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Interactive comment on "Dead zone or oasis in the open ocean? Zooplankton distribution and migration in low-oxygen modewater eddies" *by* H. Hauss et al.

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Dear Editor, dear Reviewers,

We would like to thank you for the thorough review and insightful remarks, which will lead to considerable improvement of the paper! In the following, we would like to point out how we intend to address your main concerns in the review process.

First (since this was remarked on by both reviewers), we have to admit it is true that the use of the term "Target Strength" was ill-defined here (resulting from jargon use in

the context of current velocity analysis, see e.g. technical note by Plimpton et al. 2004, p 39) and that it is synonymous to Sv, the mean volume backscattering coefficient according to MacLennan et al. (2002). This will be changed throughout the manuscript and the reference added.

Second, it was noted by both reviewers that comparison between the three methods is hampered by differences in sampling volume and size range of sampled organisms. We will expand the discussion on the use of the ADCP to investigate the distribution patterns of pelagic organisms, and specifically address the technical issues of the three approaches (ADCP, UVP, multinet). Nevertheless, it should be noted that we deliberately chose not to attempt a direct comparison of methods (e.g. by trying to derive biomass from ADCP backscatter), but rather use the three methods complementary to each other:

1) The acoustic survey reveals the fine-scale spatial distribution (both horizontal and vertical) of scatterers (macrozooplankton and micronekton), suggesting a complete avoidance of the OMZ by these groups (whose identity remains somewhat unclear).

2) The UVP has an excellent vertical and an intermediate horizontal (several profiles along transect) resolution, with restricted information regarding the identity of the organisms (limited by image resolution and sampling volume to more abundant mesozooplankton).

3) The multinet has very low vertical and horizontal resolution, and low catch efficiency for fast-swimming organisms, but allows a detailed investigation of zooplankton organisms (since the samples are still quantitatively extant after scanning, taxonomists interested in one of the groups presented here would even be able proceed with more detailed work).

In some cases, we however use the overlap of the sampling methods to provide tentative explanations for the patterns observed in the ADCP. For example, euphausiids contribute substantially to the backscatter at 75kHz in this region (as observed through horizontal MOCNESS tows during dusk and dawn resolving ADCP migration traces, Buchholz, Kiko, Hauss, Fischer unpubl.). Although the multinet is not suitable to provide quantitative estimates of euphausiid biomass (see above), and the UVP is not either, the relative decrease of observed euphausiids in the OMZ (and in the eddy in general) in both multinet samples and UVP profiles suggests that they may be partly responsible for the lack of backscatter in the OMZ, and we are reluctant to drop the discussion on this as suggested by reviewer #2. In a contrary line of argument, we do not think that siphonophores are in this survey quantitatively important in the mean volume backscattering strength in the OMZ (as suggested by reviewer #1), because they are quite abundant in multinet samples from the OMZ layer, which features very low acoustic backscatter (Fig. 6D). Furthermore, siphonophores retrieved by the multinet were almost exclusively calycophorans (see Fig. 6D for a type specimen), which do not have a pneumatophore (and, therefore, lack gas bubbles). We will present these arguments in a revised version of our manuscript.

We agree with reviewer #1 that the use of a calibrated multiple frequency echosounder rather than an ADCP would increase the biological information. However, in the particular case of mapping and sampling an eddy, the current structure is of crucial importance, and the underway measurements with the ADCP preclude the simultaneous use of other ship-borne echosounders operating at similar frequencies. A possible strategy would be to use the ADCP for transects, and a multifrequency echosounder when on station. Still, to draw robust conclusions on the identity and whereabouts of acoustic scatterers, the additional use of several types of stratified nets is necessary (e.g. 10m2 MOCNESS in addition to multinet and/or 1m2 MOCNESS) but was logistically impossible during the opportunistic sampling on M105. Since gelatinous plankton organisms appear to play a key role in these oceanic OMZs and is notoriously undersampled by nets, it even seems worthwhile to employ a dedicated camera system (with larger sampling volume than the UVP) for such a survey. We will add these technical recommendations to the discussion.

Reviewer #2 suggested to split the discussion into two parts (acoustics and nets/optics), which we will partly follow. We will restructure and expand the first, general part of the discussion to accommodate technical issues and separately discuss results as provided by the different methods (and, here, divide as suggested by reviewer #2). However, we would like to keep the synoptic structure when discussing the different strategies followed by zooplankton/micronekton.

Reviewer #2 also suggested to open the analysis up regarding environmental drivers other than oxygen, particularly towards including light levels as an explanatory variable for vertical distribution and chl-a as an explanatory variable for total biomass, and to provide more background information about eddies in general. Unfortunately, we lack light profiles since there was no PAR sensor mounted on the CTD, but we will include chl-a (CTD and/or satellite data) and/or POC (bottle data from eddy core and CVOO) to complete the productivity/food availability picture, and also discuss the shallowing of the photic zone due to enhanced attenuation in high-productivity systems. More information on eddies in general (and in this region in particular) will be added to the introduction and discussion. Please note that meanwhile several companion papers are available online that describe the origin, development and hydrographic as well as biogeochemical characteristics in far greater detail than is the scope of the present manuscript.

Answers to Specific Comments Reviewer #1 (review and supplement):

R #1 p18321 L7: It is important to realize that the acoustic backscatter from 70 kHz and 300 kHz are strictly not comparable as most plankton increase in backscatter with frequency until flattening at 100s of kHz. OS38 will be more exposed to resonance phenomena.

Hauss et al: Backscatter from OS38 was not used as an indicator of scatterer distribution for the reason mentioned by the reviewer; it is included in the methods because it was used for the current velocity analysis (Fig. 1); this will be clarified. We will also elaborate more on the difference between the signal from the moored 300kHz ADCP compared to the shipboard OS75.

R #1 p18324 L19-22: Difficult to understand the connection between the Figure and the text. Clarification in the Figure caption of Fig. S1 would help.

Hauss et al: Caption of Fig. S1 will be revised to read: "Daily cycles of moored ADCP mean volume backscatter Sv (dB) during transit of ACME in 2010 (data from Jan 1 to Mar 14). Left: Depth-resolved contour plot of Sv over daytime; Data are averaged for days with a mean O2 concentration (at the depth of the moored O2 sensor, approximately 50 m) below 20 μmol kg-1 (row A, n=5), 20-50 μmol kg-1 (row B, n=7), and 100-250 μmol kg-1 (row C, n=54). right: Sv at four different depth levels of approximately 50, 60, 80, and 100m; exact mean depth dependent on position of ADCP indicated by corresponding colored lines the contour plots (left column)."

R #1 p18325 L28: The information from the applied net sampling gear is hardly relevant with respect to most fish due to size selectivity.

Hauss et al: We agree that we can hardly say anything about fishes with the gear used. We do think, however, that it is legitimate to mention that not a single fish was caught in the eddy core night haul, because this is very unusual. We have by now collected dozens if multinet hauls in this region, which typically contain a few small mesopelagics and fish larvae.

R #1 p18326 L22: This is an understatement. The correspondence between acoustic backscatter and catch with these sampling tools is close to nil.

Hauss et al: Will be rephrased to read: "Thus, the community of organisms contributing most to the backscatter (e.g. mesopelagic fishes and other micronekton) is not quantitatively sampled by the multinet and the UVP5, as both mostly target organisms < 10 mm in size and the sampling volume is small, in particular with the UVP5." Please note that this first section of the discussion will be largely rewritten to accommodate all

above-mentioned changes (structure, technical issues).

R #1 p18328 L1: Siphonophors often give high acoustic backscatter due to the pneumatophore

Hauss et al: As noted above, siphonophores retrieved by the multinet were almost exclusively calycophorans, which do not have a pneumatophore (and, therefore, lack gas bubbles).

R #1 p18330 L7: Long and difficult sentence. Not sure I understand

Hauss et al: Will be split and rephrased to read: "The enhanced surface primary productivity of the eddy also resulted in an approximately 5-fold increase of large particles, well visible down to 600 m depth. This indicates a massive export flux by sinking marine snow (see also Fischer et al. 2015 for sediment trap data of the 2010 ACME), which is thus made available to higher trophic levels at greater depths."

R #1 Discussion: There is no comments related to the fact that standing stock/densities of plankton does not tell the truth about production. As long as the authors are not able to assess the higher trophic predator component it is difficult to give an overall evaluation. Needs some attention in the discussion.

Hauss et al: It is true that we lack production estimates and therefore cannot conclude whether the system is ultimately bottom-up or top-down controlled. We will comment on this in the revised discussion.

R #1 Fig.4 No explanation of the information provided by this column

Hauss et al: Information on this column (example UVP images of respective plankton group) will be added to the figure caption.

R #1 Figure S1: The figure caption of Fig. S1 is unclear to me. Want are the line in the left panel showing? And what is the connection to the right panel?

Hauss et al: The figure caption will be revised (see above); the colored lines in the left panel denote the depth of the mean Sv depicted in the right panel.

Answers to Specific Comments Reviewer #2:

R #2 Abstract L. 4: I would rephrase to something like " are expected to decline under future expectations of global warming"

Hauss et al: Will be rephrased as suggested.

R #2 Abstract L. 13-14: Sentence is unclear to me: reduction in values compared to daytime or outside of the ACME? Or low backscattering levels at OMZ depths during nighttime?

Hauss et al: Sentence will be rephrased to read: "At nighttime, when a large proportion of acoustic scatterers is ascending into the upper 150 m, a drastic reduction in mean volume backscattering (Sv, shipboard ADCP, 75kHz) within the shallow OMZ of the eddy was evident compared to the nighttime distribution outside the eddy."

R #2 Abstract L. 28 -> As far as I see the habitat compression you observe is based on the acoustic data. As you note in the Methods section, the acoustic results probably reflect a wider range of organisms than just mesozooplankton (and the mesozooplankton is not covered well), so I would suggest moving this section out of the abstract, as it is speculative, given that your other data on the larger components is scarce. Still an important finding, and a good example, but I don't think you have shown it for the zooplankton component (in addition your N is low).

Hauss et al: We do not agree on this comment/suggestion, as the strategies and responses we identified and summarize in the abstract are not only based upon acoustic observations, but resemble a synthesis of our observations available from the three approaches. Calanoid copepods are a good example of a "zooplankton component" that are subject to habitat compression above the OMZ as suggested by UVP and multinet data. It might be misleading that only zooplankton is mentioned in the sentence line 28ff, therefore we suggest to change this part to "...rendering zooplankton and

micronekton more vulnerable to predation...".

R #2 P. 18318, L 4: last part of sentence seems awkward to me, but english is not my first language.

Hauss et al: Will be rephrased to read: "...are predicted to further deoxygenate and expand laterally (Stramma et al., 2008; Stramma et al., 2009) under future expectations of anthropogenic global warming (Cocco et al., 2013)."

R #2 P. 18321, L6, repeated information (e.g. 90 min)

Hauss et al: Sentence will be deleted.

R #2 P. 18326, L21-26. First you state that the Multinet and UVP do not quantitatively sample euphausiids, then you state that UVP data suggest that euphausiids avoided the OMZ. To me this is a bit sketchy. My claim is that neither UVP nor Multinet data is suitable for studies of euphausiid distribution, unless dealing with larva or very small forms: how many of the mean values – 1.96*sd presented for euphausiids in figs 4 and 6 would span 0? Your scale of aggregation seems to high for this group (in figure 4). Looking at the figures, figure 5 seems to support your conclusions (horisontally), but this is data based on a total scanned volume of < 7 m3 per profile, for a "normalized" volume of 600 m3, with a density of 100 equalling 1 observation, if I'm correct? This implies that the actual observations for figures 5 c,d,e,f are all considerably fewer than 40 observations per profile, which seem to be very low numbers to draw strong inference about distribution from, or have I misunderstood? Have you performed a power analysis? Why not use the Multinet data for this figure (fig. 5), or a combination of these 2 datasets, the multinet should at least have a significantly bigger volume sampled.

Hauss et al: As already pointed out above (and will be clarified in the revised manuscript), we claim that although neither multinet nor UVP are suitable instruments to obtain quantitative euphausiid abundance estimates (i.e., provide accurate numbers per volume or area), observations are expected to be internally consistent. We cannot think of reasons to decrease krill catchability within the eddy compared to outside of it. The unequaled advantage of the UVP observations is that the specific observation depth of each individual is known, which, in our opinion, nicely complements the picture – in particular when comparing to the "gelatinous" group, which occur in similarly low abundance, but completely different distribution (surface vs. OMZ, and in vs. out of eddy). It is true that presenting mean profiles +-SD (Fig. 4) in the case of these groups contains a large proportion of zero observations, but this fact should be evident from the left panels (section) and figure caption, and we would like to keep the same figure format as for the three more abundant groups. An alternative would be to create a separate figure with presence/absence data for these two groups. We would like to leave this decision to the editor. Using the multinet data for Fig. 5 is not possible for e.g. aggregates and radiolarians, and the multinet integrated abundance data are already presented in Fig. 6 (here, the summed area of the bars is proportional to the integrated abundance) and table S2.

References

MacLennan, D. N., Fernandes, P. G., and Dalen, J.: A consistent approach to definitions and symbols in fisheries acoustics, ICES Journal of Marine Science, 59, 365-369, 2002. Plimpton, P. E., Freitag, H. P., and McPhaden, M. J.: Processing of subsurface ADCP data in the equatorial Pacific, NOAA, Oceanic and Atmospheric Research Laboratories, 2004.

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