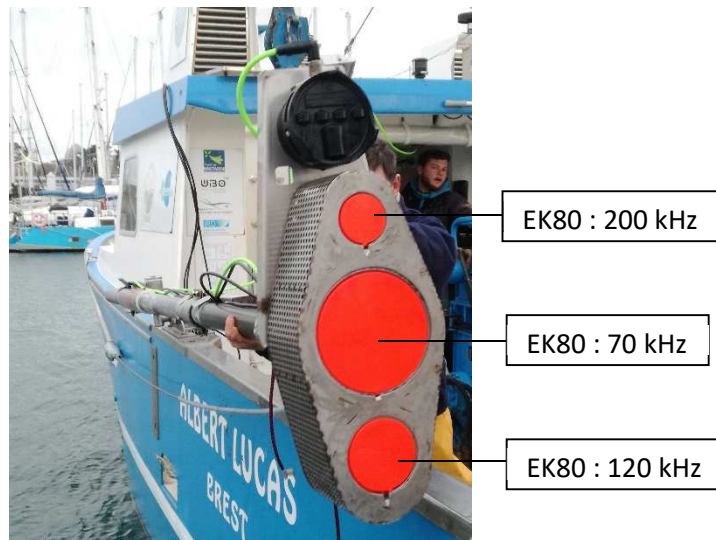


Figure 2. Installation of EK80 heads on the vessel "Albert Lucas". The three acoustic heads are set in a unique structure, which is adapted to small vessel and shallow waters.

Acoustic data have been cleaned and treated using Matecho (Perrot *et al.*, 2018) software, based on Movies 3D algorithm (Trenkel *et al.*, 2009) to obtain echo-integrated data and shoal information. Echo-integration and shoal extraction methodologies were used to produce morphological, spatial and acoustic descriptors of fish shoals and other components of the biocenoses within the water column. Descriptors are (i) the mean S_v to present the acoustic density in dB; (ii) the shoal length in m, (iii) the shoal width in m, (iv) the shoal surface in m^2 and (v) the shoal volume in m^3 to describe the shoal shape; (vi) altitude of the shoal (in m) *i.e.* the distance between bottom and shoal and (vii) shoal depth (in m) to localize the shoal in the water column.

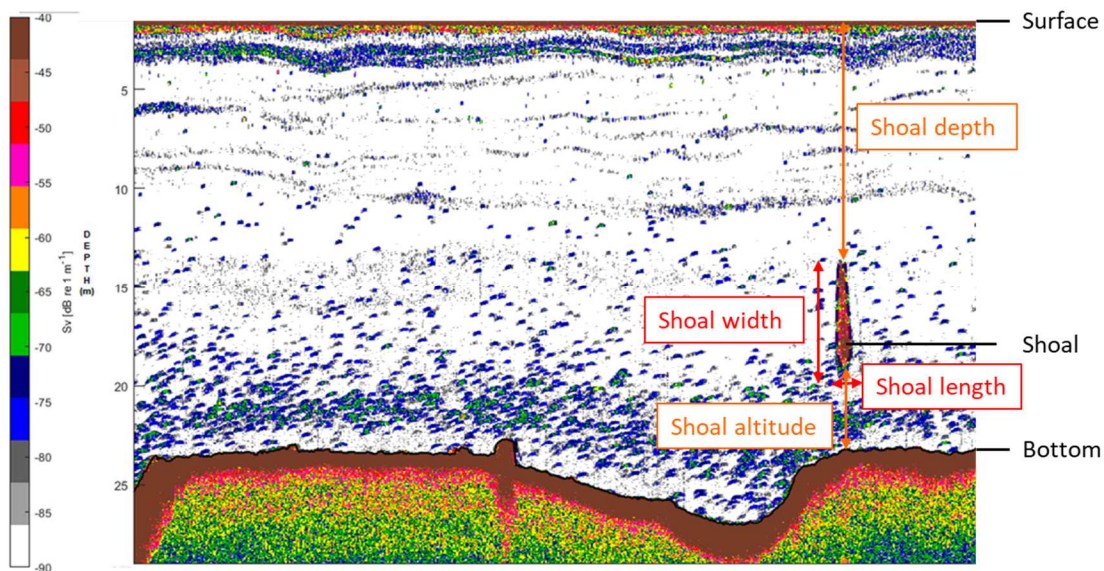


Figure 3. Echogram from EK80 at 120 kHz. The extracted shoal is delimited by a dotted line. The coloured scale represents the S_v value (in dB). Some descriptors are presented on this echogram: shoal length (in m) and shoal width (in m) in red and shoal depth (in m) and shoal altitude (in m) in orange.

Descriptors from shoal extractions were analysed and applied sequentially to the three frequencies (70, 120, 200 kHz). We only work on shoals, which have been detected by all frequencies. Therefore, for each shoal, descriptors are calculated for all frequencies. In order to select only shoals, we also

excluded shoals with an estimated volume under 1 m³. All selected shoals have been manually checked to avoid surface bubbles or other non-fish detections. Analysis was conducted under R software (R Core Team, 2019), using adapted statistical tests (Student tests) and graphical visualisation.

The differential answers between 70, 120 and 200 kHz could also be an important indicator of the species group (Blanluet et al., 2019). So, two descriptors have been added, with the S_v difference between (i) 200 and 120 kHz (ii) 70 and 120 kHz. If these differences change over areas, it could imply different species. As frequency 120 kHz is largely used for stock estimation and other scientific survey, we present here results only for this frequency.

Results

Vertical profiles show differences in water column structuration between the Bay of Brest and the Iroise Sea (Figure 4), which is logical taking into account their respective geographical specificities. The bay of Brest presents an important water column stratification with a high heterogeneity of the temperature, dissolved oxygen and salinity between surface and bottom and between the different CTD sites. However, the Iroise presents a water column completely homogeneous as seen for all physico-chemical parameters, probably due to current and waves.

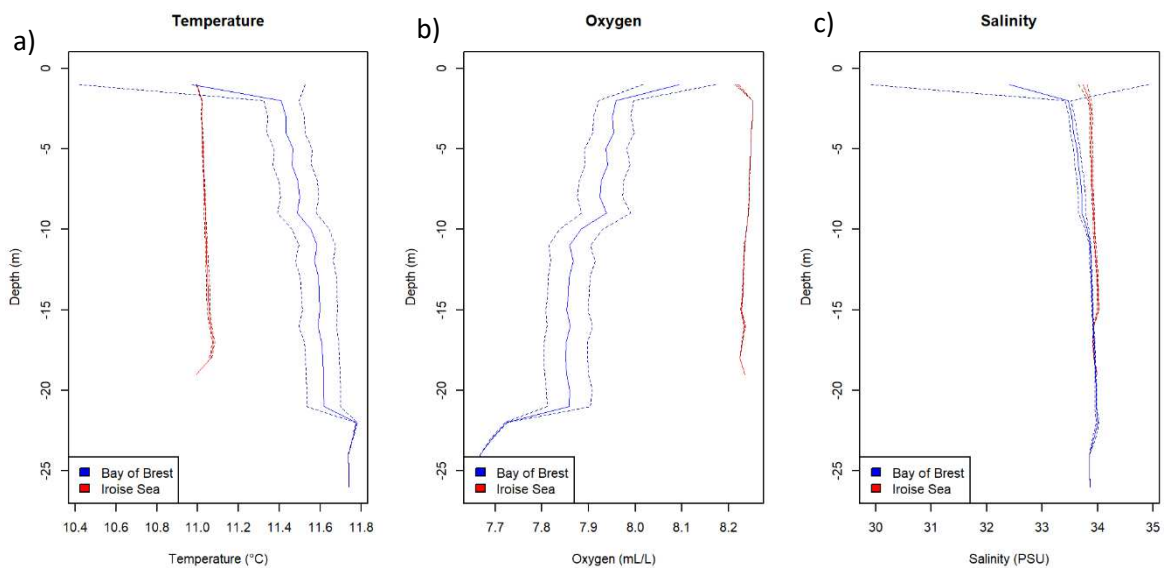


Figure 4. Comparison of mean profiles (plain line) and their standard errors (dotted line) from CTD station in bay of Brest (blue) and Iroise sea (red) for (a) Temperature ; (b) Oxygen ; (c) Salinity.

Descriptors of each frequency have been analysed to compare the three study areas (Table 1). Only four descriptors have been presented above, a morphological one (volume of fish shoals, **Error! Reference source not found.a**), a spatial one (altitude of fish shoals, Figure 5b), an acoustic one (mean S_v , Figure 5c) and a difference between two frequencies (200 and 120 kHz, Figure 5d).

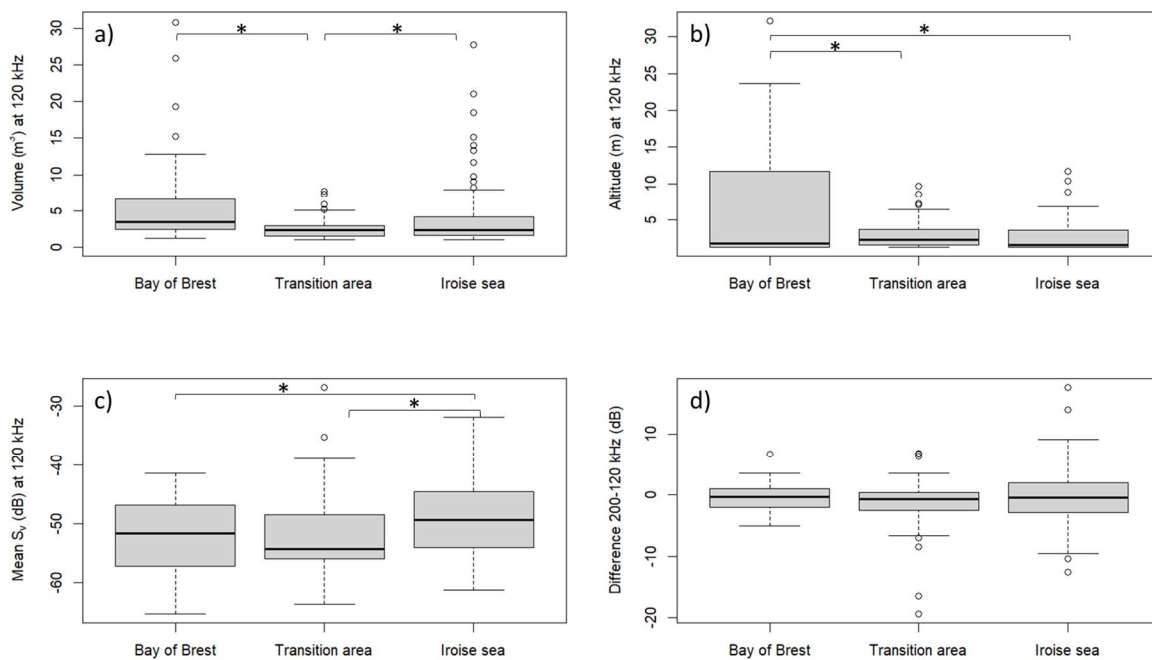


Figure 5. Boxplots of shoals descriptors at 120 kHz in the three study areas: Bay of Brest, transition area and Iroise sea (a) Volume of shoals (m³) (b) Altitude of shoals (m) (c) Mean S_v of shoal (d) Difference between mean S_v of two frequencies, 200 and 120 kHz. “*” indicates a significant difference.

The mean S_v significantly differs between the Iroise Sea and the bay of Brest as well as the transition area. The shoal volumes was similar between the Bay of Brest and the Iroise Sea, but significantly differs in the transition area.

Analyse of morphological descriptors presents a difference of shoal size and shape depending of the localisation. Shoals are smaller in transition area (smaller volume, smaller width). Spatial descriptors highlight a high variability (in altitude and depth) in the Bay of Brest whereas shoal are located deeper in Iroise Sea than other area. The acoustic descriptor shows that smallest values are in transition area and the highest in the Iroise Sea. Difference between frequencies are not significantly different, whatever frequencies and areas.

Results are similar for all frequencies, with some minor differences, probably due to different shoal contouring, inherent in each frequency.

Table 1. Summary of all statistical tests comparing the three study areas: Bay of Brest, transition area and Iroise Sea for all shoal descriptors at 70, 120 and 200 kHz. “ns” means non-significant and “*” represents a p-value under 0.05.

	Bay of Brest vs. transition area	Transition area vs. Iroise Sea	Bay of Brest vs. Iroise Sea
Length, 70 kHz	ns	*	*
Length, 120 kHz	ns	ns	*
Length, 200 kHz	ns	ns	ns
Width, 70 kHz	*	*	*

Width, 120 kHz	*	*	*
Width, 200 kHz	*	*	*
Surface, 70 kHz	*	*	ns
Surface, 120 kHz	*	*	ns
Surface, 200 kHz	*	*	ns
Volume, 70 kHz	*	ns	ns
Volume, 120 kHz	*	*	ns
Volume, 200 kHz	ns	ns	ns
Altitude, 70 kHz	*	ns	*
Altitude, 120 kHz	*	ns	*
Altitude, 200 kHz	*	ns	*
Depth, 70 kHz	ns	*	*
Depth, 120 kHz	ns	*	*
Depth, 200 kHz	ns	*	*
S _v , 70 kHz	*	*	*
S _v , 120 kHz	ns	*	*
S _v , 200 kHz	ns	*	*
Difference 200-120 kHz	ns	ns	ns
Difference 70-120 kHz	ns	ns	ns

Discussion and conclusion

The three studied areas (Bay of Brest, turbulent area, Iroise Sea) present a high contrast, confirmed by CTD stations. CTD analyses highlighted a strong stratification in the Bay of Brest and a high heterogeneity between CTD sites while Iroise Sea is completely homogeneous, inside water column and between sites. Indeed, Iroise Sea is well influenced by Manche Channel cold water, with important currents, strong enough to homogenise the whole water column (Delmas, 1981). The bay of Brest is highly heterogeneous because of multiple influences. There is especially a strong influence of the two different estuaries, the Aulne and the Elorn (Pommepuy et al., 1979) which can be very active in winter due to high level of precipitations. The impact of different rivers can lead to different structures of water column, which explain the high heterogeneity of CTD stations from the Bay of Brest. Bay of Brest and Iroise Sea jointly influence the turbulent area. However, the geographic situation of this area, a narrow isthmus, involves strong currents mainly due to tides and waves. This particularity makes this area different from the others, even without CTD data.

Acoustic data enabled to show a similarity of frequencies answer between areas. Frequencies answer is commonly used to identify fish species or group of fishes (Ballón et al., 2011; Berger et al., 2018; D'Elia et al., 2014; Remond, 2015). Indeed, each specie or group of specie can respond differently

depending of frequencies. Therefore, composition of biocenoses of the three areas could be similar, which would be logical taking into account of the proximity of the areas (2.4 nmi between them). However, without any ground truth or biological data, we cannot confirm this hypothesis.

The other descriptors present significant differences between areas. We notice that shoals are smaller in transition area, even if S_v level is close to the Bay of Brest. As the transition area is highly subject to high currents and waves, this could disturb shoal formations. For some descriptors (*e.g.* mean S_v or altitude), the transition area is highly different of the two others, probably due to the specific current regime in the area. For some other descriptors (*e.g.* minimum depth or height), the transition area is intermediate between the Bay of Brest and the Iroise Sea. This is logical, in view of the spatial proximity and the probable links between areas. Therefore, the transition area has its own specificities, but is also linked to neighbouring areas.

We also notice a high variability of shoal positions in the Bay of Brest, even if bottom depths are similar to other areas. Fish are highly sensitive to their environmental parameters. Temperature is especially important with lethal threshold but also optimum and preferences (Coutant, 1977; Huey and Kingsolver, 1989). Fish also need a minimal oxygen concentration but the variability of oxygen concentration is less restrictive for fish (Miller et al., 2002). Salinity is known to highly impact biocenoses in estuary (*e.g.* Cyrus and Blaber, 1987; Marshall et al., 2016) but is less studied in ocean as it is more stable. These parameters, and especially temperature, can influence localisation and shape of shoals (Dempster, 2005). The variability of morphologic and spatial descriptors in the Bay of Brest could be linked with the high variability of functioning (*e.g.* currents, estuaries, coastal influences) and habitats offered by this protected bay as illustrated by CTD results.

Descriptors of shoals in Iroise Sea are more homogeneous, as its physico-chemical parameters. Some descriptors are different from the two other areas, as it is an open sea, with an influence of ocean. Some other descriptors are similar to the Bay of Brest, unlike transition area. We can suppose that currents are lower in Bay of Brest and Iroise Sea, allowing shoals to adopt similar shapes. The Iroise Sea is close to the coast, with a high influence of the Bay of Brest and its estuaries but the Iroise Sea is less protected and under influence of ocean.

The three study areas are linked, especially by their spatial proximity, although highly contrasted. The similarity of frequencies answers could be due to similar biocenoses but shoals present different spatial and morphologic characteristics, depending of specificities from each area. This study highlighted that during winter the Bay of Brest presented a broad heterogeneity of conditions, and a well-stratified water column, whereas sites from Iroise Sea and transition area were more homogeneous. Descriptors of fish shoals, echointegrated profiles and frequency response allowed discriminating the three areas and their respective biocenose. Results suggested that organisation of pelagic communities could be highly heterogeneous in shallow areas, even in winter with low water stratification and at similar depths. Moreover, some similar acoustic population could adopt different behaviour depending on their living area (Brehmer, 2006; Simmonds and MacLennan, 2005).

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