Did acoustic miss much spawning anchovy surface schools in the Bay of Biscay in spring 2019 ?

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WGACEGG2020 Working Document

1. Introduction

Investigating discrepancies observed in particular years between acoustic (Simmonds and MacLennan, 2005) and Daily Egg Production Method (DEPM) (Lasker, 1985) fish biomass estimates can reveal potential bias impacting one of the estimates. It is also a necessary step towards the development of a weighting factor assessing the coherence between survey estimates, to input in stock assessment models (Petitgas *et al.*, 2009; ICES, 2017).

Egg-based anchovy biomass indices derived in 2019 from DEPM data from BIOMAN survey (Massé *et al.*, 2018) and CUFES data collected during the PELGAS survey (Doray et al., 2018) were relatively larger than anchovy biomass estimate derived from acoustic and trawl data from PELGAS survey, whereas both surveys covered the same area at the same time in the Bay of Biscay (ICES, 2020; Figure 1).

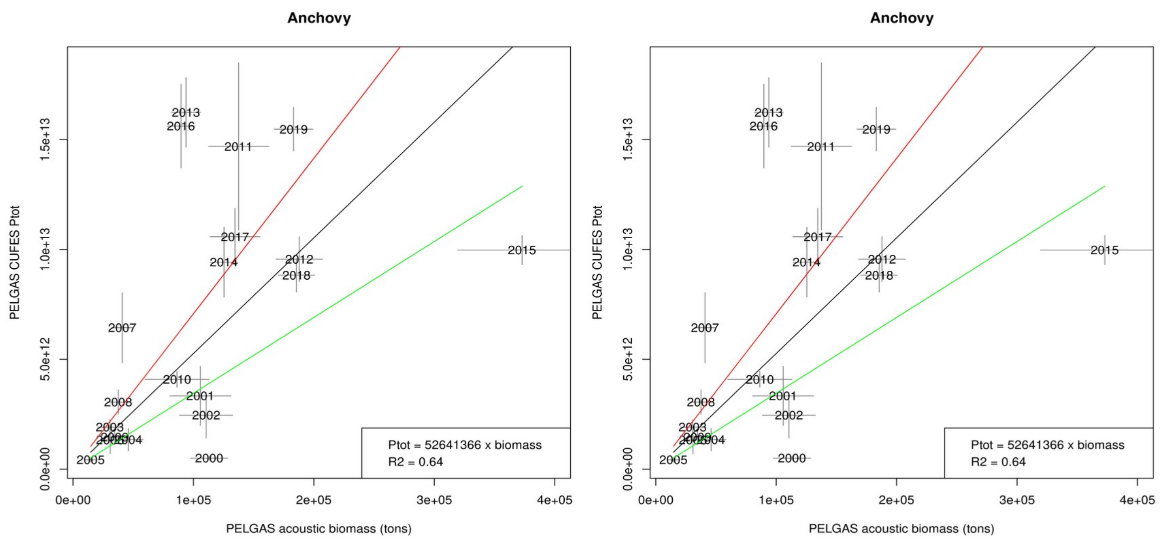

Figure 1. Anchovy acoustic biomass estimates from PELGAS survey vs. BIOMAN DEPM biomass estimate (left) and PELGAS CUFES egg total daily production (Ptot) estimate (right). Crosses: estimation errors. Black line: linear regression between acoustic and egg estimates, with 95% lower (green line) and higher (red line) confidence intervals.

Acoustic estimates can be biased low by the presence of the echosounder surface blind zone. This blind zone, together with vessel draught, prevents the recording of fish school echoes in the 0-10 m depth layer during the PELGAS survey. This may bias low acoustic biomass estimates if a significant amount of fish biomass is distributed near the sea surface.

This study aims at estimating the anchovy biomass that was missed in the echosounder surface blind zone during the PELGAS survey, in an attempt to explain the relative difference between acoustic and DEPM biomass estimates in springtime 2019 in the Bay of Biscay. Acoustic data collected by a side-looking echosounder are analysed in order to estimate the negative bias introduced in acoustic biomass estimates by the acoustic blind zone. Corrected anchovy acoustic biomass estimates and maps are compared to DEPM ones, in an attempt to reconcile egg and acoustic estimates. Remaining discrepancies are discussed in the light of acoustic and egg biomass estimation assumptions.

2. Material and methods

2.1. Mapping

Smoothed raster maps (grid maps, (Petitgas *et al.*, 2009) of anchovy acoustic biomass and CUFES egg counts have been produced at a 30 km resolution to compare acoustic and egg spatial fields, in both surface and near seabed depth layers. Acoustic and egg maps have been standardised (divided by their maximum values to scale them between 0 and 1). Standardised egg maps have been substracted from standardised acoustic maps to highlight local differences.

2.2. Horizontal acoustic data analysis

During the PELGAS2019 survey, acoustic data have been collected in the surface layer (0-15 m depth) using a Simrad EK80 echosounder operating at 200 kHz. Those horizontal acoustic data have been recorded over the same time and space range as 38kHz acoustic data collected with the downward looking echosounder used to calculate acoustic fish biomass estimates.

The horizontal echosounder was fitted with a 3° beam opening transducer mounted in the vessel moon pool and orientated perpendicularly to the vessel course on starboard. The transducer beam axis was tilted by a few degrees below the surface to avoid interferences with sea surface.

Acoustic data recorded with the horizontal and vertical echosounders were analysed using the methodology described in Doray *et al.*, (2010) to derive biomass estimates. Echograms were first scrutinised using the MOVIES3D software, in order to: i) echo-integrate acoustic data in 1 NM long Elementary Distance Sampling Units (EDSUs) and 10 m wide depth layers, and ii) separate fish from other echoes. To allow for comparison with acoustic data collected with the vertical echosounder, Fish Nautical Areal Scattering Coefficients (NASC) derived from the horizontal echosounder, $NASC_{horiz}$, were corrected for beam geometry, using the equation below:

$$NASC_{horiz\_layer} = NASC_{horiz} \times H_{layer} / R_{max} \qquad \text{Equation 1}$$

Where H_{layer} is the mean maximum depth of the layer insonifed by the horizontal echosounder, estimated as 15 m; R_{max} is the average echosounder maximum range, estimated as 280 m.

2.3. Surface fish acoustic biomass estimation

Acoustic densities values can be scaled to fish density of species *i* with the equation:

$$B_{acou-i} = Area \times NASC / ts_i \qquad \text{(Simmonds and MacLennan, 2005)} \qquad \text{Equation 2}$$

Where: *Area* (survey area) and *NASC* (areal fish acoustic density) are the observation terms, and ts_i is the species-specific Target Strength scaling factor used to convert acoustic into fish density in natural scale.

NASC values recorded with the vertical echosounder were converted to fish biomass using a TS to fish length established for dorsally insonified clupeiforms:

$$TSi = 20 \times \log10(L) -71.2 \qquad \text{(ICES, 1982)} \qquad \text{Equation 3}$$

As most fish caught in the surface layer in the anchovy distribution area in Southern Bay of Biscay during the PELGAS2019 survey were anchovies, one assumed that fish echoes recorded by the horizontal echosounder in this area had been produced by anchovies.

TS of laterally insonified anchovy have been recorded during the PELGAS2019 survey, using the horizontal echosounder in broadband mode. TS measurements have been conducted while trawling at low speed (2-3 knots) in the surface layer, where anchovy schools had been detected by the horizontal echosounder. The combination of low vessel speed and high range resolution provided by the broadband echosounder (1 cm for a 100 kHz bandwidth in this case), allowed to record TS within daytime schools of 13 cm anchovies. The average value of in-situ TS of laterally insonified anchovies was used to derive a TS-length equation for surface anchovy to convert $NASC_{horiz\_layer}$ values into fish density using Equation 2.

Surface anchovy acoustic biomass were calculated within 1NM long EDSUs within the anchovy core distribution area, delineated based on anchovy biomass field derived from vertical acoustic data.

The global anchovy biomass derived from horizontal acoustic data was compared to the global biomass estimates derived from vertical echosounder data. Grid maps of surface anchovy biomass derived from horizontal acoustic data were produced using the same grid as for biomass estimates derived from vertical echosounder. Horizontal and vertical acoustic biomass maps were summed and compared to egg map, following the methodology described in section 2.1, to assess if the correction for surface blind zone effect could reconciliate acoustic and egg distributions.

3. Results

3.1. Mapping

Figure 2 shows grid maps of anchovy indices derived from the PELGAS2019 survey data.

Two specific areas with more eggs relative to acoustic biomass were identified in Souther Biscay (~ 44-44.5° N) and off the Gironde river mouth (~ 2°W, 45.7° N) in Figure 2e.

Those areas are characterised by the presence of more anchovy biomass in the 10-30 m depth surface layer relative to deeper layers (Figure 2c & d). Those local differences in surface school abundance might have induced a negative bias in acoustic biomass estimates, if a significant amount of anchovy schools were distributed in the acoustic blind zone.

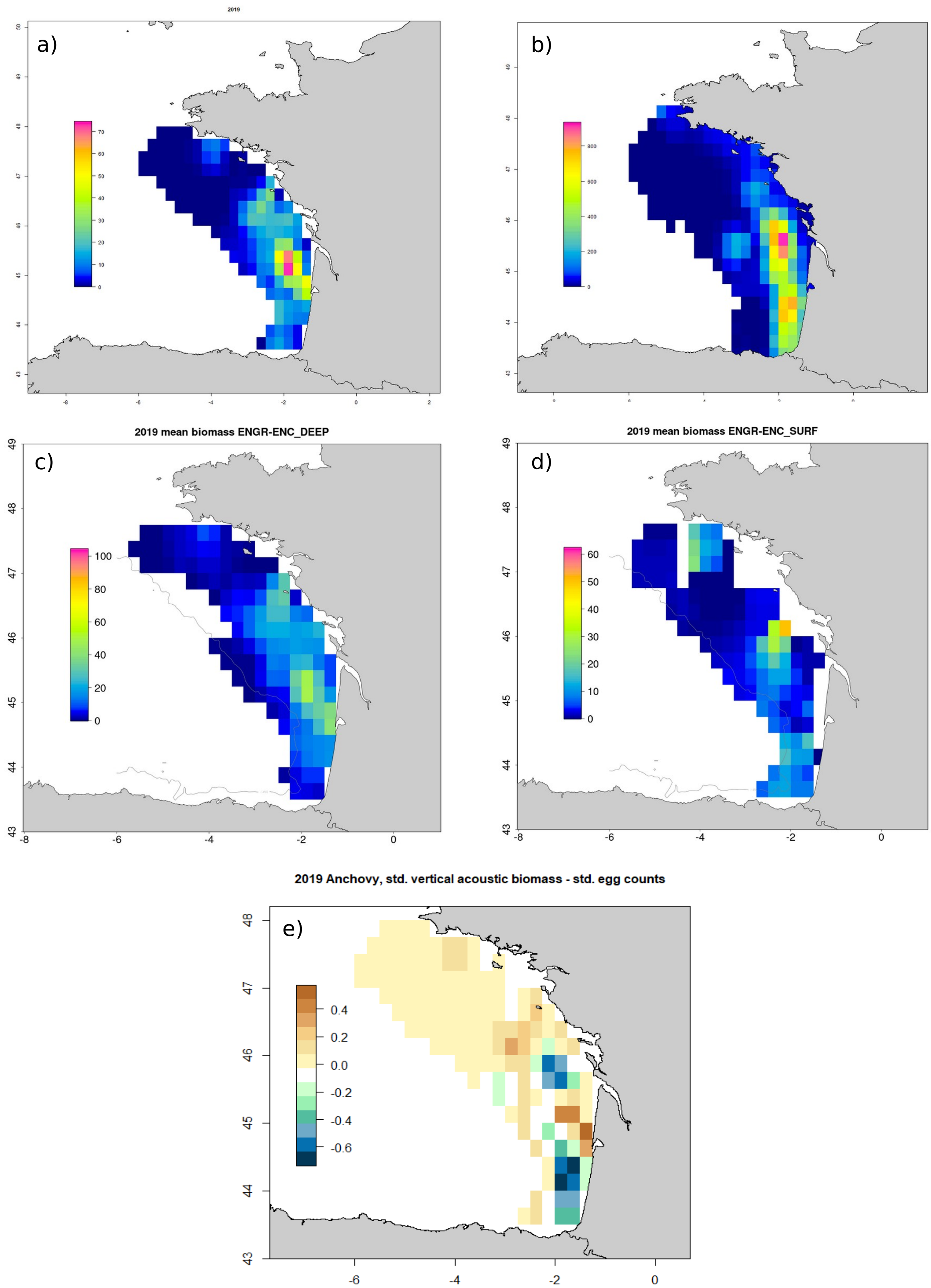

Figure 2. Grid maps (0.25° resolution) of anchovy indices from PELGAS2019 survey: a) acoustic biomass (tons); b) CUFES anchovy raw egg count; c) acoustic biomass (tons) below 30 m; d) acoustic biomass in 10-30m layer; e) Map of differences between standardised acoustic biomass and egg count.

3.2. Lateral aspect, in situ TS measurements of anchovy schooling near sea-surface

The average in-situ TS value of laterally insonified 13 cm anchovies measured during PELGAS2019 was -44 dB. The TS-length (L) equation derived from those measurements for surface anchovy was:

$TS_{horiz} = 20\log(L) - 66.3$ Equation 4

3.3. Surface fish acoustic biomass estimation and distribution

Horizontal echosounder echograms have been scrutinised in 634 1NM EDSUs out of 741 (86%) in the anchovy core distribution area. A total of 107 EDSUs (14%) could not be scrutinised, due to bad weather generating acoustic noise on the horizontal echosounder (natural areation (Delacroix *et al.*, 2016)).

Total anchovy biomass derived from horizontal echosounder data represented 9 158 tons, i.e. 5% of the total anchovy biomass derived from vertical echosounder data. The magnitude of the negative bias caused by the vertical echosounder blind zone was hence estimated as 5% of the total anchovy biomass estimate (183 165 tons) derived from vertical echosounder data used in stock assessment models in 2019.

Figure 3 presents the anchovy biomass maps derived from the horizontal and vertical echosounders, as well as the updated map of relative differences between anchovy total acoustic biomass and egg counts.

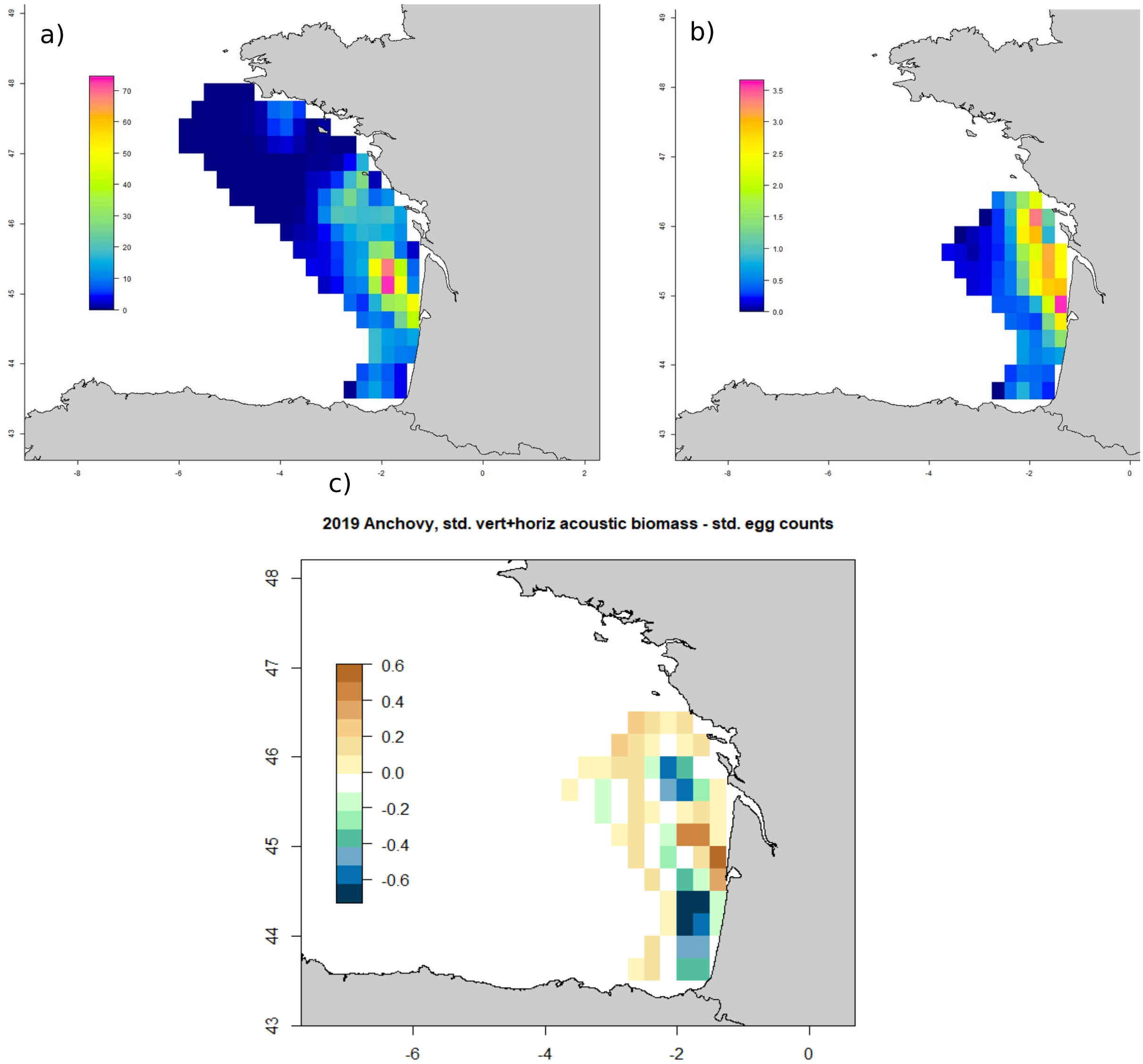

Figure 3. Grid maps (0.25° resolution) of anchovy indices from PELGAS2019 survey: a) acoustic biomass from vertical echosounder (tons); b) acoustic biomass from horizontal echosounder (tons); c) Map of differences between standardised total acoustic biomass (vertical+horizontal) and egg counts.

The core distribution of surface anchovy schools detected with the horizontal echosounder was located in the Gironde's mouth coastal areas from 44.5° to 46.5°N (Figure 3b). Those superfical schools were more coastal than the rest of the anchovy population, as assessed based on vertical echosounder data (Figure 3a).

The addition of the surface anchovy schools biomass map derived from horizontal echosounder data to the vertical echosounder biomass map resulted in few local changes. Patterns of differences between acoustic biomass and egg maps remained similar, wether considering differences between total acoustic biomass (vertical+horizontal) and egg counts (Figure 3c), or differences between biomass derived from vertical echosounder data only and egg counts (Figure 2e).

4. Discussion

Lateral aspect anchovy TS

The TS-length equation *b20* parameter estimated in this study for laterally insonified adult European anchovy was in the range of TS-length equation *b20* parameters derived from in-situ TS measurements of 32 cm herring (Pedersen *et al.*, 2009). Our *b20* estimate would correspond to fish insonified under an angle of about 20° relative to the echosounder beam axis, according to Pedersen et al. (2009)'s results. This mean insonification angle estimate appears plausible, as fish detected in the 0- 15 m depth layer were likely to be escaping the approaching R/V hauling a pelagic trawl. We assumed that anchovy adopted the same avoidance behaviour and displayed similar angle relatively to vessel track when detected by the R/V sailing at 10 knots during standard acoustic prospections.

Our lateral aspect anchovy TS estimate should however be refined to exclude potential multiple targets detected in dense anchovy schools, while applying e.g. a fish tracking procedure.

Estimation of surface blind zone bias in acoustic biomass estimate

This study showed that, at the survey area scale, the magnitude of the negative bias introduced in anchovy acoustic biomass estimates by the vertical echosounder blind zone was limited (5%), while using the aforementioned TS equations. The same methodology should be applied to horizontal echosounder datasets collected during previous and future survey to assess if this bias is constant overtime.

The difference between acoustic and DEPM biomass estimates observed in 2019 was likely not caused by the echosounder surface blind zone bias.

Differences between egg counts and acoustic biomass maps

At the finer gridmap scale, large differences remain between the CUFES egg counts map and the acoustic biomass map, corrected for surface blind zone bias. We assume that those spatial discrepancies might be caused by local differences in fish fecundity. Egg-based (B_{egg-i}) fish biomass estimates are indeed derived for a species *i* using the following equation:

$B_{egg-i} = P_{tot-i} / DF_i = P_{0-i}.SA.W_i / (R.F.S)$ (Lasker, 1985) Equation 5

Where P_{tot-i} is the observation term (total daily egg production in the survey area), and DF_i is the daily fecundity scaling factor used to convert egg into spawning fish density. DF_i is derived from P_{0-i}, the mean daily egg production (mean number of eggs produced per day per unit area) in the survey area *SA*, the mean weight W_i of mature females, the fraction of females in mature population biomass *R*, the batch fecundity *F* (number of eggs spawned per mature female per batch) and the spawning fraction *S* (fraction of mature females spawning per day) (Massé *et al.*, 2018).

CUFES egg-counts per gridmap cell used in this study are a proxy for daily egg production P_{0-i}.(or P_{tot-i} if multiplied by cell surface). Differences observed between egg counts and acoustic biomass maps might reveal local variations in the daily fecundity DF_i term that is used to scale egg production to fish biomass.

As all obvious bias have been corrected in egg and acoustic based biomass estimates derived for BoB anchovy in spring 2019, one can assume that those estimates should be equal ($B_{egg-i} = B_{acou-i}$). Further, assuming that CUFES egg counts (*Eggsi*) are a reasonible estimate of daily egg production, daily fecundities DF_i can be estimated in each gridmap cell *x* using Equation 5 as:

$DF_{i-proxy}(x) = Eggsi(x) / Bacou\text{-}i(x)$ Equation 6

Moreover, an anchovy mean weight (W_i) map can be derived from acoustic biomass and abundance maps as:

$W_i (x) = B_{acou-i} (x) / A_{acou-i} (x)$ Equation 7

where $A_{acou-i} (x)$ is the adult anchovy abundance estimated in gridmap cell x, from acoustic-trawl data.

Considering that $DF_i = (R.F.S) / W_i$ (Equation 5), and assuming that sex has no significant effect on mean weight, a map of the average number of eggs spawned per fish per day can also be derived as:

$(R.F.S)(x)= DF_{i\text{-}proxy} (x) / W_i (x) = (A_{acou-i} (x) \times Eggs_i)/ (B_{acou-i} (x)^2)$ Equation 8

Figure 4 presents the $DF_{i\text{-}proxy}$, W_i and $R.F.S$ maps derived from Equations 6, 7 and 8.

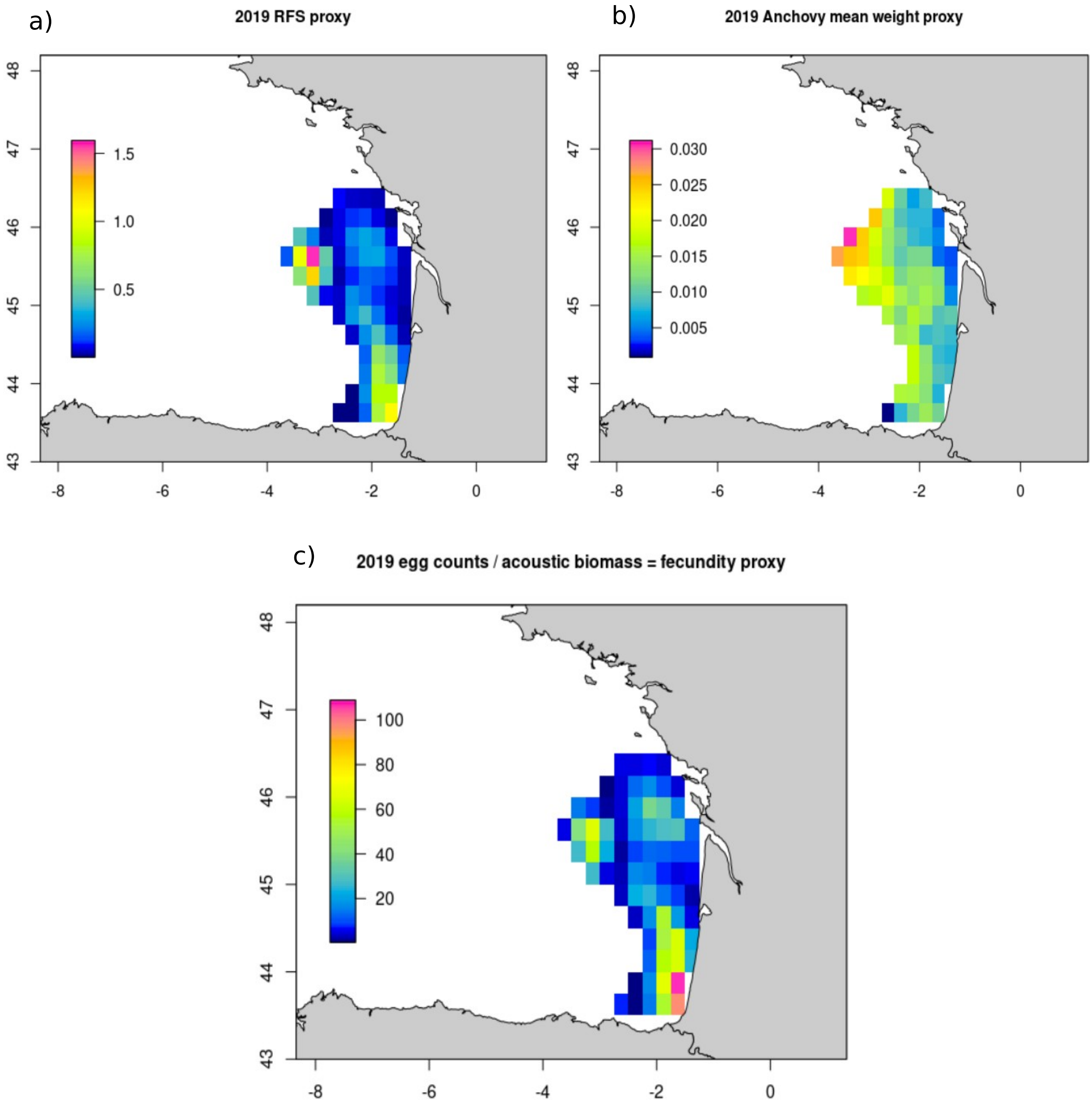

Figure 4. Grid maps (0.25° resolution) of anchovy daily fecundity proxy from PELGAS2019 survey. Daily fecundity proxy map = CUFES egg counts / total acoustic biomass (vertical+horizontal) map.

Figure 4a and 4c display similar spatial patterns, as DF_{proxy}, and *RFS* are closely related through Equation 8. Those maps show local differences in fish fecundity, with core high fecundity in South-Eastern and North Western areas and secondary in a coastal area North of Gironde mouth. Figure 4b reveals that anchovy mean weight is higher in NW and offshore areas relative to Southern and coastal areas.

Higher fecundity values are observed when larger, more fecund fish are present, and/or when feeding rates are good (Somarakis *et al.*, 2004). Higher fecundities observed in NW areas in Figure 4a and 4c might be related to the presence of larger fish (Figure 4b), especially near the sea surface (Figure 5) and potentially less competition for food. The second area displaying high fecundity values in South Eastern Biscay might reveal a more favorable trophic environment. The BIOMAN2019 survey has detected larger anchovies in this area at almost the same time as the PELGAS2019 survey. Those larger fish with higher fecundity might also not have been accessible to the PELGAS survey.

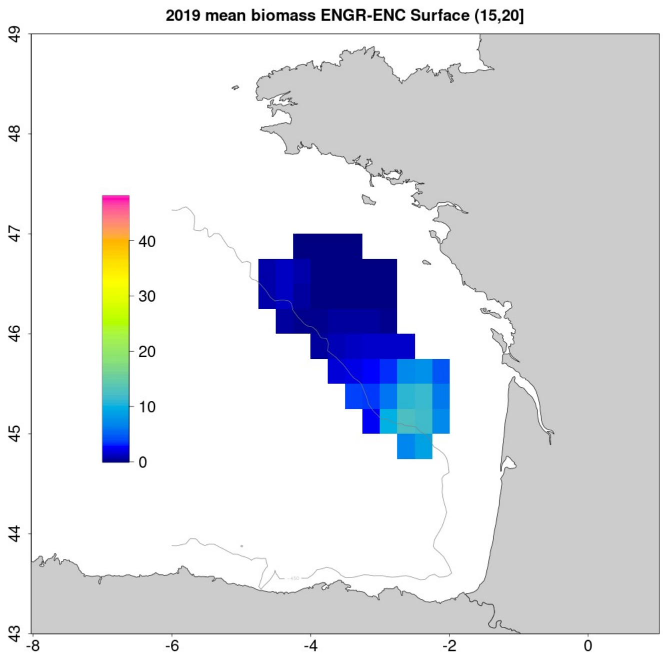

Figure 5. Grid maps (0.25° resolution) of acoustic biomass (tons) of large (15-20cm) anchovy detected in the 10-30 m depth layer during the PELGAS2019 survey.

Implications for daily fecundity estimation/assessment

A global estimate of Daily Fecundity (*DF*) is used to calculate egg-based anchovy biomass from BIOMAN data with DEPM. This *DF* estimate is calculated based on biological analysis performed on a subset of anchovy caught during the survey. The more variable adult parameters used to calculate *DF* estimates are the mean female weight and the batch fecundity, *F*. *F* value has been estimated based on 78 hydrated females ranging from 3.5 to 45.4 g, taken from 19 hauls during BIOMAN2019 (Santos et al. this volume). The global DF estimate was 61 eggs/g/day(CV 0.0610) (Santos et al. this volume).

The spatial distribution of detailed biological/histological data on adults collected during the BIOMAN survey should be compared to DF_{proxy} maps derived from PELGAS egg and acoustic data, to better assess and understand the spatial heterogeneity of anchovy daily fecundity. Mean *DF* estimates should indeed be calculated in areas as spatially homogeneous as possible, to reduce bias and improve precision in biomass estimates. A better understanding of anchovy fecundity in space might hence improve the precision of egg-based biomass estimates.

Further, the average and variance of DF_{proxy} values derived from PELGAS data could be compared to the mean and dispersion of the *DF* estimate based on BIOMAN2019 biological data

Figure 6 displays the distribution of $DF_{i\text{-}proxy}(x)$ values estimated using Equation 6 and PELGAS2019 data collected over the anchovy core distribution area.

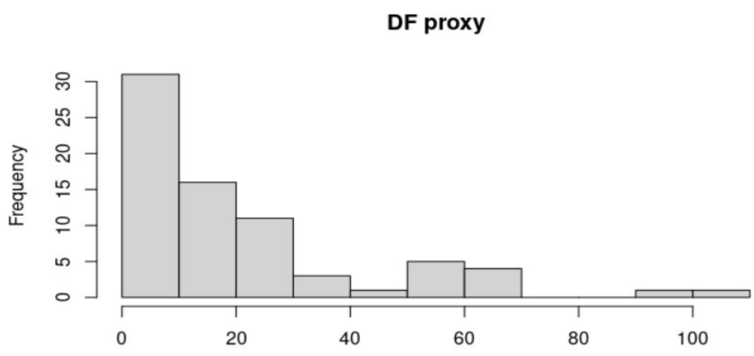

Figure 6. Distribution of the anchovy Daily Fecundity proxy estimated from PELGAS2019 data.

The distribution of the *DFproxy* values derived from PELGAS data and using ICES (1982)'s TS-length equation for anchovy is left skewed, with a mean of 21.4 eggs/g/day and a CV of 105%.

Using Ona, (2003)'s TS equation with depth effect correction, the mean *DFproxy* value would be 53 eggs/g/day (CV = 1.05), which is closer to the *DF* value estimated based on BIOMAN2019 biological data (61 eggs/g/day(CV 0.0610)).

Comparing *DF* mean values derived from biological data on one hand and egg and acoustic estimates combination on the other hand could further contribute to quality check biomass estimates.

The precision of the DF proxy derived from PELGAS survey data should however be improved by using mean daily production (P_0) maps, instead of raw egg counts in the calculations, to take into account the egg mortality and spatial distribution.

Conclusion

This study shows that surface school biomass can be calculated while applying standard acoustic data analysis methodology to horizontal echosounder data, combined to broadband in-situ TS measurements.

In spring 2019, the surface blind zone observation bias was not significant, as only 5% of the anchovy biomass was located in the 0-10m surface layer. The difference between acoustic and DEPM global biomass estimates observed in 2019 hence remains unexplained.

Differences between acoustic biomass and egg counts maps were likely due to local differences in fecundity, probably caused, at least in the North Western area, by the presence of shallow schooling large anchovy displaying higher fecundity.

This pilot study might pave the way to the routine combination of vertical and horizontal acoustic data to correct surface blind zone bias and improve small pelagic fish acoustic biomass estimates.

DEPM and acoustic biomass estimates have to be calculated within post-stratification regions as homogeneous as possible, to reduce bias and improve estimate precision. The high spatial resolution of acoustic backscatter generally allows to delineate reasonibly homogeneous post-stratification regions. The coarser spatial resolution of the trawl hauls providing biological data used to calculate daily fecundity estimates in the DEPM method so far prevented to assess the spatial heterogeneity of fish fecundity.

Daily Fecundity proxy maps derived from surveys such as PELGAS, where both egg and acoustic data are collected, might be used to assess the spatial heterogeneity of fish fecundity. Those new information could contribute to improve the precision of DEPM estimates, by improving post-stratification region delineation. Assessing the spatial and statistical distributions of daily fish fecundity might hence contribute to improve the precision of mean *DF* values used in DEPM, and ultimately better explain the discrepancies observed during some years between egg and acoustic indices.

References

Delacroix, S., Germain, G., Berger, L., and Billard, J.-Y. 2016. Bubble sweep-down occurrence characterization on Research Vessels. Ocean Engineering, 111: 34–42.

Doray, M., Massé, J., and Petitgas, P. 2010. Pelagic fish stock assessment by acoustic methods at Ifremer. Rapp. Int. Ifremer, DOP/DCN/EMH 10-02: 1–17.

Doray, M., Petitgas, P., Romagnan, J. B., Huret, M., Duhamel, E., Dupuy, C., Spitz, J., *et al.* 2018. The PELGAS survey: Ship-based integrated monitoring of the Bay of Biscay pelagic ecosystem. Progress in Oceanography, 166: 15–29.

ICES. 1982. Report of the 1982 Planning Group on ICES-Coordinated Herring and Sprat Acoustic Surveys. ICES Document CM, 1982/H: 04.

ICES. 2017. Report of the Working Group on Acoustic and Egg Surveys for Sardine and Anchovy in ICES Areas 7, 8, and 9. ICES CM, 2016/SSGIEOM:31. Capo, Granitola, Sicily, Italy. 14-18 November 2016. http://www.ices.dk/community/groups/Pages/WGACEGG.aspx.

ICES. 2020. Working Group on Acoustic and Egg Surveys for Sardine and Anchovy in ICES areas 7, 8 and 9 (WGACEGG; outputs from 2019 meeting). ICES Scientific Reports, 2:44: 490.

Lasker, R. (Ed). 1985. An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy (Engraulis mordax). NOAA Tech. Rep. NMFS. 99 pp.

Massé, J., Uriarte, A., Angelico, M. M., and Carrera, P. 2018. Pelagic survey series for sardine and anchovy in ICES subareas 8 and 9 (WGACEGG) – Towards an ecosystem approach. ICES Coop. Res. Rep., 332. http://ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/CRR%20332.pdf.

Ona, E. 2003. An expanded target-strength relationship for herring. ICES Journal of Marine Science [ICES J. Mar. Sci.], 60: 493–499.

Pedersen, G., Handegard, N. O., and Ona, E. 2009. Lateral-aspect, target-strength measurements of in situ herring (Clupea harengus). ICES Journal of Marine Science, 66: 1191–1196.

Petitgas, P., Goarant, A., Massé, J., and Bourriau, P. 2009. Combining acoustic and CUFES data for the quality control of fish-stock survey estimates. ICES J. Mar. Sci., 66: 1384–1390.

Simmonds, E. J., and MacLennan, D. N. 2005. Fisheries Acoustics. Theory and Practice. Blackwell publishing, Oxford, UK. 456 pp.

Somarakis, S., Palomera, I., Garcia, A., Quintanilla, L., Koutsikopoulos, C., Uriarte, A., and Motos, L. 2004. Daily egg production of anchovy in European waters. ICES Journal of Marine Science, 61: 944–958. Oxford Academic.