Interactive comment on "Zooplankton diel vertical migration in the Corsica Channel (north-western Mediterranean Sea) detected by a moored ADCP" by Davide Guerra et al.
Anonymous Referee #1

Answers (*A*) to reviewer's comments (R) are written in *italics*.

General comments

The paper deals with the analysis of backscattered acoustic ADCP data in the Corsica Channel during a period of two and half years to provide understanding on zooplankton behavior and evidence of its vertical migration. The paper contains interesting analysis and findings, but it's lack in some parts and in some discussions. It seems to me that it has been written in a hurry, neglecting some aspects and argumentation on several items with the consequence of not being always clear and correct. Moreover, biological measurements are not really linked to other data. There are several main corrections to do or parts to explain. As the items treated in the paper are interesting, I recommend the publication after all the main following issues have been addresses.

Main points:

R: There is at least one other recent publication on this item in the Mediterranean Sea (page 3, lines 25--27), that is the 2018 paper by Ursella et al. published in Progress in Oceanography on the Southern Adriatic Sea.
A: Thank you, the reference has been added and briefly described. It was available online just a few days before our submission, thus we missed it

R: Potiris et al. 2018, and Pinot et Jansà 2001 also studied the link between DVM and lunar cycle (page 4, line3).
A: Added

R: At lines 12--18, page3, it is not totally clear what is referred to the whole Mediterranean Sea and what to the Ligurian (also the reference list at line 13 is mixed, but then you speak of the Mediterranean, with a parenthesis on the Ligurian). Please rewrite the sentence.
A: we rewrote the sentence

R: At page 4, Line 10 you write: "to determine how much zooplankton"; this sentence means that you are able through backscattering energy data to measure quantitatively how much zooplankton is present, that is not true, as you also mentioned few lines above. Please change.
A: We rephrased the sentence, which is now: "allow to know relative abundances of zooplankton present at a certain depth"

R: At line 12, page4, you write: "to identify the drivers": this is a final sentence. As the driving mechanisms of DVM are not totally understood, I would suggest a softer sentence: "to identify the possible drivers". The same at lines 18--21, page 9: the sentence it is very definitive/strong and should be softened and contextualized.
A: Done, we accepted the suggestion to use a softer statement. At p. 9 we deleted ''understand'' and put ''improve knowledge about what might possibly drive''.

R: you speak of two general and widely accepted assumptions in zooplankton studies (page 5, lines 29--31), but this is not really true. In reality, the sentence found in Heywood 1996 has a slightly different meaning from the one in your text. He says:" For vertical velocities, the water upwelling or downwelling is usually small under general oceanic conditions, except during events such as internal waves... ". I think you should better explain why in your case you can consider the upwelling/downwelling negligible or change the sentence. Moreover, the second assumption is not generally true: in the case of strong phyto blooming, the layers interested by it, "produce" quite strong signal. The same happens in zones rich in particulate as it could be the layer near the bottom. Anyway, there is no reference for this second assumption. Please explain.
A: We have rephrased and added a reference study from which it results that the Corsica Channel does not belong to the group of upwelling/downwelling areas of the Mediterranean. The second is especially an assumption that we made for our work, but

that is often done in previous studies, among which we decided to mention one. We also added a small remark on the fact that sound backscatter has also other causes, which we are not able to discriminate. This is the sense of an "assumption"

R: the sentence at page 6, Lines 1--2, is not a consequence of the previous one. Moreover, data of zooplankton biomass are not "obtained by the ADCP". Please rewrite the sentence.
A: The sentence is still valid, we have cancelled the term "therefore" and made some other changes. The sentence is now: "In general, information on zooplankton biomass and vertical motion inferred from ADCP data are more qualitative than quantitative".

R: The paragraph at page 6 from line 25 to line 31 is quite confusing and it should be rewritten. There are not--explained variables in the definition of the two slant range limits, and also the reference is inappropriate.
Moreover, the sentence at lines 27--28 is quite twisted. In addition, which "values detected" (line 29) do you mean? As it is, sentence at lines 30--31 is not appropriate as you use eq. 2 to calculate R. Finally, as state by Deines 1999 and Bozzano et al. 2014, the lower limit for the slant range is defined as pi*Ro/4, in order to be used it in the formula of backscatter coefficient (Sv) and not as a general criteria of quality control. Therefore, I would move all this discussion in the following paragraph after definition of R, also for clarity.
A: We have rewritten this part and added the missing definition of two variables. We think that the explanation is now much clearer. We do not understand what is inappropriate about the reference, it is a technical manual for the instrument written by the manufacturer. The order in which equations are presented has also been changed.
Concerning the comment about the lower limit of the slant range, the reviewer is right, but in our case no data were rejected because of this, but only because some were exceeding the maximum threshold, which is indeed a general criteria of quality control. Therefore, for the sake of clarity, we split the text, leaving discussion about Rmax here and moving Rmin to the following paragraph for the calculation of Sv.

R: Do you really have percent good greater than 90% also for data during the day in the parts of the water column where zooplankton has migrated away?
A: All data where PG<90% were discarded, before analyzing them, so the answer is yes.

R: The paragraph 3.2 is nested and difficult to follow. Why don't you give formulas 3 and 4 when you mention them the first time at lines 14--15? Eq.2 and 3 are not correct, maybe typing error. Please re--write the paragraph. Moreover, why do you use the formula by Deines 1999 to calculate Sv instead of the upgraded/corrected one suggested by Gostiaux and van Haren 2010 (also in Bozzano et al. 2014)? Please explain.
A: Following a previous comment, we reorganized the whole part and moved formulas to the right place. Typos were corrected. We did a choice of one of the methods available in literature, also more recent papers than Bozzano et al. still continue to use Deines approach. Also Potiris et al 2018 used Deines formula, and they had an experiment setup more similar to ours, than Bozzano et al. Our aim was not to compare methodologies. In addition, our dataset does not have low signal to noise ratios (<10), for which the method has been developed by Gostiaux and van Haren.

R: At line 18, page 9, you speak of biomass, but previously, at page 5, you said that you assume that the signal comes only from zooplankton. In many other parts of the text you use biomass in different meanings; this generates some misunderstanding on the word biomass. However, this item should be better explained in the whole text and/or define the terms at the beginning. Please explain and change accordingly.
A: Thank you for outlining this. We have added zooplanktonic to all "biomass" words where it was necessary.

R: lines from 21 to 28, page 9, are superfluous.
A: We cancelled them

R: Why do you speak of Deep Chlorophyll Maximum if it is seen in the surface layer (line 3 page 10)? The same in conclusions.
A: DCM is a widely accepted definition which refers to the region below the surface of water with the maximum concentration of chlorophyll. In the study area it is located between 20 and 100 meters, depending on the season. Sometimes it is also called

subsurface Chlorophyll maximum, but more frequently DCM, regardless of depth. For clarity we moved this definition to section 3.3.

R: At line 19, page 10, you say that you use w and Sv "to characterize different migratory behaviors of different zooplanktonic migrator groups", but it doesn't seem to me that you perform this kind analysis, except saying that there are probably two different communities at surface and bottom. Moreover, the following sentence ("To this aim….") is very generic and should be rephrased and the concepts better explained.
A: Ok, we have canceled the part "to characterize…groups". The sentence "To this aim…" in our opinion explains in a straightforward way that without a proper calibration, we can use MVBS only as an indirect and qualitative indicator of zoopl. biomass. We have therefore left it, rephrasing it a bit: "Without the necessary net samples that would allow a proper calibration, MVBS is considered as an indirect and qualitative proxy of zooplanktonic biomass".

R: The lack of information you mention at page 10 line 27 concerns w and MVBS not biomass and migration, except as a consequence. It is quite confusing to a reader.
A: Ok, we replaced biomass and migration with MVBS and W. The consequence is obviously that nothing can be said about zooplanktonic biomass and migration in this layer.

R: At page 10, line 30, you speak of surface values, but you have just said that there is a lack of data in the surface layer. As this misunderstanding with the term "surface" is found quite often in the text, please fix it throughout the text.
A: OK, thanks, we replaced ''surface'' with ''in the upper part of investigated water column'' or "upper layer". Checked out also throughout the paper.

R: at line 31 page 10 you write "since MVBS is a proxy": since this is your assumption and not a general one, it should be changed to "since we use MVBS as a proxy"
A: Done

R: Why do you affirm that the behavior observed in MVBS (lines 8--9 page 11, fig.3b, surface layer) is consistent with twilight migrating organism? It is not consistent with the definition you give in the introduction.
The same is found at line 18 when speaking of intermediate layer, at line 24 page 13 and in conclusions. Please explain and/or change.
A: We removed the "twilight" part from the surface layer discussion. However, what we observe in the intermediate layer is consistent with the definition of twilight migration we gave in the introduction (upward motion right after sunrise can be due to twilight migrators and reverse migrators). In addition, we have cancelled the part at page 13 "During both periods, an upward motion is evident after sunrise, a feature that is characteristic of twilight and reverse migration." Conclusions has been rewritten accordingly

R: It seems to me that in the w plot (fig.3c) the persisting positive values are better seen in January--February than February--March (line 11 page 11).
A: There was a problem with the labels in Fig. 3b-f, they were misplaced, the correct ones were those of Fig. 3g. So February-March was correct.

R: The sentence at line 22--23 of page 11 is not totally true (not for all periods daily vales are slightly higher…). And, are you sure there is no effect of the bottom (like resuspension or particulate) at this quote? please explain.
A: Actually, we analyzed several (this word has been added) profiles from transmissometers routinely mounted on our CTD-rosette system, and turbidity values at the depths above the ADCP were always very low. We corrected the sentence by adding "except during the zooplanktonic blooming period".

R: I am not so sure that in Fig.4a the MVBS has a peak in February –March that involves all the water column as you write at line 1 page 12. Maybe in March, but February is not very different from April, except at about 300m.
A: OK, we wrote only "March"

R: Are you sure that the reference of Pinot et Jansà 2001 at line 10 page 12 is correct? Their measurements reach 220m depth.
A: Yes, because besides the difference of depth, we as well hypothesize the possible presence of two communities (like Pinot and Jansà)

R: It would be clearer if you define what you mean by blooming period and no--blooming period, at the beginning of the discussion on the differences in MVBS between the periods (i.e. end of page 11). Moreover, it is not clear what do you mean with the definition of the blooming and no--blooming periods given at page 12 lines 19--22. How do you calculate the periods? Please explain.
A: The definition of the two periods has been moved to the part that was at the end of page 11 as you suggested.

R: At line 6 page 13 you mention the fact that the timing of the downward motion in the blooming period is later than in the no--blooming situation due to the later sunrise. But what about the upward motion that happens at the same time in the blooming and no-- blooming periods? And what is the timing of sunset in the blooming period: the time written in red in the figures? This is also related to what you write at lines 22--23: it would mean a different timing of reverse migration in the two periods, i.e. 4 hours and 2 hours after upward motion. Please explain.
A: We commented the upward motion already, it happens at the same time but is more intense during the blooming. Sunset and sunrise times varies during the blooming period and the non-blooming period since it is a period of about 6 months. In red is only written the timing that was found to be the most evident in W. We added this information on the figure caption. We can not be more precise because of the 2h sampling, and also because the figures are averages of long periods.

R: It is hard to understand your affirmation at lines 7--9 page 13, after the discussion just done: DVM is not just presence of more zooplankton in the water column (here again, are you using the term "biomass" instead of zooplankton?); moreover, the upward vertical velocities are stronger in the blooming period, but during the no--blooming period the downward velocities are stronger. What do you exactly mean with "DVM is intensified"? Please explain.
A: We have added "zooplanktonic" before "biomass" to be clearer. DVM is not the presence of more zooplankton and the comment in fact refers to intensified W values. We replaced the concept of intensified DVM with intensified active upward motion.

R: The affirmation ("During both periods…") at lines 23--24 page 13, is not so evident to me when looking at figure 4d and 4f: in the no--blooming period it is really weak and should be taken with caution taking into account errors; moreover, these values cover the entire daytime.
A: You are right, we have deleted the sentence

R: In order to calculate the FFT, did you interpolate linearly the time series between one deployment and the other? Are you sure that the peaks you find in Fig. 5a and 5b are related to physical phenomena and are not fictitious features? And what about the error bar? Because some of the peaks are really small. The 12--hour peak at 353m is quite evident in w power spectra (lines 32--33 page 13).
What do you mean with "taken singularly" at line 33 page 13?
Moreover, your discussion at the beginning of page 14 is not convincing me: the reverse migration should be masked by the nocturnal one if it happens exactly at the same time and it is weaker (the bins measure the average movement). Please explain it and give more evidence.
Also, the discussion on 4.75 and 8 hours peak (lines 8--10 page 14) is not convincing: the variability you discuss seems not to be a cyclic one with that period. Finally, the spectra of low pass data contain peaks that sometimes are not very evident, and as there are no error bars it is difficult to distinguish them from the surroundings. Please re--do all this part regarding power spectra.
A: We interpolated with the matlab function inpaint_nans which is based on a PDE that is assumed to apply in the domain of the artifact to be interpolated. Then the PDE is approximated using finite difference methods and is solved for the NaN elements in the array. This method did not produce any peaks in Fig. 5a and b. We added this information in section 3.5.
We specified at which periods and depths peaks are really small (added this information where it was missing).

We removed "taken singularly", the sentence should be clearer. The meaning was that if reverse migration occurs alone the peak would be at 24 h, the same is true for nocturnal migration. But if they occur both the resulting peaks are at both 24h and 12h. It is quite difficult to explain the 12h peak existence, but the most plausible explanation is that reverse and nocturnal occur both, even though not at the exact same time (which would be rather strange indeed). The other peaks are representative of some cyclic variability, although it is rather difficult to identify which kind of migration is responsible for it. We smooth out the text a bit to take into account that we don't know how much we can trust these peaks. Finally, the spectrum was computed with a straightforward FFT, without segmentation and overlapping. Especially when looking for the long periods, segmentation would not have allowed to detect them. This is why we could not compute the confidence intervals here. Also here we smooth out the text a bit to take into account that we don't know how much we can trust these peaks.

R: I do not understand what is the sense of table2 with the list of all the species, if this feature is not used for the discussion in relation to MVBS and w, and if it is just a snapshot of a summer situation. Also, the small discussion at page 14 is superfluous. The affirmation at lines 30--31 is quite strong and partially not true (evidences of the contrary are found in literature).
A: We decided to keep this table, to summarize the net sample findings, which not entirely are described in the text, even if they are just a snapshot, compare to the acoustic data these represent a sort of ground truth, which is important to account for (this remark has been added to the text). In addition, it could be a useful reference for future studies of the communities in this area. It shows that the characteristics of this community are mainly epipelagic, which are not strong vertical migrators, as is evident also from the acoustic data of august. It is not clear to us what the reviewer wants to criticize about L30-31, and to which references in the literature he is referring to.

R: It is not evident to me the descent during the day between 150 and 250m (fig.6b) as described at line 4 page 15. Moreover, at lines 6--7 page 15, you explain the migration from 100 to 300m citing two references, but you do not say whether you found these organisms in your sampling. You should use your data at least in this discussion Finally, the sentences at lines 9--12, page15, should be better explained: where do you see the zooplankton descent? Which behavior do you mean? A reference for it is needed. Here you use "biomass" for phytoplankton.
A: We have removed Fig. 6a and now the plot 6b should be more readable. We replaced with "low MVBS levels" instead of "descent". We have specified that the groups of organisms we hypothesized have although not been sampled, stressing that the sample, even if it is necessary ground-truth base, is just a snapshot of a summer situation during day.
Line 9-12 page 15: there are probably zooplanktonic organisms in the upper layer we do not see except during their descent when DCM deepens. We add the reference to Fig. 4a where this is visible. We added ''phytoplankton" before "biomass ''.

R: From line 31 page15 to line 13 page 16, you try to explain the unexpected result (zero-- lag correlation) with different considerations. It is not clear to me why one of these arguments is the lack of data in the very surface layer if the correlation is the surface layer is ok (by the way, which is the depth of the euphotic layer?). Moreover, why do you cite Warren et al 2004 if they found no correlation or negative one, contrary to your results? Finally, why the changes in the amount of zooplankton should be related to lateral current only in the bottom layer and not in the surface one where the correlation is as you expect? Maybe the MVBS is not always a good proxy for zooplankton biomass, in the sense that it can include other signals? Please, rewrite this part explaining better the concepts.
A: This part has been completely rearranged (some results change after correction on the computing method suggested by the reviewer#2). We think that now the part is clearer. We mentioned the fact that satellite data are just surface data because as we know from Fig. 2d the DCM can be as deep as 100 m and, in this case, the phytoplanktonic bloom might not be correctly sampled by satellites or its timing might be different to what is seen from satellites. The depth of the euphotic layer is approx. the lower limit of the DCM, Fig. 2d. Reference to Warren 2004 has been removed as well as the sentence containing it. We do however do not follow the reviewer's reasoning when he says that lateral currents influence only the bottom layer and that MVBS is representing also other signals. Lateral currents are able to influence the whole water column (and this is the sense of what is written in the ms). Nepheloid layers have already been excluded in the paper, based on transmissometer data analysis.

R: At page16 line you mention an analysis of the behavior of zooplankton in relation with oxygen concentration, but in reality, this kind of analysis is not performed.

A: Oxygenation has been described for different season, so yes an in depth analysis has not been performed, but it was part of the description of the water mass properties. This part on oxygen has been deleted from the conclusions.

R: Taking into consideration all the points above, please change conclusions.
A: Conclusions have been rewritten accordingly

Minor changes:

Comments	***Corrections***
Line 14: "Biomass evolution": maybe do you mean "biomass distribution"?	*We replace "evolution" with "temporal distribution".*
Line 20: cancel "near"	*Done.*
Line22: "others" is quite too general. Please rewrite the sentence.	*Replaced with "other factors, like lunar cycle and primary production, are taken in consideration"*
Page1: Line 26: "At dawn…." It seems a general feature, indeed it is just one type of migration. Please rewrite the paragraph.	*Replaced with "During nocturnal migration at dawn…".*
Line 31: you are speaking of twilight migration, aren't you? It is not clear.	*Replaced with "The typical descent of twilight migration that…".*
Page 2 Line 28: does phytoplankton perform vertical migration?	*Some of them do it, especially dinoflagellate. Phytoplankton plays a role in the vertical flows of matter / energy and the range of autotrophic organisms capable of prolonged direct vertical movements also involves flagellated phytoplankton*
Page 3: Line3: instead of "an ADCP" write "an upward--looking ADCP"	*Done.*
Line 15: cancel "are"	*Done, this part has been rewritten according to your comment #3*
Page 4: Line 5: please correct "by the depth of the depth of"	*Done*
Line 7: change "calibration" in "calibrate"	*Done.*
Page 5: Line 4 and 5: I think that the units are m/s and not cm/s.	*Yes you're right, thanks*
Page 5: Line 20: change "proportional to how fast particles move and it is used to infer the velocity" in "proportional to the velocity of the moving particles and it is used to infer the speed "	*Done.*
Line 23: change "how much sound reflection" in "how much of the sound reflected signal"	*Done.*
Lines 23--26: what you are saying is certainly true, but there is some confusion on the terms you use here (reflection and scatter) and above/below (back--scatter). Please, try to uniform the language.	*Back-scatter vs backscatter have been uniformed throughout the paper. The confusion between reflection and scattering is not evident to us, since they are two different physical processes. However, it is true that what is commonly called "backscatter" in the water column includes also those particles that reflect the sound wave, and not only those that scatter it.*
Page 9: Line 2: add ":" after "These parameters are"	*Done.*

Lines 2--10: the list of parameters would be more readable if a list number/letter is added (i.e. i) ii) etc.) or it is listed in bullets.	*We decided not to use a list, but keep a text.*
Line 4: cancel “here”	*Done.*
Line 8: cancel “here”	*Done.*
Lines 9--10: moon phases are obtained from where?	*We have added the source “(retrieved from https://aa.usno.navy.mil/data/docs/MoonPhase.php)”*
Page 10: Line 13: “Fig 2d--2e” should be “Fig.2e--2g”	*Done.*
Line 24: the acronym has already been defined at page 7.	*Deleted.*
Line 29: add “approximatively” before “between”	*Done.*
Line 30: change “whole” in “the greatest part of the”;	*We replaced it with “most of the“*
Page 11: Line 3: “Less evident in fig.3a”: I think that it is impossible to see the daily cycle in this panel.	*You’re right and we removed this, changing this and the following sentence.*
Line 11: change “persisting” in “quite persisting”.	*Done.*
Line 19: change “very high” in “quite high”	*Done.*
Line 21--22: cancel “which is below the depth of the ADCP.”	*Done*
Line 24: change “is much lower” in “is hardly seen”, also because of what you write few lines below at line 27 (“is not clearly correlated with sunlight etc…”).	*Done.*
Line 29: change “from noon to sunset and” in “from noon to sunset in some periods and”	*Done.*
Lines 30--32: the sentence is redundant. Please rewrite it. Moreover, what are DVM parameters?	*We rewrote the sentence.*
Line 33: cancel “integrated over the whole investigated water column”: the figs.3a and 4a show MVBSs that vary along the water column.	*Done, thanks*
Page 12: Line 14: cancel “which the ADCP data …..”: it is a repetition	*Done.*
Page13: Line20: change “Fig 3b--3g” in “Fig3b--g”	*Corrected to ‘’in Fig.3b-g and Fig4c-f’’.*
Line 20: what is “Fig 4--4f”?	*corrected*
Page 14: Line 9: maybe “Fig.4d”?	*Yes. Done, thanks*
Page16: Line 33: a reference for the last part of the sentence would be appreciated	*We modified the text a bit and added the reference Tarling et al., 2002*
Page17: Line 1: change “surface” with “upper”	*Done.*
Line6: change “daily” with “diurnal”	*Done.*
Line 20: maybe 2000 is 2001?	*Done.*
Figures:	
Fig. 3: in panels b→g numbers, letters and labels are unreadable. Also, the lines with times of sunset and sunrise are difficult to see.	*Corrected*
Fig 4c→f: numbers and letters are too small and units are missing.	*Corrected*
Fig. 5: units on the y axis are missing.	*Corrected*
Fig. 6 the moon, the sunset and the sunrise symbols are not visible. Fig 6b can be a bit larger and 6a smaller.	*We have modified the sizes of the two plots, and used bigger symbols for the moon phase. We could not make the symbols of sunset and sunrise larger, because of lacking*

The use of symbols for sunset and sunrise at the base of the plot makes the plot difficult to interpret.	*space. If one zooms into the pdf of the ms they result visible.*
In general: units are missing in various figures.	*Corrected*
Potiris et al. 2018: the reference is not complete	*Corrected*
Ringelberg 2009: the reference is not complete	*Corrected*

Interactive comment on "Zooplankton diel vertical migration in the Corsica Channel (north-western Mediterranean Sea) detected by a moored ADCP" by Davide Guerra et al.

Anonymous Referee #2

Answers (*A*) to reviewer's comments (R) are written in *italics*.

General comments

The paper by Guerra et al is a study of diurnal vertical migration of zooplankton in the Corsica Channel observed with an Acoustic Doppler current profiler for a period of about two and a half years. The study produced interesting results about the vertical and temporal variation of zooplankton distribution and its relation to environmental conditions. The introduction and methodology sections are in general well written. However, some important information regarding the statistical analysis is missing in the methodology section *(A: These parts have been added when required)*. The results and discussion section requires several changes and a few additions, as some of the text is not easy to follow and understand, and some of the text is not clearly supported by the present graphs *(A: changes have been made according to specific comments below)*. The length of conclusions section should be significantly shortened (*A: has been shortened*), as it is largely a repetition of the results and discussion section, through a more synthetic writing. As the results are interesting *(A: thank you)*, I suggest publication after the issues presented below are addressed.

Specific comments

R: Although authors appreciate that the MVBS is only a proxy of zooplankton biomass, they use the term biomass to refer to variations in MVBS. Biomass should be replaced with absolute backscatter or another appropriate term to avoid reader confusion, as details regarding their difference are given only in later sections.
A: We have added a sentence where we say that in the following parts of the paper the term zooplanktonic biomass will be used when referring to results coming from MVBS data

R: Results should be presented in the past tense.
A: We decided to keep our style, which is used consistently throughout the paper.

R: Please add units that are missing in several figures and use equation editor for the units in figure captions, not text.
A: Added, but did not see the need to use equation editor. Some apexes in the text of the captions have been corrected.

R: Please consider adding density profiles to figure 2 and refer to the pycnocline instead of the thermocline when mentioning stratification.
A: Since T is leading density, the thermocline is equivalent to the pycnocline. Adding density would therefore not add any useful information and would just take up space. We added a small text in the caption explaining this

R: Please distinguish between primary (phytoplankton) and secondary (zooplankton) bloom throughout the text (or at least once in each paragraph). In some cases, it was obvious from context which one was meant, in others, it was a bit confusing.
A: Done, thanks

R: p.3, l.21-24: Please consider expanding a bit the discussion on the drivers of DVM.
A: We think that the Introduction is already very long to go further in detail. However, all the relevant previous works are there, so the reader can find the sources.

R: p.3, l.25: van Haren, J. Plankton Res., 2014 and Ursella et al, Deep-Sea Res., 2018 are two additional ADCP studies on zooplankton in the Mediterranean Sea. Please consider including them.
A: Done

R: p.3, l.28: ": : :to infer the composition in the Ligurian Sea: : :". This is incorrect, they only suggest that a change in composition is probable. Please remove.
A: Done

R: p.4, l.6-8: Please consider including Brierley et al, Deep-Sea Res., 1998.
A: Done

R: p.5, l.18-24: Please consider moving "The operating : : : (Thomson and Emery, 2014)." to introduction and merge the rest of this paragraph with the next one.
A: Done

R: p.5, l.32: Do you mean composition instead of ": : :consistency: : :"?
A: We actually meant consistency (in the sense of texture…).

R: p.6, l.1-2: "Therefore, : : : quantitative." Repetition (also on p.4, l.6). Please consider removing.
A: This part has been moved to the introduction, and reworded

R: p.6, l.5: Please consider moving "The four : : : signals." to the previous paragraph which explain the operation principles.
A: The previous part has been moved to the introduction, but this is too technical, and has been left in Materials and Methods. However 3.1 and 3.2 has been merged, the new title of this section is "3.1 ADCP settings, and data quality control and estimation of the Mean Volume Backscatter Strength"

R: p.6, l.6: Please replace ": : :is upward looking: : :" with ": : :is placed at an upward looking position: : :". The way is stated, one might understand that this particular ADCP can be used only in an upward looking position, which is incorrect.
A: Done

R: p.6, l.16-20: This paragraph could be removed.
A: Done

R: p.6, l.27: Please explain symbols H and θ.
A: Done

R: p.7, l.1: There is one PG per transducer and an average PG. Which one was used? The average, the minimum of all separate transducers or something else?
A: Our data are collected in Earth Coordinates, consequently the four Percent Good values represent (in order):
PG1) The percentage of good three-beam solutions (one beam rejected);
PG2) The percentage of good transformations (error velocity threshold not exceeded);
PG3) The percentage of measurements where more than one beam was bad; and
PG4) The percentage of measurements with four-beam solutions.
We have used PG4 discarding values below 90%.

R: p.7, l.13: What data were used for the calculation of the absorption coefficient ?
A: As it is written in the text, the sound absorption coefficient was computed using a matlab script that needs 3 input parameters: the frequency of the sound pulse in Hz (76800 Hz in this case), temperature in °C (Tx) and pressure (atm). All data were considered at the depth of the ADCP

R: p.8, l.18: Perhaps you meant ": : :complemented: : :" instead of ": : :integrated: : :"?
A: Yes you're right

R: p.8, l.22: Please take also into consideration that large organisms can escape the 200 m mesh. Moriarty et al, Earth Syst. Sci. Data, 2013.
A: We have mentioned it explicitly in the amended version of the manuscript. at p.8l22 we added: "Some undersampling is possible since large organisms can avoid nets with a small mesh size (Moriarty et al., 2013)."

R: p.9, l.9: The sentence seems incomplete.
A: Reviewer 1 suggested modifications, now it should be clearer. Source for moon phases has been added to the list.

R: p.9, l.12: Please provide more information on spectral analysis. Are the data de-trended, windowed, block-band averaged, which is the number of segments for the spectral estimate, what is the segment overlap? These are necessary for the calculation of confidence intervals.
A: The spectrum was computed with a straightforward FFT, without segmentation and overlapping. Especially when looking for the long periods, segmentation would not have allowed to detect them. This is why we could not compute the confidence intervals here. We smooth out the text a bit to take into account that we don't know how much we can trust these peaks.

R: p.9, l.15: Please consider replacing ": : :verify: : :" with ": : :investigate: : :".
A: Done

R: p.9, l.18-28: "". Repetition (also on p.4, l.15-24). Please consider removing.
A: We have cancelled from L21 to 28, the rest was kept to very shortly introduce the Results section

R: p.10,l.4: Please consider moving the DCM definition to p.5, l.10-15 and add some information regarding its variability from literature.
A: DCM is a widely accepted definition which refers to the region below the surface of water with the maximum concentration of chlorophyll. We moved its definition to section 3.3. Variability is strongly dependent on season and region, so no general reference concerning it would be meaningful

R: p.10, l.10: It is not clear to me which this interface is.
A: It is the interface between AW and IW, in the text we have reworded the sentence to make this clear

R: p10, l.18-23: I think that "Vertical : : : range." should be moved to methodology.
A: We left this part here, since it is not really about methods, but what are the implication of this method for the results that we can obtain

R: p.10, l.26: "All considerations : : : bottom." Repetition (p.7, l.3-4). Please consider removing.
A: Even in this case we consider that this is important to state, to be clear that we are aware of the limitations that we are faced with.

R: p.11, l.3: The daily cycle is embedded in the plot, but it is not distinguishable. Please consider including a representative subplot with time span of a few days.
A: To show this cycle in detail we included the fig.3b to 3g. Another plot would be repetitive

R: p11, l.7: "June-July 2016". I think it's around April, not June-July.
A: There was a problem with the labels in Fig. 3b-f, they were misplaced, the correct ones were those of Fig. 3g. So June-July was correct.

R: p11, l.9: ": : :a pattern : : : organisms." Please add reference.
A: Done.

R: p.11, l.22: ": : :daily values are slightly higher than nocturnal values: : :". Please include a supporting graph or mean daily and night MVBS values.
A: The difference between day and night is well evident from fig. 3b to 3g, because the lines are showing the hour of the day of sunset and sunrise, so "day" is everything between the two black curves, while "night" is everything below the lower curve and above the upper curve. Therefore we think that no supporting additional graph is needed here.

R: p.11, l.33-34: Please include a plot of integrated MVBS as the argument is not evident from figures 3 - 4.
A: We think that the Fig. 3a and especially 4a show this, the colourbar shows high values over large parts of the water column between Nov/dec (late fall) and Apr (spring)

R: p.12, l.3: I think it's ": : :intra-annual: : :" instead of ": : :interannual: : :".
A: No. we meant interannual, maybe is not ''marked'', we replaced with "clear". The variability is high when you consider the same months of different years and average them, so "interannual" is the right term

R: p.13, l.5 and figure 4c-4f: Since light intensity was found to be the governing factor controlling DVM (e.g. figure 3), the x axis should be hours relative to sunrise and sunset instead of hour of the day for the W ADCP to be more representative of actual zooplankton migrating velocity. Qualitatively, the results will be the same as those in figure 4d and 4f, but I expect that the duration of upwards and downwards motion will last less time than is shown in the present plot. Please consider, either including a plot with such an x axis, or adding some text explaining that the vertical velocity values are not optimally presented in this plot.
A: The plot would look like the same, because the x axis represents the actual measurement time, which has a 2-hours interval. Since the plot is an average situation over the whole blooming (or non blooming) we cannot compute the hours relative to sunrise and sunset, because they change every day. An average value of the hour relative to sunrise or sunset would not be so significant and difficult to interpret.

R: p.14, l.4: ": : :or does not involve a large number of organisms." This applies only (and partially) to MVBS spectra. The way it is stated both MVBS and W are meant, which is incorrect.
A: We modified the text accordingly

R: p.14, l.6 and 8: The smallest annotated period in figure 5 is 4.45 hours. It is 4.75 hours in the text.
A: In the text it is 4.75 hours which is the same as 4 <u>hours</u> and 45 <u>minutes</u>, denoted in the figure.

R: p.14, l.30-31: "The community is essentially composed by organisms that do not migrate significantly: : :". Please add reference.
A: We have added "Scotto di Carlo, B., Ianora, A., Fresi, E., and Hure, J.: Vertical zonation patterns for Mediterranean copepods from the surface to 3000 m at a fixed station in the Tyrrhenian Sea, J. Plankton Res., 6, 1031–1056, 1984."

R: p.15, l.10: Please replace ": : :which is accompanied: : :" with ": : :which is possibly accompanied: : :" as the lack of surface data hampers further investigation.
A: Done

R: p.15, l.11-12: Please add reference.
A: Done

R: p.15, l.17: Is the distinguish between shallow and deep layers based on the photic layer depth or on another criterion?
A: We used a simple depth criterion, as it is written in the text, with the data we have we could not use any other definition. The water column was split in half, and the limit of 200m corresponds to about the interface between AW and IW (the values 73m, 201, 378m are the mean bin depths that were used to divide between surface and deep layers).

R: p.15, l.27: ": : :that well correlate: : :". The Chl- and MVBS time series should be pre-whitened (i.e. remove autocorrelation) before a conclusion is drawn regarding their degree of correlation.
A: We have now prewhitened the times series (smoothing and detrending), and correlation is even higher, although lags changes a bit. We have modified the text accordingly. Thank you for this comment.

R: p.15, l.32: Please consider replacing ": : :a surface value: : :" with ": : :an exponentially weighted near-surface value: : :".
A: Done

R: p.15-16, l.29-13: Please consider placing the part of literature that supports/contradicts the findings of this study at the beginning of the paragraph and then present possible explanations for this agreement/disagreement. I was confused.
A: We have rearranged this part

R: Conclusions section: I think that this part should be rewritten to avoid repetition of results. Instead, the relation of the results of the present study with the relevant literature should be stressed. Also, the length of this section should be substantially shortened.
A: We have shortened and rewritten some parts of the conclusions

R: figure 1: Please include information about the data set of SST field in the data availability section.
A: Done

R: figure 4a and 4b: The x axis is month or climatological month? It was not clear to me from the text. If climatological please add this to the axis label. Otherwise, state which year the plot refers to.
A: They are the monthly averages of all available data (average of all Januaries, of all Februaries…). However this is not a proper climatological value. In the caption it is written "monthly mean". We have added this also in the text in this version.

R: figure 5: Please add confidence intervals. This is particularly important for the low-passed series (5c and 5d) and subsequent interpretation of results.
A: The spectrum was computed with a straightforward FFT, without segmentation and overlapping. Especially when looking for the long periods as in Fig. 5c and 5d, segmentation would not have allowed to detect them. This is why we did not compute the confidence intervals here. We smooth out the text a bit to take into account that we don't know how much we can trust these peaks.

R: figure 6a: It seems redundant to me as the three numbers in this plot are already present in the text.
A: Ok you're right, we removed it.

R: figure 7b: Please add confidence intervals.
A: Done

R: table 1: Please explain symbols in table caption or replace B, L, D, C with blank distance, etc.
A: The symbols are already explained in the text were the equations are presented. No need for repetition is therefore required according to us.

R: table 2: I think that this table is redundant, as the useful information of taxonomic analysis has been already presented in the text. Please consider removing.
A: We decided to keep this table, to summarize the net sample findings, which are not entirely described in the text.

Technical corrections

Comments	***Correction***
Please add the data availability section that is missing (required by journal).	*Done*

Bibliography is not formatted according to journal standards. Number of volume and pages are missing. Also, doi representation is not consistent among references (some are doi:: : : others are https://doi...).	*Done*
p.3, l.16: Please merge the two sentences or rephrase.	*Rephrased. Done.*
p.4, l.5: “: : :by the depth of the depth: : :”. Typo.	*Done.*
p.4, l.7: “: : :attempts to calibration: : :”. Typo.	*Done.*
p.4, l.17: “: : :Data collections: : :”. Typo.	*‘’collected’’.*
p.4, l.22: Perhaps replace “: : :is completed by: : :” with “: : :concludes with: : :”?	*Modified*
p.5, l.18: Please replace “: : :as sediments: : :” with “: : :such as sediments: : :”. Typo.	*Done.*
p.6, l.5: “: : :increments to each other: : :”. Typo.	*Done.*
p.6, l.28: #7 deployment is missing. Typo.	*Done.*
p.7, l.3: Perhaps replace “: : :will be done: : :” with “: : :will be made: : :”?	*Done.*
p.9, l.15: Please consider replacing “: : :results to be: : :” with “: : :is a relevant: : :”.	*I replaced.*
p.9, l.31: Please replace “: : :servicing: : :” with “: : :mooring maintenance: : :”.	*Done.*
p.9-10, l.31-3: please consider merging the two sentences.	*We prefer to keep the sentences separated*
p.10, l.1: “: : :are representative of: : :” instead of “: : :represents: : :”. Typo.	*Done.*
p.10, l.4: “: : :in correspondence with: : :” instead of “: : :in correspondence of: : :”. Typo.	*Done.*
p.11, l.24: Perhaps replace “: : :much lower.” with “: : :much weaker.”?	*As suggested by both reviewers we replaced with “hardly seen”*
p.14, l.4: “: : :take place: : :” instead of “: : :take places: : :”. Typo.	*Done.*
p.14, l.24: Please consider replacing “: : :by far the most abundant group were the copepods: : :” with “: : :the copepods were by far the most abundant: : :”.	*Ok*
p.14, l.29: Please consider removing “more” in “: : :more western: : :”.	*Done.*
p.15, l.3: Please consider replacing “: : :more superficial: : :” with “shallower”.	*Done.*
p.15, l.9: “Fig.” instead of “fig.”. Typo.	*Done.*
p.15, l.26: “: : :are shown: : :” instead of “: : :is shown: : :”. Typo.	*Done.*
figure 1: Please change “IW=Intermediate Water” to “IW=Intermediate Water path-way” or something similar.	*Done*
table 1. “: : :-400 mis: : :”. Typo.	*Done. ‘’400 m is’’.*

Zooplankton diel vertical migration in the Corsica Channel (north-western Mediterranean Sea) detected by a moored ADCP

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Abstract. Diel vertical migration (DVM) is a survival strategy adopted by zooplankton that we investigated in the Corsica Channel using ADCP data from April 2014 to November 2016. The principal aim of the study is to characterize migration patterns and biomass temporal evolution of zooplanktonic organisms along the water column. The ADCP measured vertical velocity and echo intensity in the water column range between about 70 m and 390 m (the bottom depth is 443 m). During the investigated period, zooplanktonic biomass had a well-defined daily and seasonal cycle, with peaks occurring in late winter – spring (2015 and 2016), when the stratification of water column is weaker. Zooplanktonic ~~B~~biomass ~~temporal distribution~~temporal distribution ~~– evolution~~ in the whole water column is ~~coincident and~~ well correlated with primary production estimated with satellite data. Zooplanktonic b~~B~~looming and no-blooming periods have been identified and studied separately. During the no-blooming period zooplanktonic biomass was most abundant in the ~~surface~~ upper and the deep layers, while during the blooming period the ~~surface~~ upper layer maximum in zooplanktonic biomass disappeared and the deep layer with high zooplanktonic biomass became thicker. These two layers are likely to correspond to two different zooplanktonic communities. The evolution of zooplanktonic biomass ~~in the deep layer is coincident~~is ~~and~~ well correlated with primary production~~, while the biomass evolution in the surface layer is less correlated with it~~ (~~and~~ , with primary production peaks preceding ~~a temporal lag of about three weeks~~the upper layer secondary production by a lag of about three and a half weeks~~)~~. Nocturnal DVM appears to be the main pattern during both periods, but also reverse and twilight migration are detected. Nocturnal DVM was more evident at mid-water than ~~near~~ in the deep and the ~~surface~~ upper layers. DVM occurred with different intensities during ~~in~~ blooming and no-blooming periods~~, and phenomena like nocturnal sinking were found to be stronger during the blooming period~~. One of the main outcomes is that the principal drivers for DVM are light intensity and stratification, but also other~~s~~ factors, like ~~lunar~~moon cycle and primary production, are taken in consideration.

1 Introduction

Diel vertical migration (DVM) is one of the most important survival strategies adopted by zooplankton. During migration these marine organisms can cover vertical distances of a few hundred meters. During nocturnal migration ~~A~~at dawn zooplankton descends and remains at depth, where the probability of being predated by a visually hunting predator is lower; at dusk zooplankton rises to the euphotic layer and stays there during night to feed on phytoplankton (Ringelberg, ~~2009~~2010;

Zaret and Suffern, 1976). This~~ so called nocturnal migration~~ is only one of the three most common migration patterns. Indeed, also twilight migration (ascent at dusk and sunrise, descent at midnight and immediately after sunrise) and reverse migration (ascent at sunrise, descent at sunset) have been described in previous studies (Haney, 1988 and references therein). The typical descent of twilight migration that occurs during night is called midnight or nocturnal sinking and is a downward movement accomplished after the sunset ascent and before the sunrise descent, which some zooplanktonic organisms do to leave the surface feeding layer and return to depth (Pearre, 2003 and references therein). Indeed, many authors agree on the presence of a *continuum* of migrating behaviours between the two opposed patterns of nocturnal and reversed migration (Haney, 1988). Essentially, in nocturnal DVM, the benefit of a reduced probability of predation is suggested to outweigh the cost of being spatially separated from the near-surface food, with a resulting reduced potential for daytime feeding (Hays, 2003). The less common twilight and reverse migration patterns have advantages as well, one of which could be to avoid other nocturnal migrators, as e.g. non-visually hunting invertebrate predators or simply competitors (Heywood, 1996; Ringelberg, 20~~09~~10). DVM is that much widespread and is found within practically all taxonomic groups, that it is generally assumed that in many cases there must be a common underlying ultimate driving force (Pearre, 2003). Pioneering studies (Clarke, 1934; Eyden, 1923) hypothesized that migrators ascend into food-rich layers when hungry and descend after feeding, thus directly linking DVM to feeding. Likewise, Hardy (1953) and Stuart and Verheye (1991) suggested that carnivorous migrators, such as chaetognaths, might be simply following their herbivorous preys. However, in some cases, diel migration appears to have no link to feeding, e.g. when benthically feeding animals rise at night (as reported e.g. by Neverman and Wurtsbaugh, 1994). On the other hand, theories of migration based only on light or temperature effects, as driving factors, might not fully explain this complex biological phenomenon and ignore individual behaviours and responses to the environment (Gibbons, 1993). Laboratory studies show that organisms kept constantly at dark, with similar in situ conditions, continue to maintain a damped DVM rhythm, with an evening ascent and a clear downward movement in the morning (Häfker et al., 2017). This suggests the importance of an endogenous circadian biochemical internal clock and might explain the midnight sinking, the sunrise ascent (twilight migration) and DVM within the aphotic layer (van Haren and Compton, 2013). In fact, DVM is conditioned by a larger number of endogenous and exogenous factors (Ringelberg, 20~~09~~10). Among endogenous factors there are sex, developmental stage, age, genotype, size, and internal rhythms (Richards et al., 1996), while exogenous factors include light, food availability, gravity, thermohaline characteristics (temperature, salinity, stratification), oxygen and hydrostatic pressure.

Studying the diel vertical distributions of zooplanktonic biomass is essential to achieve a better understanding of the functioning of pelagic ecosystems and the biological pump. By feeding near the surface at night, and then fasting at depth during the day, where it continues to defecate, respire and excrete, migrating zooplankton removes carbon and nitrogen from the surface layers and releases them at depth (Hays et al., 1997; Longhurst and Glen Harrison, 1989; Schnetzer and Steinberg, 2002). Vertical migrators (including both zooplankton and phytoplankton) play a relevant role in the vertical fluxes of matter and energy in the marine environment. The net direction of this flux is downward, although migrators are able to return significant amounts of matter/energy upward, contributing to the effective recycling of nutrients within the euphotic zone (Pearre, 2003), thus supporting regenerated primary production.

Traditionally, DVM surveys are very time and labour intensive. Emerging technologies, such as acoustic techniques, can reduce this investment, greatly increasing the ability to decrypt the drivers, benefits for migrating organisms and total extent of vertical migrations. The Acoustic Doppler Current Profiler (ADCP) is a widespread instrument used to measure water current profiles. Since the pioneering work of Flagg and Smith (1989) ADCPs are used to investigate zooplanktonic DVM and zooplanktonic biomass from measurements of vertical velocity and echo intensity (a measure of acoustic backscattered energy). The operating principle of ADCP is based on sound backscattering by particles (such as sediments, organisms or bubbles) suspended in the water. The instrument emits acoustic impulses, with known frequency and receives the echoes, with a shifted frequency. The frequency shift is directly proportional to the velocity of the moving particles (Doppler effect) and is used to infer the velocity and direction of passive particles suspended along the water column (Teledyne RD Instruments, 2011). The basic assumption is that the particles are passively carried by water masses, and that they move together at the same speed. It is not possible to determine exactly how much of the sound reflected signal is due to zooplankton, since the acoustic waves are reflected by all objects of the size of about ¼ wavelength of the acoustic impulses (Thomson and Emery, 2014). If we consider the speed of sound in seawater around 1475 m/s and the ADCP working frequency of 76.8 kHz, the wavelength is about 1.9 cm, so objects greater than 0.48 cm reflect sound, while objects smaller than this scatter the sound. However, since swarms of zooplankton tend to aggregate at specific depths, also smaller organisms can be easily detected because acoustic backscatter strength is proportional to the density distribution of organisms (Iida et al., 1996).

In zooplankton DVM studies, usually two important assumptions are made: vertical velocity detected by an ADCP is due principally to zooplankton motion, under general oceanic conditions with negligible upwelling and downwelling phenomena (Heywood, 1996), as is the case in the Corsica Channel (e.g. Bakun and Agostini, 2001), and sound backscatter is due, in most cases, to zooplanktonic biomass (Wormuth et al., 2000). Sound backscattering is influenced by organism shape, orientation (Chu et al., 1992) and consistency, e.g. organisms made up mostly of protoplasm do not backscatter the acoustic signal proportionally to their size (Flagg and Smith, 1989), but can indeed also be due to phytoplanktonic organisms or turbulent events. Thus, in general, information on zooplanktonic biomass and vertical motion inferred from ADCP data are more qualitative than quantitative.

In this study an upward looking ADCP, moored at about 400 m depth within the 443 m deep Corsica Channel (western Mediterranean Sea) between Corsica and Capraia islands (Fig. 1), was used to investigate the DVM of zooplankton and its biomass variations along the water column from April 2014 to November 2016. The ADCP is part of a long-term fixed deployment (CIESM Hydrochanges Programme, Schroeder et al., 2013) and is used to measure water properties and currents ~~(Schroeder et al., 2013)~~, so the setting of the instrument was not originally thought for the application presented here. However, although the temporal and spatial resolutions are not in the optimal ranges, this method still provides a valuable insight on zooplankton DVM in the north-western Mediterranean Sea. The information derived by the ADCP is complemented by a morphological community analysis of in situ samples obtained with two net casts in the same area in August 2015. CTDs performed from a ship during maintenance operations of the mooring and from a moored profiling system provided data to characterize the study site.

To better interpret the ADCP data it is essential to know which organisms are common in the zooplanktonic community of the Tyrrhenian and the Ligurian Seas (Andersen et al., 1998; Pinca and Dallot, 1995; Sardou et al., 1996; Warren et al., 2004, McGehee et al., 2004). According to previous studies (e.g., Siokou-Frangou et al., 2010), in the Mediterranean Sea copepods are the most important epipelagic mesozooplanktonic group in terms of abundance and ~~biomass~~ biomass. Indeed, they represent 70% of the total zooplanktonic biomass during spring in the Ligurian Sea (Pinca and Dallot, 1955), mainly represented by e.g. *Clausocalanus* spp., *Oithona* spp., *Oncaea* spp.. ~~-~~According to Warren et al. (2014), the most abundant macrozooplankton groups in the Ligurian Sea during spring are ~~Euphausiids~~euphausiids, such as northern krill (*Meganyctiphanes norvegica),* siphonophores (e.g. *Chelophyes appendiculata*) and salps (e.g. *Salpa fusiformis* and *Thalia democratica*). In their review on macrozooplankton and micronekton in the ~~northwestern~~north-~~-~~western Mediterranean Sea, Andersen et al. (1998) and Sardou et al. (1996) also mentioned hydromedusae (e.g. *Solmissus albescens*), pteropods (e.g. *Cavolina inflexa*), mysids (e.g. *Eucopia Unguiculata*), peneideae, and two species of micronektonic fish genus cyclothone. These authors also described the vertical migratory behaviour of north-western Mediterranean species, finding an intraspecific variability in some of them, that show a bimodal distribution of their population at two different depths, with consequent different migratory behaviour, originated by differences of size and season.

ADCPs have been used in previous studies to investigate DVM in the Mediterranean Sea, in particular in the Ligurian Sea (Tarling et al., 2001, and Bozzano et al., 2014), in the Ibiza Channel (Pinot and Jansá, 2001), ~~and~~ in the Cretan Sea (Potiris et al., 2018), the Alboran Sea (van Haren, 2014) and in the Adriatic Sea (Ursella et al. 2018). Bozzano et al. (2014) used acoustic backscatter data from a moored ADCP to investigate zooplankton dynamics in the upper thermocline in the Ligurian Sea ~~and to infer the composition of the community in the Ligurian Sea~~. In the same area, Tarling et al. (2001) combined data collected by a vessel-mounted ADCP and net samples and found that in September the dominant groups in the first 500 m were euphausiids and pteropods during night, making inferences on the vertical migration velocities of these swarms as well. Pinot and Jansá (2001) studied DVM in the Ibiza channel, where they described light irradiance as the primary factor that controls DVM on the daily and seasonal basis. Potiris et al. (2018) studied the role of DVM for the functioning of the biological pump in the Cretan Sea, using a moored ADCP, CTD casts, net samples and other auxiliary information on environmental conditions, finding four different patterns of nocturnal DVM (divided by depth ranges). Ursella et al. (2018) studied how backscatter signal in the southern Adriatic Sea is linked with different environmental condition and the presence of different zooplanktonic groups. ~~-~~Other studies that successfully used this technique were conducted in other parts of the world oceans, e.g. in the North Atlantic (Heywood, 1996; Jiang et al., 2007; van Haren, 2007; van Haren and Compton, 2013) and in the South Pacific (Valle-Levinson et al., 2014). Pinot et Jansà (2001), Van Haren and Compton (2013) and Potiris et al. (2018) ~~for instance~~ investigated the link between the monthly lunar cycle and the DVM of deep planktonic organisms and pointed out the importance of the biochemical internal clock, while Valle-Levinson et al. (2014) found that twilight migration was predominant within Chilean fjords and was strongly influenced by the depth ~~of the depth~~ of the pycnocline. Most of these studies denote that acoustic data are more qualitative than quantitative, because attempts to calibrate~~ion~~ sound backscatter and zooplanktonic biomass from net samples are complex and not yet satisfactory (Flagg and Smith, 1989; Pinot and Jansá, 2001, ~~).~~Brierley et al., 1998).

Vertical velocity data show when zooplankton moves and in which direction, while data of acoustic backscattered energy allow to ~~determine how much~~ know relative ~~quantity~~abundances of zooplankton ~~is~~ present at a certain depth range and a certain time. In this study it is investigated how both parameters change at different temporal scales, from daily to seasonal, and at different depth ranges. Additional data (CTD casts, net samples, satellite data, sunrise-sunset hours, moon phases) are used to identify the possible drivers of zooplankton migration in the Corsica Channel, the zooplanktonic groups that can be found in the area, what kind of migration they do perform and how their biomass varies along the water column and in time.

The paper is organised as follows. First, the study area is described, based on previous knowledge and on a literature review, then, in section 3, the ADCP settings and quality control procedure are described, along with the explanation on how to compute the mean volume backscatter strength from the ADCP data. Data collected~~ions~~ by means of CTD casts, moored profiling systems, net samples and additional systems and methods are described in the rest of section 3. The presentation of the results and their discussion (section 4) starts with the characterization of the water column in the Corsica Channel (thermohaline properties, stratification, oxygenation, depth of the chlorophyll maximum) and the description of the acoustic backscatter and vertical velocities on the daily and the seasonal scale. The zooplankton community composition in summer 2015 is ~~then~~ described afterwards and put in relation to the acoustic observations of the same period. The section ~~is~~ concludes with ~~completed by~~ a lagged correlation analysis of the backscatter data and a time series of primary production in the area, to look for the timing of primary production blooms vs secondary production blooms. Finally, the conclusions are drawn at the end of the paper.

2 Study Area

The Corsica Channel separates Corsica and Italy and is the only (narrow) connection between the Tyrrhenian and the Ligurian Seas. Two water masses flow through this channel: the Atlantic Water (AW) in the upper layer and the Intermediate Water (IW) between 150-200 m and the bottom (maximum depth of about 450 m). The IW is the saltiest and warmest water mass of the whole Mediterranean Sea and originates in the eastern Mediterranean Sea; the AW comes from the Atlantic Ocean, crossing the Gibraltar strait, flowing into the Mediterranean Sea. While moving eastward above the IW, the AW is continuously modified by the interaction with the atmosphere and the underneath water masses, becoming gradually saltier and denser (Millot and Taupier-Letage, 2005). Both water masses enter the Tyrrhenian Sea from the south and then follow a cyclonic circulation along the Italian peninsula. When reaching the northernmost Tyrrhenian, parts of AW and IW cross the Corsica Channel (as the Eastern Corsica Current, ECC), where the mooring is located (Fig. 1), reaching the Ligurian Sea. The IW flows through the channel only in its deepest part, located between the islands of Corsica and Capraia. The flow is generally northward, stronger between winter and late spring (mean velocity 0.15-0.2 ~~c~~m/s), weaker during summer until late autumn (mean velocity 0.05-0.1 ~~c~~m/s). This pattern undergoes noticeable variations of intensity and duration mostly in the stronger flow period (Astraldi and Gasparini, 1992). To the north of Corsica, the ECC merges with the Western Corsica Current (WCC). The resulting current proceeds northward and then westward becoming the so-called Northern Current, a geostrophic frontal system along the continental slope, dividing coastal waters from denser waters of the central Ligurian Sea (Millot and Taupier-Letage, 2005).

The Mediterranean, as a whole, is considered an oligotrophic sea. The north-western Mediterranean (e.g., the Ligurian Sea), however, exhibits large areas of high chlorophyll values thanks to the upwelling in the central part of the basin induced by the cyclonic circulation, providing conditions for enhanced primary productivity, and a classical spring bloom. On the other hand, the Tyrrhenian Sea only has intermittent spring blooms, i.e. characterized by significant interannual variability (D'Ortenzio and D'Alcalà, 2009). The region of the Corsica Channel has intermediate characteristics between these two adjacent biogeographic regions.

3 Materials and Methods

3.1 ADCP settings, ~~and~~ data quality control and estimation of the Mean Volume Backscatter Strength

~~The operating principle of ADCP is based on sound back-scattering by particles (~~such ~~as sediments, organisms or bubbles) suspended in the water. The instrument emits acoustic impulses, with known frequency and receives the echoes, with a shifted frequency. The frequency shift is directly proportional to how fast~~ the velocity of the moving ~~particles move (Doppler effect) and is used to infer the velocity and direction of passive particles suspended along the water column (Teledyne RD Instruments, 2011). The basic assumption is that the particles are passively carried by water masses, and that they move together at the same speed. It is not possible to determine exactly how much~~ of the sound reflected signal ~~sound reflection is due to zooplankton, since the acoustic waves are reflected by all objects of the size of about ¼ wavelength of the acoustic impulses (Thomson and Emery, 2014). If we consider the speed of sound in seawater around 1475 m/s and the ADCP working frequency of 76.8 kHz, the wavelength is about 1.9 cm, so objects greater than 0.48 cm reflect sound, while objects smaller than this scatter the sound. However, since swarms of zooplankton tend to aggregate at specific depths, also smaller organisms can be easily detected because acoustic backscatter strength is proportional to the density distribution of organisms (Iida et al., 1996). In zooplankton DVM studies, usually two important assumptions are made: vertical velocity, detected under general oceanic conditions by an ADCP, is due principally to zooplankton motion, with negligible upwelling and downwelling phenomena (Heywood, 1996) and sound backscatter is due~~, in most cases, ~~principally to zooplanktonic biomass. Sound backscattering is influenced by organism shape, orientation (Chu et al., 1992) and consistency, e.g. organisms made up mostly of protoplasm do not backscatter the acoustic signal proportionally to their size (Flagg and Smith, 1989). Therefore, the data of zooplankton biomass and vertical velocity obtained by ADCP are more qualitative than quantitative.~~

Data of echo intensity and vertical velocity (W) were collected with an RDI WH Long Ranger 76.8 kHz ADCP, an instrument that is used in a long-term deployment and has a wide profiling range. The ADCP has four beams, which emit sound signals and receive echoes. These are put at 90° azimuthal increments to each other and pointing at 20° to the instrument axis. The four beams work as transducers converting sound signals in electrical signals. The ~~RDI WH Long Ranger~~ADCP is placed ~~at~~in ~~an~~ upward looking position~~upward looking~~ (the beams emit sound towards the surface) and is moored at about 400 m depth, near the bottom (which is at 443 m depth) of the Corsica Channel, between Corsica and Capraia islands (position 43.03° E, 9.68° N). The time series used for this study spans from April 5th 2014 to November 26th 2016. During the collecting period, the ADCP has been recovered 6 times for maintenance, therefore there are six interruptions (generally < 24 h) in the time series. The time series of vertical velocity and echo intensity were collected with a temporal resolution of 2 hours, an ensemble value resulting of 45 or 60 pings average (which means a sound pulse every 2.4 or 2 minutes, depending on the deployment configuration), and a vertical spatial resolution of 16 meters, which is the length of the depth cells (or bins) in which the vertical profile is subdivided. The blanking length, where the instrument does not measure, is 7.04 m above the transducer. All details of the ADCP setting during the 7 deployments are listed in Table 1.

~~It is noteworthy that a higher temporal resolution would have given a better estimation of patterns of vertical migration: during the averaging period of 2 hours some of the 45 or 60 pings might have intercepted organisms while they were moving, while other pings might have intercepted organisms when they were almost still at their comfortable depth. The spatial and temporal resolution was set to allow the mooring to be in place for about 6 months without compromising battery endurance and space on the internal memory.~~

While echo intensity data need additional processing ~~(see section 3.2)~~, W data did not need further handling, except for some data selection criteria and quality control considerations to discard the low-quality data (this was applied also to backscatter data). Given that the total bin number was set to 28 and considering the blanking length plus the bin size of 16 m ~~(D)~~, there were at least four bins above the sea surface, which were discarded. Also, the first bin, closest to the transducers, is not used because it may record erroneous data due to the time taken for transient acoustic waves to decay (Lane et al., 1999). Moreover, R, the slant range, i.e. the range of relevant scattering layers along each beam, defined as (see Deines, 1999)

$$R = \frac{B + \frac{(L+D)}{2} + [(N-1)\times D] + \frac{D}{4}}{\cos\theta} \times \frac{c}{c_0} \qquad (1)$$

must satisfy R< Hcosθ, where B is the blank distance from transducers to the first bin ~~(7.04 m for all deployments)~~; L is the transmit pulse length (m); D is the cell, or bin, length (m); N is the number of the cell (bin number); the angle θ, in degrees, is the inclination of each beam respect to the vertical axis of the instrument (20°); c is the sound velocity (m/s) for each bin (computed following IOC/SCOR/IAPSO, 2010) which depends on salinity (a nominal value of 38 has been used), temperature in °C and pressure in dbar; c_0 is the sound speed in seawater used by the ADCP (1475.1 m/s), H is the distance between the head of the ADCP and the surface (Teledyne RD Instruments, 2011). All R values from the 20th bin upwards exceeded the Hcosθ threshold and were thus discarded. -Only ~~in~~ for data collected during the 4th deployment (the deepest one, see Table 1) the R values ~~detected~~ computed in the 20th bin ~~was~~ were not exceeding the threshold and were not discarded. Thus, ~~in Eq. (2)~~ N maximum value is equal to 20 for the 4th deployment and 19 for all other deployments. To avoid tilt error, pitch and roll of the instrument must not exceed 15°, and the data collected when pitch and roll were higher than 15° have been discarded as well (Teledyne RD Instruments, 2011). Only few data were discarded due to this criterion, mainly in late winter and early spring, because of the strong currents that occur in this period of the year (Astraldi and Gasparini, 1992), which can cause the inclination of the entire mooring line. A last data selection criterion was the Percent Good (PG) that had to be greater than 90%. PG is a measure of the percentage of pings accepted to obtain the ensemble value of vertical velocity or echo intensity. Given all these constraints, ADCP gives information on DVM in a layer between about 70 m and 390 m. All considerations that will be made~~done~~ in the following need to take into account that there is a lack of information concerning zooplanktonic biomass and migration in the very surface layer and in the 50 m above the bottom.

~~3.2 Estimation of the Mean Volume Backscatter Strength~~

To express the measured quantities in sound backscattered energy instead of echo intensity (which is measured in counts), first the Mean Volume Backscatter Strength (MVBS), measured in dB re (4π~~/~~m)$^{-1}$, is calculated~~ following Eq. (1)~~, as described in Deines (1999):

$$MVBS = C + 10log_{10}\left[(T_x + 273.16)R^2\right] - L_{DBM} - P_{DBM} + 2\alpha R + K_c(E - E_r)\text{~~,~~} \qquad (\text{~~1~~}2)$$

where C is a constant factor specific of the ADCP model used (dB); T_x is the temperature detected at the transducer (°C); R is the slant rage (m) as defined by Eq. (~~2~~1); L_{DBM} is the $10log_{10}$ of the transmit pulse length (m), which is specific for each deployment; P_{DBM} is the $10log_{10}$ of the transmit power, specific for this ADCP model (24 W); α (dB/m) is the coefficient of sound absorption in seawater (Fisher and Simmons, 1977) at the specific bin depth and depends on the frequency of the sound pulse (76800 Hz in this case), temperature (T_x) and pressure; K_c converts counts in decibel and is defined by Eq. (~~4~~3) (Heywood, 1996); E is echo intensity (counts) calculated by averaging echo intensity detected by the four beams, while E_r is the noise value, i.e. the echo intensity detected by the instrument when there is no signal (50 counts in this case). The formula to compute K_c, that appears on the right-hand-side of Eq. (2), is given in Eq. (3):

$$K_c = \frac{127.3}{T_x+273} \qquad (3)$$

To be used in Eq. (2) R must not be less than $\pi R_0/4$ (Deines, 1999), with R_0 (Rayleigh distance) being 1.3 m for this specific ADCP model. Following Deines (1999), the equation to compute the term 2αR is Eq. (~~3~~4):

$$2\alpha R = \frac{2\alpha_p B}{cos\,(\theta)} + \sum_{n=1}^{b} \alpha_n \qquad (\text{~~3~~}4)$$

where α_p (dB/m) is the sound absorption at the depth of the ADCP; ~~B~~ b is the last bin number; $\alpha_n = 2\alpha D/cos(20)$ is the sound absorption for each cell. ~~The formula to compute K_c, that appears on the right-hand-side of Eq. (1), is given in Eq. (4):~~

~~$$K_c = \frac{127.3}{T_x+273}, \qquad (4)$$~~

All parameters are summarized in Table 1.

3.~~3~~2 CTD data

During servicing, between one deployment and the following one (see dates in Table 1), CTD casts are regularly performed, from surface to bottom. These 6-monthly data are useful to provide information on the stratification and the depth of the chlorophyll maximum (the so-called Deep Chlorophyll Maximum, or DCM) along the duration of the experiment. Each time pressure, conductivity, temperature, dissolved oxygen concentration and chlorophyll fluorescence were measured with a CTD-rosette system consisting of a CTD SBE 911 plus, a Wetlab fluorescence sensor, and a General Oceanics rosette. The CTD probes were calibrated before and after each cruise (dissolved oxygen and salinity also during each cruise). Maintenance operations and CTD casts were done from the Italian vessels *R/V Urania* and *R/V Minerva Uno*.

In addition, a profiling buoy system for real time data transmission has been mounted on the mooring from November 28th 2014 to March 20th 2015. The system is composed of two units: (i) a profiling buoy, carrying a CTD sensor (with temperature, salinity, oxygen and chlorophyll fluorescence sensors), Iridium antenna, and (ii) an underwater winch. Both units are provided with acoustic remote transceivers to communicate with each other, and with a deck unit. The profiling system is moored at 190 m depth on the mooring line, and it has been set to perform an upcast CTD profile from 190 m to surface once a day. Conversely to CTD casts, which are only snapshots of the thermohaline conditions at a specific day and time, these data gives a daily information on the whole upper layer for several months. A previous deployment in 2013 is extensively described in Aracri et al. (2016).

3.~~4~~ 3 Zooplankton net samples

The backscatter strength and vertical velocities data collected by ADCP were complemented~~integrated~~ by data on zooplankton community composition, obtained from two ~~net~~ samples retrieved in the Corsica Channel with a net of 1.13 m diameter and 200 µm mesh size. Some undersampling is possible since large organisms can avoid nets with a small mesh size (Moriarty et al., 2013). One net tow was done at the mooring location (Sample #1, August 24th 2015 at 8:37 UTC, bottom depth 443 m), while the mooring was recovered for maintenance, and the second one about 6.5 km to the west (Sample #2, 43.03° N, 9.60° E, August 24th 2015 at 10 UTC, bottom depth 234 m), from the Italian vessel *R/V Minerva Uno*. As the sampling net did not reach the bottom (it remains 10-15 meters above it), some organism might not be sampled if they stay in the deepest layer, close to the bottom, a common behaviour especially during the day (Vinogradov, 1997). Indeed, populations of many pelagic species extent into the hyperbenthic and benthopelagic environments within a few meters from the seafloor, where there may be significant accumulation of zooplanktonic biomass during the day in specific seasons (Mauchline, 1998 and references therein). The two stations were sampled for the taxonomic and quantitative characterization of mesozooplanktonic communities. Samples were collected by vertical hauls, almost from the bottom to the surface, using a standard Indian Ocean net equipped with flowmeters for filtered-volume calculation ~~(1.13 m diameter and 200 µm mesh size)~~ and preserved with borax-buffered formaldehyde. Taxonomic and quantitative zooplankton determinations were performed using a Zeiss stereomicroscope at the lowest possible taxonomic level (species level for copepods and cladocerans) on a representative subsample, while the total samples were analysed for rare species determination.

3.~~5~~ 4 Additional ancillary data and statistical methods

Additional environmental parameters were used for this study, to investigate a potential correlation with vertical migration and the amount of zooplanktonic biomass in the Corsica Channel and to explain what drives them. These parameters are: sunrise and sunset time (using the script *suncycle.m*, downloaded from ~~here:~~ http://mooring.ucsd.edu/software/matlab/doc/toolbox/geo/suncycle.html); surface Chlorophyll *a* concentration (Chl *a* in mg m^{-3}, 1 km resolution, 8-days averages) in the area of the mooring (downloaded for the domain latitude=43.0097°N, 9.4°E<longitude<9.8°E), computed via regional algorithms (Volpe et al., 2007) and retrieved from the COPERNICUS Marine Environment Monitoring Service, or CMEMS (product name "OCEANCOLOUR_MED_CHL_L4_REP_OBSERVATIONS_009_078", downloaded from ~~here:~~ http://marine.copernicus.eu/services-portfolio/access-to-products/); the moon phases (retrieved from https://aa.usno.navy.mil/data/docs/MoonPhase.php) to estimate the potential effect of moonlight on vertical migration patterns. Two statistical analyses were applied on the MVBS and W datasets, a spectral analysis using the fast Fourier transform (FFT) and a lagged cross-correlation analysis. FFT was applied to the datasets after data gaps were filled using a partial differential equation method, to identify the most relevant oscillations in the vertical migration patterns, observing the peaks with the highest amplitude at both high and low frequencies. Low frequencies peaks were determined after applying a low pass filter (frequencies < 5x10^{-7} Hz, that is approximately 23 days). The lagged cross-correlation analysis between MVBS and Chl *a* was done to investigate~~verify~~ if in this area the primary production is ~~results to be~~ a relevant driver for secondary production (for which MVBS is considered to be a proxy). The time series have been pre-whitened (a smoothing and a detrending was applied), to remove autocorrelation before assessing their cross-correlations, and the 95% confidence bounds have been computed.

4 Results and Discussion

The data collected by the ADCP are used to define the temporal and spatial variability of zooplankton DVM and zooplanktonic biomass distribution patterns during the investigated period. Additional environmental data are derived from CTD casts and satellite in order to improve knowledge about~~understand~~ what might possibly drive~~s~~ zooplankton behaviour and blooms, while the taxonomic analysis of the zooplankton net samples is used to describe the community structure. ~~In the following sections, results and their discussion are divided in four parts, starting with the description of the water column in terms of thermohaline characteristics and stratification in different seasons. Daily and seasonal cycles of acoustic backscatter intensity and vertical velocities are then discussed, while the third part is devoted to the discussion of the biological net sample data, that allow to gain a picture of which groups of organisms were present within the Corsica Channel during late August 2015. To conclude, the temporal pattern of phytoplanktonic blooming vs non-blooming periods (estimated by using Chl a concentration from satellite data) is compared to secondary production patterns (considering the integrated MVBS a proxy for zooplankton biomass in the water column) in the Corsica Channel.~~

4.1 Thermohaline characteristics within the channel

Seasonal variability of thermohaline characteristics in the area evidences marked differences between the stratified water column in summer and unstratified water column in winter. CTD data collected during mooring maintenance~~servicing~~ allow to investigate this behaviour (Fig. 2a-2d). CTD casts in March 2015 and 2016 are representative of ~~represents~~ the ending phase of winter conditions, with homogeneously stratified temperature vertical profiles and relatively higher level of dissolved oxygen at depth, as a results of wintertime open ocean convection. Chlorophyll fluorescence shows maxima in the surface layer ~~(Deep Chlorophyll Maximum, or DCM,~~ (at 20-30 m) approaching the spring phytoplanktonic bloom period and a weak secondary relative maximum in correspondence with~~of~~ an oxygen maximum at depth (200 m in March 2015 and 250 m in March 2016), possibly relict phytoplanktonic populations transported downward by vertical mixing or photosynthetic picoplankton able to use the wavelengths and low light levels that are characteristics of this depth. In summer the water column is well stratified, with the development of a sharp thermocline in the uppermost 20-40 m, lower surface oxygen contents, and a DCM at about 100 m (Fig. 2d). In fall, the surface layer undergoes a progressive cooling toward winter, the thermocline being at about 50-60 m and the DCM becoming weaker and shallower (60 m). Salinity below the interface between AW and IW (>200 m) ~~(except in winter when this interface is deeper)~~ is generally homogeneous, (except in winter when ~~is~~this interface is deeper) ~~and this level can be considered the transition between the AW above and the IW below~~ (Fig. 2b).

The evolution through winter can be followed by means of the daily data time series collected by the moored profiler (profiling range between 0 and ~~180~~ 190 m) that was in place from November ~~28th~~ 2014 to March ~~20th~~ 2015 (Fig. 2e~~d~~-2g~~e~~). Progressive cooling of the water column continues till late January (Fig. ~~2d~~2e), when fully mixed conditions are eventually met. Conversely, dissolved oxygen (Fig. 2f) as well as chlorophyll fluorescence (Fig. 2g) gradually increase in the whole upper layer while approaching spring season.

4.2 Acoustic backscatter and vertical velocity

Vertical velocities along the water column and backscatter strength are analysed to identify zooplankton motions and biomass variations~~, and to characterize different migratory behaviours of different zooplanktonic migrator groups~~. Since with a sampling period of 2 hours W values ~~result~~are very low and does not represent the actual velocity of these organisms, it is nevertheless used to provide insights on the net direction of motion (up or down) according to the hour of the day, season and depth range. ~~To this aim,~~ Additionally, without ~~lacking~~ the necessary net ~~data~~ samples that would allow ~~for~~ a proper calibration, MVBS is considered as an indirect and qualitative proxy of zooplanktonic biomass. In the following, we will refer to "zooplanktonic biomass" when referring to qualitative information inferred from MVBS data. ~~Since with a sampling period of 2 hours W values result very low and does not represent the actual velocity of these organisms, it is nevertheless used to provide insights on the net direction of motion (up or down) according to the hour of the day, season and depth range.~~

The data collected over the entire period of the seven deployments (April 2014-November 2016) are shown in Fig.~~ure~~ 3. MVBS is ~~the Mean Volume Backscatter Strength~~ computed with Eq. (~~1~~2) for each bin, while its anomalies (Fig. 3a) are obtained by subtracting from each MVBS profile the average MVBS profile of the entire period. All considerations that follow do take into account that there is a lack of information concerning MVBS ~~biomass~~ and ~~w~~W ~~migration~~ in the very surface layer and in the 50 m above the bottom.

MVBS anomalies (Fig. 3a) clearly present periodic oscillations, with notably higher than average values approximatively between November/December and April/May, denoting a zooplanktonic bloom that involves most of the ~~whole~~ investigated water column. ~~High surface values~~High values in the upper part of the investigated water column~~,~~ associated to low ~~deep~~ values in the deeper part of investigated water column are observed outside the zooplanktonic blooming periods. Since we use MVBS as~~is~~ a proxy of secondary production, the observed variability is probably linked to the primary production seasonality as well as to the alternation of stratified and mixing periods, as described earlier (Estrada et al. 1985). The peaks of the zooplanktonic blooming period in 2015 and in 2016 are slightly different, with 2015 presenting a prolonged and more intense increase in MVBS~~, as compared~~than ~~to~~ 2016.

~~Less evident~~ ~~I~~In Fig. 3a the~~,~~ ~~there is also a pronounced~~ daily cycle is not visible, and ~~as expected. T~~to show its features ~~more in detail,~~ Fig.3b-3g represent the temporal evolution of MVBS and W at selected depths (within the ~~surface~~upper, intermediate and deep layers) as a function of the hour of the day (UTC), and with the times of sunset and sunrise (that change seasonally) superimposed.

In the ~~surface~~ upper layer (bin centred at 97 m) MVBS is clearly higher during the night and lower during the day (Fig. 3b). Summer 2016 behaves differently compared to summer 2015, with very high values persisting night and day (June - July 2016). During the ~~blooming~~zooplanktonic blooming periods, MVBS peaks from 2 to 4 hours before sunset~~, a pattern that is consistent with the presence of seasonal twilight migrating organisms~~. W in the ~~surface~~ upper layer (Fig. 3c) is clearly directed upward (positive W) at sunset and downward (negative W) before dawn, during the whole duration of deployment. This is consistent with the classical picture of nocturnal DVM. In February - March (2015 and 2016) there are very strong positive values quite persisting night and day.

In the intermediate layer (bin centred at 209 m) MVBS has a more pronounced daily pattern than in the ~~surface~~ upper layer (Fig. 3d), with nocturnal high backscatter strength and diurnal MVBS minima. The summer 2016 persistent high values found in the ~~surface~~ upper layer are absent at mid-depth. Also, here the MVBS starts to ~~rise~~ increase from 2 to 4 hours before sunset, especially during the zooplanktonic blooming period, as observed in the upper layer ~~above~~. The patterns of descent and ascent (Fig. 3e) are clearly observed throughout the whole period and follow closely the seasonality of sunrise and sunset times. Downward velocities at sunrise are much stronger than in the ~~surface~~ upper layer and also than the upward velocities at sunset. In summer (2015 and 2016, less in 2014) there is a strong upward motion just after sunrise, which is ~~coherent~~ consistent with twilight or reverse migration patterns.

In the deep layer (bin centred at 353 m) MVBS is quite~~very~~ high during the whole experiment (Fig. 3f), with small differences between day and night. We discarded the possibility of this layer being a nepheloid layer, after investigating several historical turbidity data (from a transmissometer mounted on the CTD-rosette system) at the same location (above 410-420 m ~~high~~ turbidity levels were always low ~~not found at depths shallower than 410-420 m, which~~ ~~is below the depth of the ADCP~~).

Overall, except during the zooplanktonic blooming periods, it appears that ~~daily~~ diurnal MVBS values are slightly higher than nocturnal values of MVBS, ~~suggesting~~ indicating that some organisms migrate from higher levels down to ~~this~~ high depths during the day. However, ~~Fig. 3g suggests that~~ in the deep layers the migration is hardly seen (Fig. 3g)~~much lower~~. It is likely that this layer is occupied by non-migrating organisms or organisms that have a reduced migration. During the zooplanktonic blooming period in winter-spring, MVBS reaches the highest levels, with no difference between day and night, and with 2015 showing a more intense peak than 2016. At this depth, W (Fig. 3g) is not clearly correlated with sunlight, with prevalent negative velocities occurring almost at all times. Downward motions are stronger in 2016 from late winter to spring, in summer 2014 and 2015 during night and in the hours before and after sunrise. Upward motions are very weakly correlated with sunset and slightly increase from noon to sunset ~~some~~during some periods and during the 2015 ~~blooming~~zooplanktonic blooming period.

~~To investigate more in detail the seasonal variability of MVBS along the water column, as well as the different patterns of MVBS and W during blooming and non-blooming periods, the seasonal cycle and the evolution of DVM parameters as a function of the hour of the day and depth are shown in Fig. 4.~~To investigate more in detail the seasonal variability of MVBS along the water column, as well as the different patterns of MVBS and W during the zooplanktonic blooming period (approx. from December to April, defined as the period when the integrated MVBS values stay above a certain threshold value) and the non-blooming period (approx. from May to November, defined as the period when the integrated MVBS values stay below that threshold), these parameters are shown as a function of depth and month of the year (monthly means in Fig. 4a-4b) and time of the day (Fig. 4c-4f), respectively.

In particular it is observed that the highest values of monthly mean MVBS~~, integrated over the whole investigated water column,~~ occur between November/December and April~~/May~~ (Fig. ~~3a and~~ 4a), which corresponds to the zooplanktonic blooming period, and with a peak that involves the whole water column in ~~February~~ March. The associated standard deviation (Fig. 4b) shows that the zooplanktonic blooming period is also the one with less variability. During the rest of the year (the non-blooming period), MVBS is very low, especially at mid-depth (between 150 and 300 m), while it presents a ~~marked~~higher degree of interannual variability, as evidenced by the standard deviation (particularly high between 200 m and 330 m, from June to October). Such MVBS seasonal pattern is likely to be the response of zooplankton to both the different thermohaline conditions of the water column (MVBS increases when stratification is weaker and the thermocline is almost absent, see section 4.1) and the seasonality of phytoplankton blooms and DCM position (see section 4.1 and the following 4.4 for details). During summer-autumn, when stratification is stronger and the DCM is deeper (Fig. 2d), MVBS maxima are split into two layers (Fig. 4a), a shallower one and a very deep one, which is likely to be due to the presence of two zooplanktonic communities with different depth-based habitat preferences (as found also by Heywood, 1996, and Pinot and Jansà, 2001). This is a consistent pattern, as denoted by the mostly low standard deviations in these two layers during the non-blooming period (Fig. 4b). Since the ADCP measurements miss the first tens of meters of the water column, the summertime increase of MVBS at 70-100 m might be also a consequence of a cyclic summer descent (due to the increase of irradiance) of a group of epi-zooplanktonic organisms, that during the rest of the year finds food and optimal light and temperature conditions in more superficial waters~~,~~

~~which the ADCP data were not able to detect~~. It has been previously reported ~~is known~~ that in the western Mediterranean during summer the zooplanktonic biomass maximum at daytime is concentrated around the same depth as the DCM (in the range from 70 to 90 m, which is close to the upper limit of the present observations), while at night this maximum raises up to less than 20 m (Alcaraz, 1985).

~~To characterize the~~The different DVM patterns during zooplanktonic ~~no~~ blooming and no-blooming periods~~,~~ are shown ~~MVBS and W variations as a function of depth and of the hour of the day are shown as average values between May and November (defined as the no-blooming period, exact dates were defined based on the integrated MVBS values falling below a certain threshold) and between December and April (defined as the blooming period, exact dates were defined based on the integrated MVBS values exceeding the same threshold)~~ in Fig. 4c-4d and in Fig. 4e-4f, respectively. At a first analysis ~~of these figures~~, sunlight is easily identifiable as the most important driver of ~~diel vertical migration~~DVM both during no-blooming and blooming periods.

During the no-blooming period MVBS shows a bimodal distribution, with high zooplanktonic biomass levels being evident both in the upper layer (above 120 m) and in the bottom layer (below 330 m), and very low levels at mid-depth (Fig. 4c), a feature that was evident also in the seasonal full-depth analysis in Fig. 4a. In the course of the day the mid-depth minimum becomes thicker, expanding mainly towards the deeper levels (Fig. 4c): although thinner, the MVBS minimum layer persists also during night, occupying the depth range of 150-250 m, as opposed to the 120-350 m range occupied during day (with maximum thickness at midday). In the upper layer MVBS is higher during night than during day, while at depth it maintains approximately a constant level, with only a slight increase during day. Vertical motion is directed downward along the whole water column during night, with a maximal intensity at dawn (4-6 UTC) and bidirectional during the day, with a maximum upward intensity at dusk (16-18 UTC) above 300 m (Fig. 4d).

During the blooming period the bimodal distribution of MVBS is weaker (Fig. 4e), with zooplanktonic biomass in the upper layers exhibiting lower levels compared to both the deep layer and to the upper layer during the non-blooming period (Fig. 4c). However, it has to be considered that no data are available for the most superficial bins for this period (as a consequence of the quality control applied to the raw data, see section 3.1), so it remains questionable whether more zooplanktonic biomass is found above these levels or not. During the blooming period the MVBS minimum layer is thinner and resides at shallower depths if compared to the non-blooming period (80-270 m instead of 120-350 m depth range). In addition, the day-to-night differences of this layer are less pronounced during this period (Fig. 4e). Vertical motion during the blooming period (Fig. 4f) is directed downward at 6-8 UTC (a bit later because of later sunrise times during the blooming period), while the upward migration occurs mostly at 16-18 UTC, and is more intense than during the non-blooming period (Fig. 4d). Thus, it appears that in the investigated water column ~~DVM~~ active upward motion is intensified during the blooming period and that zooplanktonic biomass in the upper layers is relatively lower than during the non-blooming period.

These outcomes are consistent with the hypothesis (Hardy and Gunther, 1935; Huggett and Richardson, 2000) that when food availability is high (as occurs during phytoplankton blooms, which will be discussed in section 4.4), the migration is intensified, because herbivorous zooplankton feeds enough during the night to stand the costs of not-feeding during the day by descending in deeper layers in order to hide from visual predators. In contrast, when food availability is scarce (non-blooming periods), those organisms have to take the risk of predation by staying in ~~surface~~ the upper layers during the day to compensate the shortage in food sources. However, it needs to be taken into account that the observed differences during the two periods may also be explained by a community shift and other environmental factors, e.g. stratification, thermocline depth and position of the DCM. Indeed, according to Angel (1968) and Ringelberg (~~2009~~2010) a strong thermocline has a negative effect on vertical migration, which implies that the bimodal distribution and the reduced vertical migration observed during the non-blooming period can also be attributed to the strong thermoclines that develop during late-spring/summer (Fig. 2a and section 4.1).

As has been described and depicted in Fig. 3b-~~3~~g and Fig. 4c-f, nocturnal migration with a 24 hours cycle (a circadian cycle conditioned by sunlight) is the most evident type of migration in the study area. Yet some other migrating cycles could be hidden. For instance, from Fig. 4d and 4f, it appears that there is a strong descent after sunset, at 20-22 UTC during the non-blooming period (less strong at 18-20 UTC in the blooming period), which could be identified as a signature of reverse migration. ~~During both periods, an upward motion is evident after sunrise, a feature that is characteristic of twilight and reverse migration.~~

In order to identify other migration patterns, a fast Fourier transform (FFT) is applied to the dataset of MVBS and W (Fig. 5a and 5b, respectively). The spectral analysis is applied also to the low-pass filtered time series to identify lower frequencies signals (Fig. 5c and 5d, respectively for MVBS and W).

It is well evident that MVBS and W have the same peak frequencies at periods lower than 1 day, although with differences in amplitude (Fig. 5a-5b). The most evident peak is at 24 hours, as expected by the prevalent nocturnal DVM pattern, as well as by the less frequent reverse migration. The amplitude of the peak is the highest at mid-depth (bin centred at 209 m), while it decreases both upward and downward (being minimum within the bin centred at 353 m). This difference between layers has already been observed while discussing Fig. 3b-3d-3f. At 12 hours there is a prominent peak ~~at 97 m and 209 m (hardly visible at 353 m),~~ both for MVBS (at 97 m and 209 m, but hardly visible at 353 m) and W (at all three depths), which might be due to some zooplanktonic groups that do reverse migration: although ~~taken singularly~~ this migratory behaviour has a 24 hours cycle as well, and occurs ~~at~~ during sunset (descent) and sunrise (ascent) as does nocturnal migration, if reverse and nocturnal migration both occur this can produce a signal at 12 hours (the time lapse between two consecutive ascending events and two consecutive descending events is around 12 hours). The fact that the 12 hours peaks in MVBS are less intense than the 24 hours peaks suggests that reverse migration does not take place~~s~~ all over the year or does not involve a large number of organisms. This would also explain why reverse migration was not evident in Fig. 3b-g. ~~Other authors (Bozzano et al., 2014; Picco et al., 2016) consider t~~The 12 hours peak could also be due to twilight migration, as suggested by Bozzano et al. (2014) and Picco et al. (2016). The other peaks, at 8 hours, 6 hours (both very strong at 209 m, almost absent at 353 m) and 4.75 hours (not visible at 353 m), in both MVBS and W spectra, are quite difficult to attribute to a specific migrational behaviour, and could possibly be due to different groups performing different patterns of twilight migration ~~(ascent at dusk and sunrise, descent at midnight and immediately after sunrise)~~, with 4.75 hours being consistent with the mean time lapse between midnight descent and sunrise descent. Indeed, in Fig. 4~~3~~d (W during the no-blooming period) it is possible to see ascending motions right after the descent at sunrise, followed by upward velocities at sunset, i.e. 8 hours later on average. The low amplitude of these peaks again suggests that also twilight migration does not take place all over the year or does not involve a large number of organisms.

~~Notable low~~Some low-frequency peaks appear in the low-pass filtered MVBS and W time series (Fig. 5c-5d), although not very pronounced ~~are at~~ (28-30 days, which might indicate a cycle connected with moon phases; ~~, and thus with the alternation of strong and weak moonlight during night. The~~ 80-96 days, which might ~~peaks (visible at all three depths, but less intense at 353 m) are clearly~~ relate~~d~~ to the alternation of ~~the four~~ seasons~~,~~; ~~while the~~ 160-193 days, possibly ~~peaks~~ reflecting the broader periods of zooplanktonic blooming and non-blooming;~~. Indeed, there are so many differences between them, as seen earlier, and they correlated with water column properties (section 4.1). The~~ 322 days, ~~peak (not visible at 97 m for MVBS)~~ i.e.~~is~~ almost one-year period, ~~and since our time series is just 2 years and 8 months long, this simply~~ which might correspond~~s~~ to the mean time lapse between two consecutive spring maxima ~~(~~and/or summer minima~~) at the three selected depths~~).

4.3 Zooplanktonic community composition in summer 2015 and associated DVM patterns

In order to describe the zooplankton community, two net samples collected in the study area in August 2015 are discussed in detail in the following, keeping in mind that these samples are snapshots of a diurnal situation in a specific summer and cannot give insights into the temporal variability of the community ~~(they rather give a snapshot of it during day and in summer)~~ and that the vertical distribution is not resolved, being the samples collected by integrated vertical tows. However, they are the sole ground-truth information that is available and it is therefore relevant to be reported here.

In the two stations, ~~the~~ copepods were by far the most abundant group ~~were the copepods~~ with 83% ±0.4 of the total community, followed by other taxa, mainly represented by appendicularians and chaetognaths, with 13% ±2.8 and then by cladocerans with 4% ±3.2 ~~(Fig. 6a)~~. Both stations showed a very similar community dominated by few species, mainly belonging to epipelagic copepods, with the two most abundant genera, i.e. *Clausocalanus* spp. and *Oithona* spp., accounting for more than 50% of the total abundance (Table 2). In the ~~more~~ western and slightly shallower station (sample #2), the abundance of cladocerans was higher compared to the station at the mooring location (sample #1), as is evident from Table 2. The community is essentially composed by organisms that do not migrate significantly (Scotto di Carlo et al., 1984), which is consistent with the reduced migration during summer detected by ADCP (Fig. 4d). Most organisms found in the samples were smaller than the size detection limit in this configuration (0.48 cm), therefore the ADCP detects them only in high-density aggregations.

To explore more in detail the DVM patterns that involve the sampled community, the evolution of MVBS anomalies around the time of the zooplankton sampling (± 15 days) is shown in Fig. 6~~b~~. Around new moon MVBS shows lower levels than around full moon, especially in the shallower ~~more superficial~~ bins, which is consistent with the different light conditions during night.

An evident pattern visible in Fig. 6~~b~~ is the ~~descent~~ low MVBS levels during the day and the high levels during night, between 150 and 250 m~~, performed by organisms of shallow layers~~. The alternation between night and day is clearly visible in Fig. 6~~b~~, as well as the presence of some groups performing migrations throughout the whole investigated water column (about 100-300 m): although we did not sample them, these could be macrozooplanktonic organisms, as suggested by, e.g. Pinot and Jansà (2001) and Heywood (1996).

As described earlier (see Fig. 4a), August is generally a period of low MVBS anomalies, with the exception of the most superficial bins. The increase of phytoplanktonic biomass in the layer between 60 m and 80 m, as shown in F~~f~~ig. 2d, can be explained by the summer deepening of the DCM, which is possibly accompanied by a descent of the zooplankton maximum (i.e., from the very surface layer, outside the range of the ADCP, down to 60-80 m depth, see Fig.4a). This is consistent with the behaviour of the sampled community, ~~(~~ e.g.~~,~~ *Clausocalanus* spp. and *Oithona* spp.~~)~~ (Scotto di Carlo, 1984).

4.4 Primary and secondary production

To understand how primary production drives the seasonal cycle of secondary production (shown in Fig. 4a) in the Corsica Channel, in Fig. 7a a comparison is made between the temporal evolution of the 8-days Chl *a* average in the area of the mooring location and the 8-days averages of the integrated MVBS anomalies (obtained by summing up, along the vertical, the MVBS anomalies of each bin) of the whole investigated water column, of the shallow layer (73-201 m) and of the deep layer (201-378 m) during the whole deployment period.

It is clearly visible that MVBS anomalies and Chl *a* have a similar temporal evolution, with only slight differences in the timing of seasonal peaks: in late November 2014 a small Chl *a* peak and a contemporary peak of MVBS occurred; between early February and March 2015 an important zooplankton bloom follows a Chl *a* peak in January 2015 and occurred while Chl *a* again peaked in March 2015; in summer 2015 there were three little MVBS peaks that are absent in summers 2014 and 2016, which explains the high standard deviation of the monthly means during summer shown in Fig. 4b; finally in late winter 2016 Chl *a* reached its annual maximum, which was accompanied by a bloom in secondary production.

To further investigate the primary and secondary production blooms, in Fig. 7b the results of a lagged correlation analysis between MVBS (total, shallow and deep) and Chl *a* are~~is~~ shown. ~~There is no lag w~~When comparing the total ~~and deep~~ MVBS with Chl *a* ~~(that well correlate)~~, there is a lag of about 1 week.~~indicating that the data series co-vary with the same timing (on the 8-days window)~~, while the deep MVBS and the Chl *a* series co-vary with the same timing (on the 8-days window), with no lag. On the other hand, w~~W~~hen considering only the ~~-~~shallow MVBS it results that the peaks in primary production precede the peaks in secondary production by about three and a half ~~3~~ weeks ~~in the Corsica Channel~~. The pattern of shallow MVBS vs Chl *a*~~is~~ ~~pattern~~ is ~~what is expected~~ consistent ~~from~~ with previous knowledge, ~~since~~ according to which ~~generally after~~ about a month ~~since the~~ after the surface primary production bloom, ~~there is~~ a zooplanktonic bloom ~~in zooplankton biomass~~ develops (e.g. Truscott and Brindley, 1994). The small ~~absence of any temporal~~ lag we found for total MVBS vs Chl *a* and the zero lag for deep MVBS vs. Chl *a* ~~in the Corsica Channel is~~ are somewhat unexpected, but it is necessary to keep in mind that the temporal resolution of the Chl *a* field from satellite is 8 days and that it is an exponentially weighted near-surface value ~~a surface value~~ and not an integrated value of the primary production within the whole euphotic layer (down to the DCM). Furthermore, the MVBS data do not reach the very surface layer and the very bottom layer, where some zooplankton organisms might concentrate or peak with different timings. In addition, according to Madin et al. (2001) if the bulk of zooplankton within a water column is composed by vertical migrators, its growth dynamics are not necessarily only coupled to surface primary production.

~~Correlation between MVBS and Chl *a* in the Ligurian Sea has been investigated by Warren et al. (2004) and McGehee et al. (2004), who observed that small (large) zooplankton and Chl *a* was negatively (not) correlated.~~ Zooplanktonic biomass and distribution are strongly related to hydrodynamic processes (Champalbert, 1996). Due to the mainly northward current and the role of hydrodynamic processes in Corsica Channel, we consider that the study area is strongly influenced by the biological processes that occur upstream, i.e. in the northern Tyrrhenian sea, an oligotrophic sea that comprises neritic waters where zooplanktonic biomass might be higher and their blooms can occur earlier as compared to oceanic waters. Phytoplanktonic blooms in the neritic areas of the northern Tyrrhenian and the Ligurian Seas occur in late winter early spring, which corresponds to what can be seen in Fig. 7a (Marchese et al., 2015). Strong currents could be responsible of changes in the amount of zooplankton in the water column during their blooming period (when currents are stronger, see section 2), and organisms could have been brought in the region by lateral advection, and not be supported by local phytoplankton blooms.

5 Conclusion

DVM, one of the most important survival strategies adopted by zooplankton, has been investigated in the Corsica Channel, connecting the Tyrrhenian and the Ligurian Seas (western Mediterranean). An analysis of acoustic backscatter (MVBS) and vertical velocity (W) data, collected by a moored ADCP over more than two and a half years, was aimed to obtain a picture of the migratory behaviour of zooplankton at the daily and the seasonal scale, in relation to the alternation of day and night, to the seasonal stratification of the water column~~, to dissolved oxygen concentration~~ and to blooms of primary production. ~~The investigated area belongs to an oligotrophic region, which is characterized by a predominant northward current. Seasonal variability of the thermohaline characteristics evidences marked differences between the stratified water column in summer and unstratified water column in winter. Chlorophyll fluorescence gradually increase in the whole upper layer while approaching spring, and the deep chlorophyll maximum (DCM) is undergoing a clear seasonal cycle, being deepest in summer and autumn, and becoming shallower, but more intense, in winter and spring.~~ Along with light and food availability, stratification and DCM depth are potentially relevant drivers for the seasonal differences of zooplanktonic migratory patterns. The most significant migrations of zooplankton in the Corsica Channel occurs at sunrise (downward) and at sunset (upward). DVM is well recognizable in the intermediate and upper layers and less in the deep one, probably because of the presence of non-migrating epi-benthic or benthopelagic organisms. The night-time zooplanktonic biomass increases in the upper~~shallow~~ layers and ~~its~~ decreases in deep layers, ~~is~~ due to nocturnal feeding on phyto- or even zooplankton in the euphotic layer, as done by strong migrators, like e.g. some chaetognaths (Pearre, 2003). The net samplings evidenced copepods as the most abundant group, followed by other taxa, mainly appendicularians and chaetognaths, and by cladocerans. The zooplankton night-time descent is a well-known behavioural pattern (nocturnal sinking), when sated organisms move downward ~~sink passively due to their higher body density~~to avoid predation (Tarling et al., 2002).

At the daily scale~~, alternation of high and low MVBS is clear in the uppersurface layer. Especially during blooming periods~~, ~~it~~ MVBS peaks from 2 to 4 hours before sunset, especially during zooplanktonic blooming periods, ~~a pattern that is consistent with the seasonal presence of twilight migrating organisms~~with~~. In the intermediate layer MVBS has a more pronounced diurnaldaily pattern than in the surface layer, with nocturnal high backscatter strength and diurnal MVBS minima.~~ the alternation of upward and downward motions ~~The patterns of descent and ascent are clearly observed throughout the whole period and follow~~ closely following the seasonality of sunrise and sunset times. ~~In the deep layer MVBS is very high during the whole experiment with small differences between day and night. Here, daily MVBS values are slightly higher than nocturnal values (the opposite occurs in the intermediate and surface layers), suggesting that during the day there are organisms that migrate from above to high depths (> 350 m).~~

At the seasonal scale, acoustic backscatter clearly presents periodic oscillations, being higher between late winter and early spring. This bloom in secondary production appears to be stronger in deep layers and during its peak it involves the whole investigated water column ~~and appears to be stronger in deep layers~~. The bloom is linked to the alternation of stratified and mixing conditions in the water column (MVBS increases when stratification is weaker and the thermocline is almost absent), to the DCM depth, as well as to the seasonality of phytoplankton blooms. ~~In order to identify differences in migratory behaviour according to food availability and light conditions, the blooming and the no-blooming periods have been studied separately. During both periods there are clear upward and downward motions at sunset and sunrise, respectively. However, t~~The blooming period is characterized by a downward movement in the deeper layers and an upward movement in the upper layers throughout the day~~. ~~, while ~~D~~during the no-blooming period, zooplanktonic biomass maxima split along the water column, with one group of organisms located close to the DCM and the other one in the deep layer (below 300 m). In the course of the day the mid-depth zooplanktonic biomass minimum becomes thicker, expanding mainly towards the deeper levels. The superficial group, close to the DCM, is especially evident during the zooplanktonic no-blooming period, because of the shallower thermocline and the stronger irradiance during summer (as found also by Pinot and Jansà, 2001~~0~~). During the zooplanktonic blooming period the bimodal distribution of MVBS is weaker and the MVBS minimum layer is thinner and resides at shallower depths if compared to the non-blooming period. In addition, the day-to-night differences in zooplanktonic biomass of this layer are less pronounced during the blooming period. ~~Thus, i~~It appears that in the investigated water column ~~DVM~~ upward motions are~~is~~ intensified during the blooming period. Consistent with the hypothesis of Hardy and Gunther (1935) and Huggett and Richardson (2000), high food availability results in intensified migration, while scarce food availability results in less intense migration, given the necessity to feed in surface layers also during the day (in spite of the predation risk) in order to compensate for food lack. It is noteworthy, however, that the observed differences between the two periods might not be only correlated to the food availability, but even be a consequence of a community shift or of other seasonally changing environmental factors, e.g. stratification, thermocline depth and position of the DCM.

A spectral analysis applied on both MVBS and W time series confirms the predominance of nocturnal DVM behaviour in this area. Still, other migration patterns (twilight and reverse) could be identifiedrecognised, probably performed by a minority of organisms. The 24 hours peak in the spectrum is linked mainly to nocturnal DVM, while the 12 hours peak is thought to be due to the contemporary presence of organism performing reverse DVM. Other peaks at higher frequencies are linked to different migration patterns along the migratory *continuum* defined by Haney (1988). Longer periods have been identified, that corresponds to The spectral analysis performed on the low-passed time series evidenced peaks at the frequency of the moon cycle (28-30 days), of the four seasons (80-96 days, visible at all levels, but less intense at depth), and of periods in the range 160-193 days (depending on the depth) that might reflect the broader zooplanktonic blooming and non-blooming periods. Bozzano et al. (2014) found that in the shallow water column (0-80 m) of Ligurian Sea zooplanktonic biomass follows the primary production signal with a delay of about 1 month in the Ligurian Sea, a result that is consistent with the finding of the present study, with primary production peaks preceding the peaks in shallow secondary production by about 324 days weeks in the Corsica Channel. The absence of any temporal lag when comparing deep MVBS vs. Chl *a* in the Corsica Channel is somewhat unexpected, but also according to Madin et al. (2001), if the bulk of zooplankton within a water column is composed by vertical migrators, its growth dynamics are not necessarily only coupled to surface primary production. Other studiesother studies have shownned that zooplanktonic biomass peaks are often coincident (no lag) with chlorophyll maxima (e.g. Jiang et al., 2007).

Knowledge about zooplankton migratory patterns, especially on long time scales (seasonal to interannual), is severely limited because of the difficulties related to net sampling (particularly in the open sea) and to time-consuming taxonomic determinations. Zooplankton plays a pivotal role in the marine food web, biological pump and carbon sequestration, therefore an automatic measurement system with high temporal and spatial coverage, provided by the ADCP, greatly contributes to the understanding of zooplankton distribution along the water column in different seasons and at different hours of the day, information that are relevant for the modelling of the complex marine biogeochemical mechanisms in which zooplankton is involved. Long time series of acoustic data allows to shed light on scales not resolved by traditional net sampling and this application is a good example of intense exploitation of existing data sets for multiple purposes.

Data Availability

ADCP and CTD data can be provided upon request by the authors.

SST field data (27 Aug 2015, °C) can be downloaded from the Copernicus catalogue CMEMS (http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=SST_MED_SST_L3S_NRT_OBSERVATIONS_010_012)

Acknowledgments

The authors thank the Captains, the crews and the technicians of the Italian vessels R/V Urania and R/V Minerva Uno. This work was supported by the project OCEAN-CERTAIN (GA# 603773) and JERICO NEXT (GA# 654410) of the European Commission, SSD Pesca project of the Ministry of Economics and Finance; RITMARE flagship project of the Ministry of Education, Universities and Research and the Italian Ministry of Environment for the implementation of the Marine Strategy Framework Directive in Italian waters; the CIESM Hydrochanges Programme. Finally, we would like to thank to anonymous reviewers for the constructive criticisms and their valuable suggestions that greatly helped to improve the manuscript.

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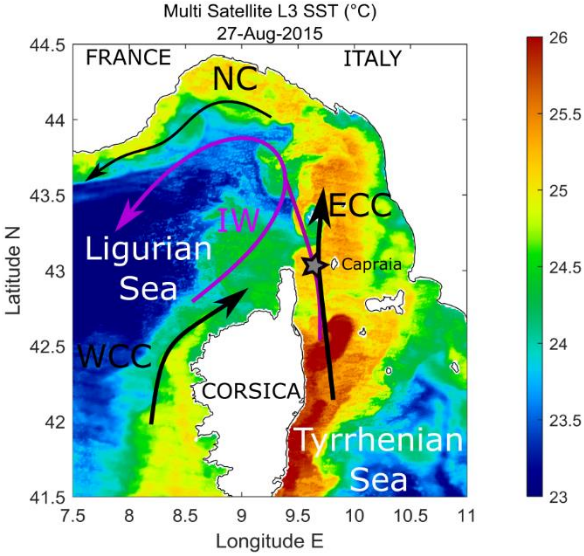

Figure 1: Map of the area. Main current features (ECC=Eastern Corsica Current; WCC=Western Corsica Current; NC=Northern Current; IW=Intermediate Water pathway) and the position of the moored ADCP (star), are indicated. In the background (colour coded), the SST field from a sample day (27 Aug 2015, °C) is provided to highlight the mesoscale and frontal systems (source CMEMS).

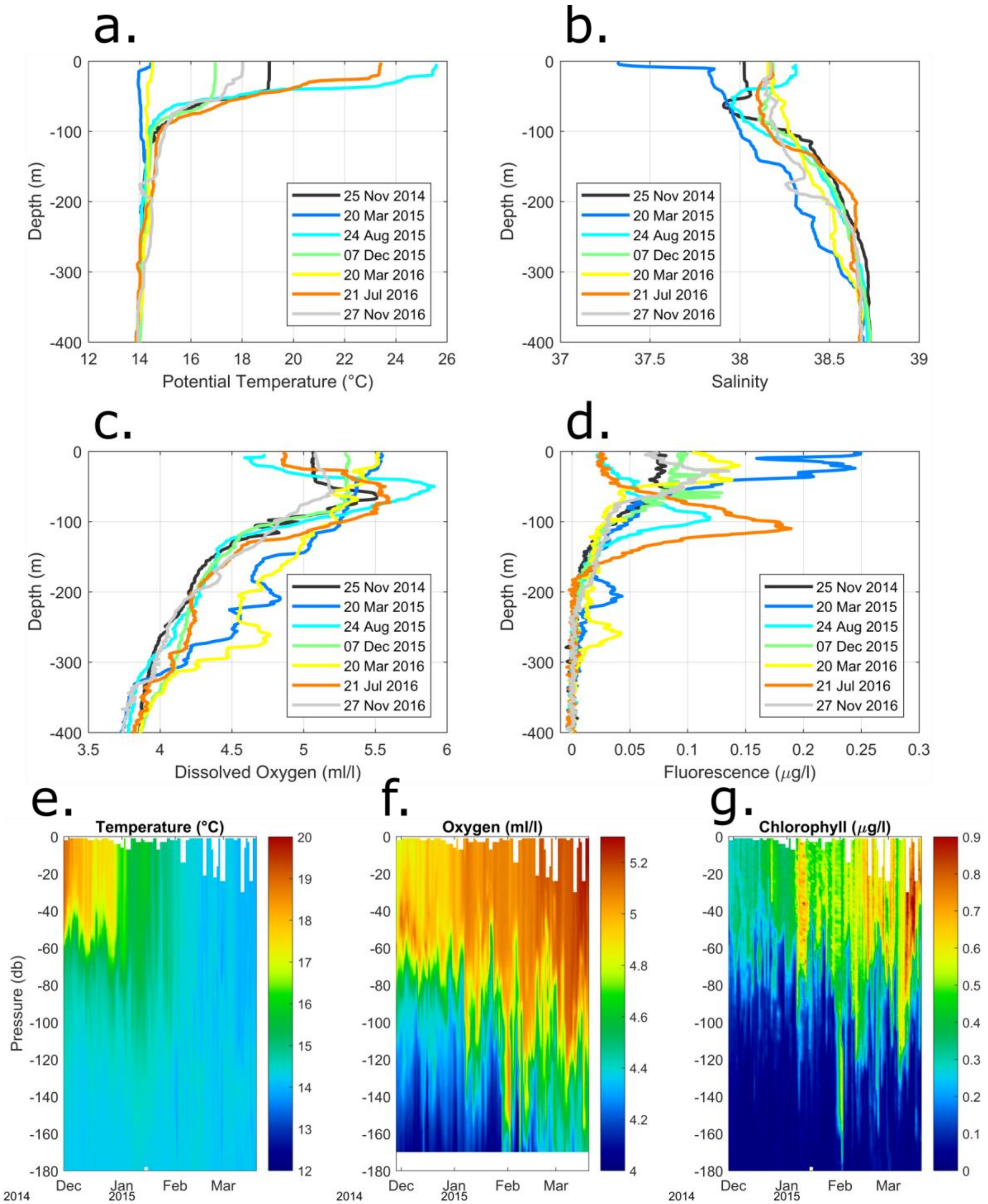

Figure 2: (a-d) Vertical profiles of potential temperature, salinity, dissolved oxygen and chlorophyll fluorescence, respectively, from CTD casts carried out during servicing at the mooring location; since density is controlled by temperature the thermocline depth is essentially equivalent to the pycnocline depth; (e-f) daily vertical profiles of temperature, dissolved oxygen and chlorophyll concentrations, respectively, ~~between 0 and 180 m,~~ from ~~December~~ November ~~2015~~ 2014 to March ~~2016~~2015, as recorded by the moored profiler.

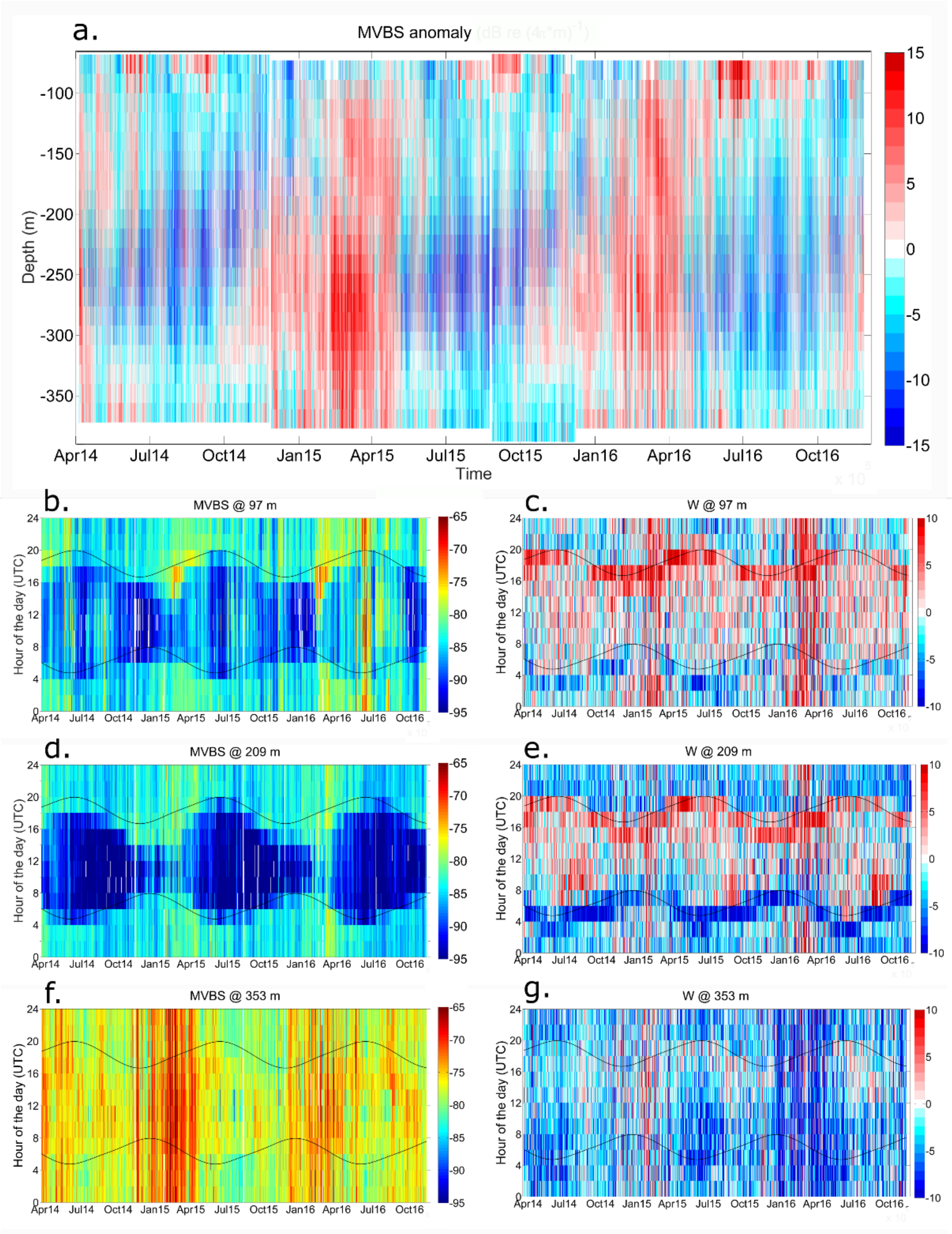

Figure 3: (a) Time series (2-hourly) of vertical profiles of MVBS (mean volume of backscatter in dB re(4π*m)$^{-1}$) anomalies (referred to the mean profile of the entire dataset) from April 2014 to November 2016; (b-c) MVBS (in dB re(4π*m)$^{-1}$) and W (mm s^{-1}) variations in time as a function of the hour of the day (UTC) at 97m, with the time of sunset and sunrise superimposed (black lines); (d-e) same as (b-c) but at 209 m; (f-g) same as (b-dc) but at 353 m.

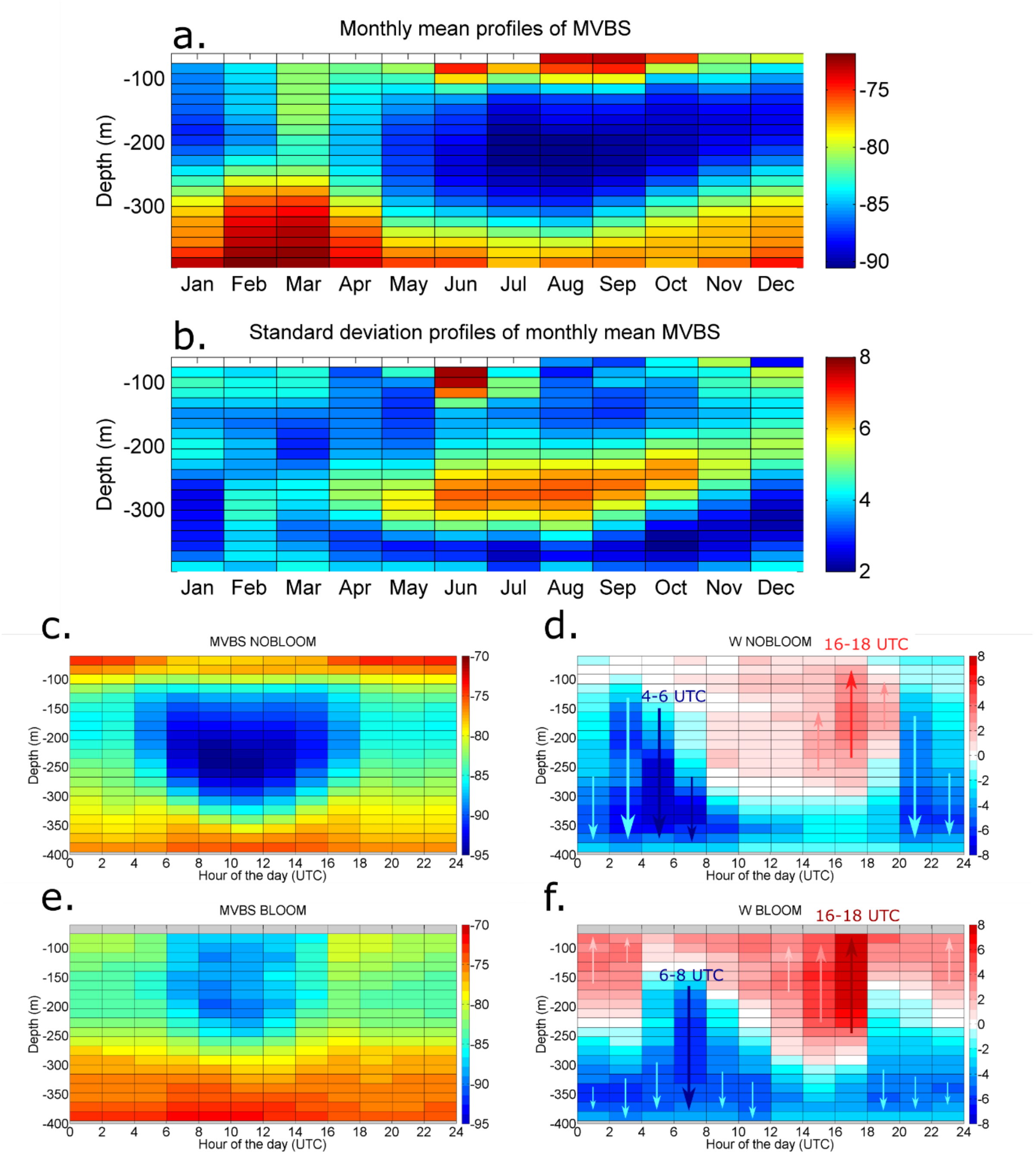

Figure 4: Monthly mean (a) vertical MVBS profiles (in dB re(4πm)$^{-1}$) and their standard deviation (b); (c-d) mean MVBS dB re(4πm)$^{-1}$) and W (in mm s^{-1}) during zooplanktonic non-blooming periods (approximately between May and November) as a function of depth (in m) and of the hour of the day; (e-f) mean MVBS (in dB re(4πm)$^{-1}$) and W (in mm s^{-1}) during zooplanktonic blooming periods (approximately between December and April) as a function of depth (in m) and of the hour of the day. Bluish and reddish arrows in (d) and (f) indicate main downward and upward motions, respectively. The time span of the most evident downward and upward events is given in (d) and (f).

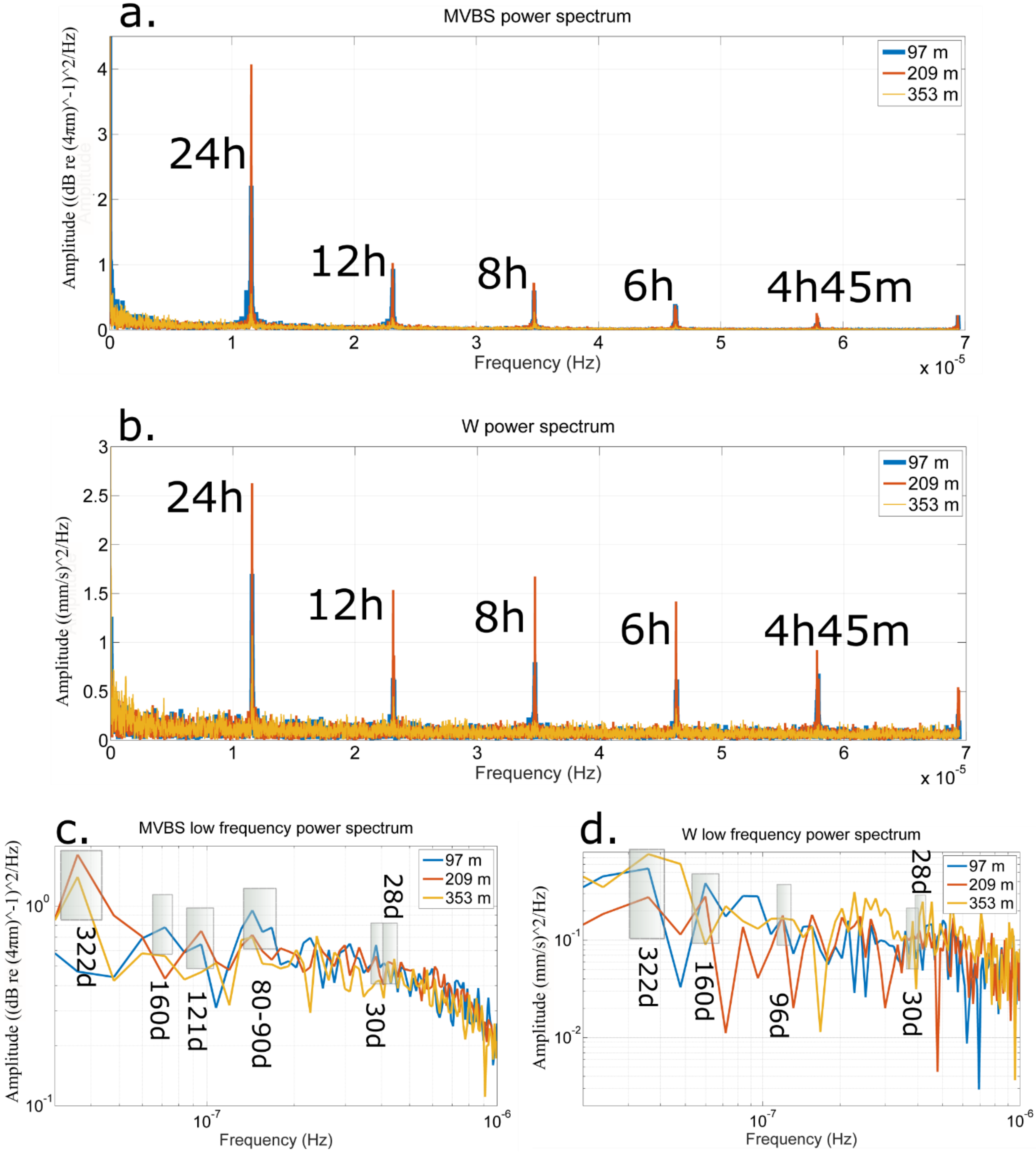

Figure 5: (a) Power spectrum of MVBS (high frequency range) at three selected bins (97m, 209m, 353m); (b) same as (a) but for W; (c) power spectrum of the low-passed MVBS time series (low frequency range) at three selected bins (97m, 209m, 353m); (d) same as (b) but for W.

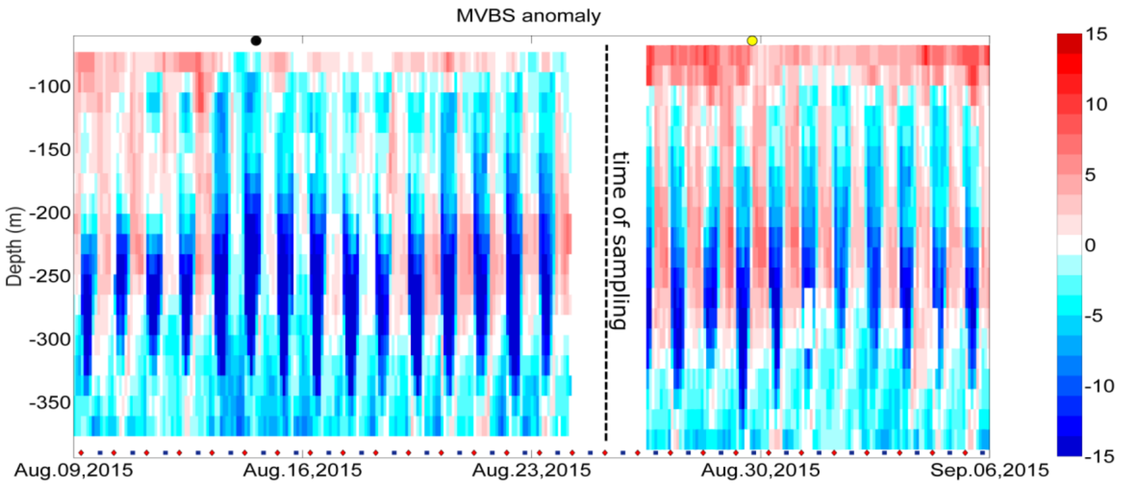

Figure 6: (a) Mean zooplankton abundances (in %) at the sampling sites in August 2015. (b) MVBS anomalies (in dB re(4π*m)$^{-1}$) between August 9th and September 6th 2015. Timing of new moon (black dot, above the graph), full moon (yellow dot, above the graph), sunrise (red diamond, below the graph) and sunset (blue square, below the graph) are indicated.

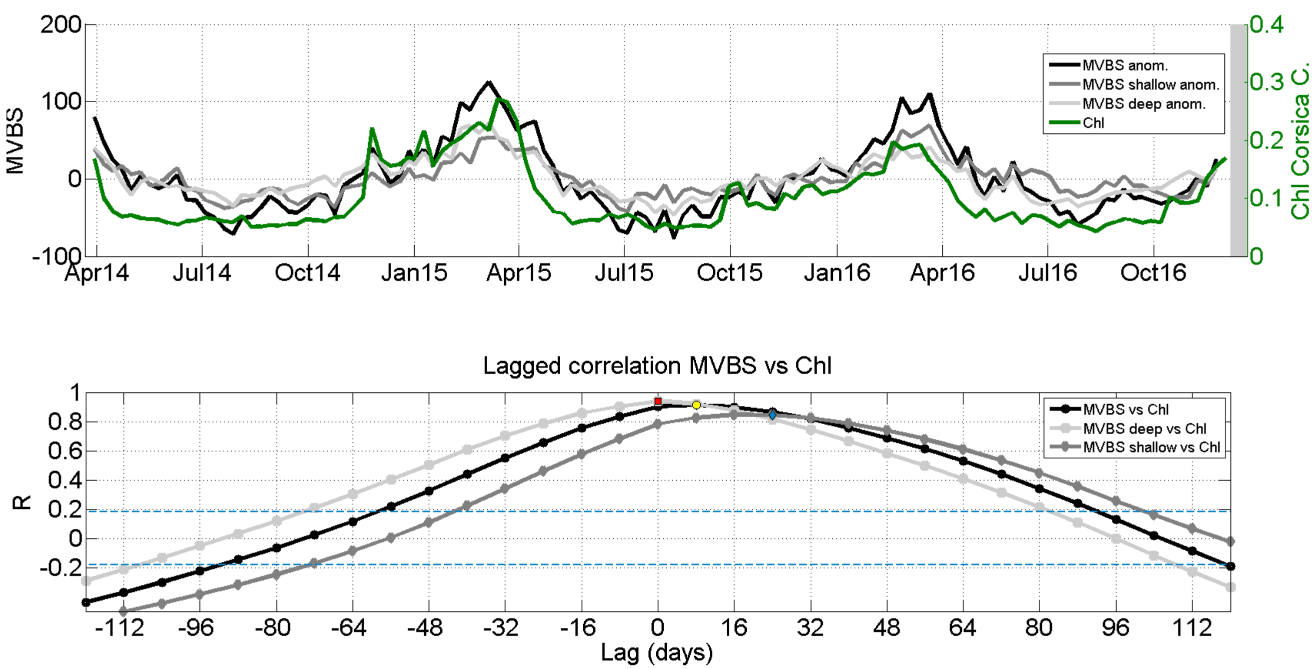

Figure 7: (a) Time series of integrated anomalies of MVBS (whole water column, in dB re(4πm)$^{-1}$), MVBS in the layer 73-201m (MVBS shallow), MVBS in the layer 201-378 m (MVBS deep), surface chlorophyll *a* concentration (Chl *a* in mg /m^{3}m^{-3}) at the mooring location in the Corsica Channel; (b) lagged correlation analysis between MVBS (whole water column, shallow, deep) and Chl *a*. Blue lines indicate the 95% confidence bounds. The red square, the yellow circle and the red square and the blue diamond indicate the maximum significant correlation, at lag=0, 0 8 and 24 days, respectively, between deep MVBS (top-bottom) and Chl *a*. and total MVBS (top-bottom) deep and Chl *a*, and respectively, while the blue diamond indicates the maximum correlation between shallow MVBS shallow and Chl *a*, at lag=24 days.

Deployment	1	2	3	4	5	6	7
First day	05/04/14	28/11/14	21/03/15	27/08/15	09/12/15	21/03/16	22/07/16
Last day	24/11/14	19/03/15	23/08/15	06/12/15	19/03/16	20/07/16	26/11/16
ADCP depth (m)	-395	-400	-400	-411	-400	-400	-400
B (m)	7.04	7.04	7.04	7.04	7.04	7.04	7.04
b (bin number used *)	19	19	19	19	19	20	19
Depth Range (m)	372-68	376-72	376-72	387-67	376-72	376-72	376-72
Ensembles	2815	1360	1878	1252	1234	1470	1544
Values discarded	318	480	77	463	780	54	178
L (m)	17.16	17.16	16.97	17.42	17.04	17.04	17.04
D (m)	16	16	16	16	16	16	16
C (dB)	-159.1	-159.1	-159.1	-159.1	-159.1	-159.1	-159.1
R_0 (m)	1.3	1.3	1.3	1.3	1.3	1.3	1.3

Table 1: Deployment characteristics: the depth -400 m is a nominal depth, while -395 m and -411 m is a mean value of the continuous record of the ADCP pressure sensor; the blank is the distance between transducer and the first bin; deployments 1 and 4 had a slowly subsidence, respectively 50 cm in 234 days and 30 cm in 102 days. *Out of 28.

Taxon	Group	N m^{-3} sample#1	N m^{-3} sample #2	Mean %
***Clausocalanus* spp.**	COP	74.22	153.31	38.96 ± 1.91
***Oithona* spp.**	COP	26.59	49.95	13.11 ± 0.23
Appendicularia indet.	OTH	8.22	12.60	3.56 ± 0.59
***Oncaea* spp.**	COP	9.19	11.29	3.51 ± 1.18
***Paracalanus* spp.**	COP	1.21	15.20	2.81 ± 2.37
Chaetognatha	OTH	6.77	8.69	2.65 ± 0.80
***Calocalanus* spp.**	COP	3.14	11.29	2.47 ± 0.96
Temora stylifera	COP	6.77	7.58	2.46 ± 1.00
Ctenocalanus vanus	COP	5.56	8.69	2.44 ± 0.37
***Pleuromamma* spp.**	COP	5.08	8.69	2.36 ± 0.20
***Corycaeus* spp.**	COP	6.29	6.08	2.12 ± 1.11
Nannocalanus minor	COP	4.59	6.95	1.98 ± 0.35
Pseudoevadne tergestina	CLA	0.24	10.42	1.83 ± 1.83
Evadne spinifera	CLA	0.97	9.12	1.73 ± 1.34

Table 2: Contribution of the most abundant species/taxa at the two sampling sites in number of individuals (N) per m^3 of water (COP: Copepods, CLA: Cladocerans, OTH: other taxa).