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Earth System Science Data Discussions

Interactive comment on "Distribution of mesozooplankton biomass in the global ocean" *by* R. Moriarty and T. D. O'Brien

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We would like to thank Anonymous Referee #2 for taking the time to thoroughly review our manuscript. We are grateful for all their suggestions which have helped improve clarity and understanding throughout the manuscript.

As background information, this mesozooplankton paper is part of an ESSD Special Issue that includes similar data compilation-focused papers on a total of 11 Plankton Functional Types (PFTs) namely picophytoplankton, diazotrophs, coccolithophores, Phaeocystis, diatoms, picoheterotrophs, microzooplankton, mesozooplankton, pteropods and macrozooplankton. Hereafter referred to as "the special issue", the introductory paper for this special issue is:

MAREDAT: towards a World Ocean Atlas of MARine Ecosystem DATa

E. T. Buitenhuis, M. Vogt, R. Moriarty, N. Bednaršek, S. C. Doney, K. Leblanc, C. Le Quéré, Y.-W. Luo, C. O'Brien, T. O'Brien, J. Peloquin, R. Schiebel, and C. Swan. Earth Syst. Sci. Data Discuss., 5, 1077-1106, 2012

The general layout and analyses of this mesozooplankton paper were based on a common layout set up by the special issue leaders to be used for all of the PFT papers in this issue. When they were designing this layout, it is important to be aware that the majority of the other plankton groups do not have near the data coverage seen in the mesozooplankton data of this paper. For these other groups, the spatial and temporal coverage were limited such that only a basic comparison of "latitudinal ranges" and "annual averages" was possible for the discussion section. To share a common layout across all of the papers, only these simple analyses were done in this mesozooplankton paper, but we also agree with Referee #2 that expanding the study into inter-regional and seasonal comparisons would be a valuable expansion. Assembling the mesozooplankton for this special issue was a "first step", whose major feat was getting the data itself assembled into one place and into a common format. Plans for a more detailed follow-up (to be done in 2015) are being drawn up, and Referee #2's comments and suggestions will be including in the goals for that next step.

Referee #2 also provided questions and suggestions about doing cross-PFT comparisons. We are happy to say that these have been addressed in the introductory paper of the special issue itself (Buitenhuis et al., 2012 , as cited above). By placing this analysis into the introductory paper, and not repeating it in each sub-paper such as this mesozooplankton paper, we avoid repeating the results in ten different papers. To make existence of this other work known to the reader, we added a short explanation and make reference to this introductory paper within the mesozooplankton text.

These and the other corrections and suggestions by Referee #2 are addressed below.

General Comments

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Referee #2: I read this manuscript with great interest. The authors and their colleagues have collected and standardized a great number of mesozooplankton biomass measurements in order to obtain a global perspective on the distribution of this important element of the marine food web. I believe that the new compendium of mesozooplankton biomass data will be a great resource, and I complement the authors on their work. In my opinion, however, the authors should consider providing additional context for their study by discussing in greater detail: a) potential errors and biases in the data, b) important regional variations in mesozooplankton biomass, c) how their biomass estimates compare with other, independent efforts, and d) what additional data or studies are needed. The impact of the paper will be increased by this additional commentary.

Author Response: The above suggestions were repeated (by the Referee) in the subsections below.

Referee #2: My main critiques of the study are as follows: General a) I confess that I am not an expert on zooplankton measurements, but I think the manuscript would benefit from greater discussion of the potential errors and biases within the new, aggregated data set. Figure 2, for example, shows how mesh size use varies from place to place. What possible errors and biases might this introduce? How well have they been corrected for? Similarly, there are likely to be errors associated with clogging of the meshes. With a large mesh, many of the smaller, more numerous zooplankton may pass through undetected. Does a large mesh size underestimate the mesozooplankton biomass? The authors should touch upon these and other similar issues. Rather than confusing the central message, I believe this discussion will help modelers and other data end users interpret the outstanding work that's been done here.

Author Response: The three biggest sampling bias and error elements that can affect zooplankton "biomass" estimates are the biomass or biovolume lab technique used to measure the sample, the mesh size of the net used to catch it, and the maximum sampling depth of the net tow. These factors were discussed and addressed briefly in Sections 2.2.1, 2.2.2, and 2.2.3: The four different biomass/biovolume methods were

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converted to "carbon" using the equations in Table 2; the different mesh sizes were converted to a "333 μm equivalent" using the equations in Table 3; and the differences in depths were addressed by creating the multiple depth layers of Table 4. To address the referee's question, we have reviewed the paper and made clarifications and additions to make sure these potential biases/errors (and our addressing and correction of them) are more clearly stated.

Note: The data compiled for this study is available in a raw format that includes raw depths and mesh sizes and original measurement values, collocated with this study's assigned mesh and depth grouping categories as well as the final calculated carbon value. This full data table of all possible values allows a user to combine, ignore, recalculate, and/or apply the original data and semi-processed data in a variety of ways.

Referee #2: General b) Other than a looking at latitudinal variations in mesozooplankton biomass, the authors do not comment on regional variations. The Kuroshio and Bering Sea regions seem to have high biomass, while the South Indian and central North Pacific have low biomass. It would be useful for the authors to consider summarizing the mesozooplankton biomass by dynamical (e.g. subtropical vs. subpolar), ecological (e.g. Longhurst provinces), or other boundaries.

Author Response: We agree with the referee on this comment. We think that this is an excellent goal to pursue in either a follow-up paper or in the 2015 update of this multiple group study. As addressed at the very top of this response document, the reason for our latitudinal-only discussion was for consistency with the other papers in this multiple plankton group Special Issue.

Referee #2: General c) I understand that the goal of this manuscript is to report a significant new source of data on mesozooplankton biomass. The results are reported with little context, however. What does it mean if the global mean mesozooplankton biomass is 5.9 micrograms C/l? How does this compare with phytoplankton, microzoo-

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plankton, or other groups?

Author Response: The introductory paper of the Special Issue provides a discussion of the requested results (e.g., discussions on carbon contribution and cross-group comparisons) from all of the different plankton groups, and includes the mesozooplankton from this paper in that summary.

Referee #2: [continued] A full interpretation of observed mesozooplankton variability is out of the scope of this paper, but it would be useful to know if these numbers fall within the range of expected values. Consider that biomass between log size bins should be roughly equivalent (Sheldon, 1972, Limnology and Oceanography, 17(3), 327-340). Perhaps this, or other modeling and observational studies, could be used to provide additional perspective on the data reported in this manuscript?

Author Response: The Sheldon paper is an interesting suggestion, for the mesozooplankton as well as the other plankton groups within the special issue. Upon the completion of this Special Issue, the author group will continue its work and look at more detailed cross-plankton-group studies. We will forward this referee's suggestion to the group.

For the last part of the referee's question, these results have been compared to both paper global maps (e.g., Bogorov) as well as regional studies (e.g., CalCOFI atlases, IIOE atlases). The data follow the same general patterns and value distributions, which is not surprising since those data are included in this product (albeit converted into carbon).

An interesting modeling study (using in situ mesozooplankton biomass data along with satellite chlorophyll) was done by Stromberg et al. 2009. This study used an older version of the COPEPOD biomass fields. It found a tight agreement between the modeled and in situ data in all regions of the world except for the Bering Strait. (This difference was due to a Japanese "summer only" data set that was the only data for the region at the time.)

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Referee #2: General d) Based on this manuscript, I cannot conclude whether we currently have insufficient data to estimate mesozooplankton biomass. Do we need more data? Where? Where do we have sufficient data? What sorts of data should be collected in the future? I encourage the authors to add a few sentences talking about the general state of our knowledge about mesozooplankton biomass, and how this field should/may develop in the coming years.

Author Response: We have added a paragraph at the end of the text addressing these topics.

Specific Comments

Referee #2: Page 893, Abstract: "Global mesozooplankton biomass. . ." It is not clear if this is an annual average. It would also be informative to see this compared, here or elsewhere, to the biomass of other important groups such as phytoplankton and microzooplankton. Is there any meaningful seasonal variability?

Author Response: Yes, it is an annual average. The remainder of this question was addressed above in our response to "General c)". The seasonality is not evident at the global scale. At the regional level, seasonality is discernible.

Referee #2: Page 894, Line 9: What does "classical food web" mean? To my mind, there are many classical food webs.

Author Response: The Referee is correct, there are many types of classical food web. In the context of the Abstract the word "classical" is ambiguous. We meant to refer to the important role that mesozooplankton play in pelagic food webs. The text of the manuscript has been altered to reflect this.

Referee #2: Page 894, Line 12: I believe there are good regional, if not global, maps of mesozooplankton biomass. Consider the Continuous Plankton Recorder data and publications, such as Planque and Fromentin (Planque & Fromentin, Marine Ecology Progress Series, 1996, Vol. 134: 101-109).

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Author Response: We agree with the Referee that these exist. In addition to the CPR (North Atlantic) maps, maps from the Indian Ocean (via IIOE), the California Current region (via. CalCOFI), the Gulf of Mexico (via SEAMAP), and the northeast Atlantic Shelf (via MARMAP) also exist.

We were hesitant to mention these individual regional maps because most (all?) are currently only available in a figure/image form (the data used to generate the actual map is lost, or (in the case of the CPR data) is not publicly available). We also did not mention the regions because MAREDAT effort is global in focus.

The uniqueness of this mesozooplankton data set is that the data itself are freely and publicly available, in both raw and pre-processed formats, and that its coverage spans much of the globe.

Referee #2: Page 897, Line 14: It is not clear whether or not microscopy enumeration data are used. If they are not, why?

Author Response: This paper uses data only from "total biomass" and/or "total biovolume" measurements. In this simple method, the entire sample of critters caught in the net is dumped into a beaker or filter paper and measured as a single lump sum value. (A microscope is not used.)

Microscopic enumeration methods (such as the CPR studies by Planque and Fromentin mentioned by the referee) are processed under a microscope to identify and enumerate contents of the entire sample or sub-sample. These counts (from tens to hundreds of species or groups) are then multiplied against (from tens to hundreds of) individual biomass equations. This method is similar to saying "An average apple weighs X grams. I have 100 apples. I have 100X grams of apples." Note that depending on the depth of the study, the investigator may or may not discern between differences in larger and smaller apples, or the fact that some apple varieties are denser weigh more than others...or that spring apples may be heavier than autumn apples of the same diameter.

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The advantage of the enumeration method is that one can see which species or groups are dominating the population in terms of number and/or biomass. The disadvantage is that the first method takes as little as a few minutes while the second takes days to produce. The enumeration to biomass method also requires length/weight/count equations for all taxa and groups in the study. Many of these equations not only vary by geographic region but also by season (i.e., gravid females in the spring vs. late summer females). And in some regions, the average size (and weight) of individuals has been changing when compare to the same taxa from 20-30 years ago. A major reason enumeration-to-biomass data were not used in this paper is because it is really rare. The SAHFOS CPR program does do this, and their data would be an interesting contribution to the "i010" (0-10m) depth layer.

Referee #2: Section 2.2.2: Based on this discussion, it is not clear to me if there are any potentially important biases associated with the different mesh sizes. Could, for example, differences between Pacific and Atlantic have anything to do with different mesh sizes employed by different survey efforts? Also, is there any biasing associated with clogging of the sampling mesh? If you used a larger mesh, it might not capture smaller zooplankton until the mesh was clogged by larger zooplankton. Is this sort of potential error important? If not, why? Perhaps these errors are taken care of by equations in Table 3.

Author Response: Portions of this question was already addressed above in the "General - a)" response. (Please see that response, too.) With reference to clogging, the incoming data were generally annotated by the original source to indicate when an algal bloom or gelatinous plankter "corrupted" the sample. (These values were excluded.) In terms of reasonably net clogging under normal towing conditions, the assumption was the incidents were rare or at least consistent and would be accounted for in the mesh conversions to the $\sim$333 μm equivalent size.

Both the 200 μm and 333 μm mesh nets have data present in both the (north) Atlantic and (north) Pacific. The differences between the Atlantic and Pacific mesozooplankton

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biomass values are present in these data even if one only looks within a single mesh group.

The mesh sizes used actually reflect the scientific groups behind the sampling.

a) The 333 μm mesh data represent US and Japanese fisheries oceanographers that were primarily interested in general plankton groups (no so much species) and fish egg and fish larvae. If you colored the data points by country, Japan would dominate the western Pacific and the US would dominate the eastern Pacific, Gulf of Mexico, and western North Atlantic.

b) The 200 μm mesh data prior to the 1980's was almost entirely done by the former Soviet Union and covered the entire globe. Their scientists were taxonomist, not fisheries scientists, and they were interested in small zooplankton taxa and individual species (not fish). After the 1980's, you see programs like JGOFS, GLOBEC, and European researchers using finer mesh nets in their work.

c) The 505 μm mesh data represent a small faction of Pacific Ocean US fisheries scientists, again focusing on fish eggs and larvae and perhaps only the larger mesozooplankton (i.e., "fish food") groups.

Please see the response to "General – a)" for additional comments.

Referee #2: Section 3.3: It is not clear what is meant by "...global annual average of mesozooplankton biomass...", both here and in the abstract. Is this a sum over the entire global over all the months? Perhaps it should read "...global sum of monthly mean mesozooplankton biomass estimates."? In calculating this number, have the authors multiplied the average biomass by the global surface seawater volume? Please explain.

Author Response: The data is gridded on monthly climatologies but an annual average is used. The data for the majority of groups in the Special Issue do not have detailed enough data for seasonal or monthly biomass averages. The median value for meso-

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zooplankton biomass is calculated from all the gridded data in the top 200 m. It is then used to calculate annual average biomass in the top 200 m of the global ocean. As the Referee suggests the average biomass, in this case the median, is multiplied by the global seawater volume, to a depth of 200 m, e.g. median mesozooplankton biomass (2.7 μg C l-1) * 1 x 1e3 * area of the global ocean (3.56 x 1e20 m2) * surface ocean (200 m) * 1x1e-15 which gives a value of 0.19 Pg C. We have added an explanation of this calculation to Section 3.3 of the manuscript as requested by the Referee.

Referee #2: Page 903, Line 11: In my view, the map of mesozooplankton biomass is a great first start, but perhaps not yet global (see Figs. 4-6). I would say: "An aggregated map of an unprecedented number of mesozooplankton biomass observations, from all the world's oceans, is presented." Table 4, and throughout: I would replace terms like "i200" and "i010" with actual intervals throughout the text, figures, and tables.

Author Response: For the first part, we have reviewed the text for uses of "global" and addressed this suggestion where appropriate.

For the second part, we have looked through the text and figures and tables. For text referring to specifically to the "COPEPOD zCAT i200" data element, we would prefer to leave the i200 text, but have added the "0-200m" text for clarity. We agree with the referee though that other instances are clearer when using only the "0-200m" notation. In the latter cases we have made the suggested changes in the text.

Referee #2: Figure 5, c-f: These plots would benefit from using a scatter plot where the density of points is color-coded. Spatial patterns in Fig. 5c, for example, would be more apparent. It is not clear to me what "latitudinal depth distribution" in 5c indicates. I also feel that Figs. 5e and f blur out real seasonal variation in mesozooplankton biomass because the figures are averaging over completely different locations. These figures seem to imply that there is no seasonal cycle in mesozooplankton biomass, which is generally not the case.

Author Response: These figures were intended to summarize the data compilation

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itself as a whole (i.e., what coverage does it have in terms of geospatial, temporal, and depth). This common figure set, designed for the more data sparse plankton groups in this special issue, would be useful in quickly visualizing and noting that surface data or non-winter data or northern hemisphere data were primarily present in the data set. For the abundant mesozooplankton data, they show that coverage is pretty decent in all aspects.

The challenge in graphically representing these data is that the compilation clumps together a large range of regions and sub-areas that differ in seasonality and value ranges. Plotting them together like this provides only a general overview of the value ranges and distributions. We have tried multiple types of figures and color scatter representations (as the referee suggested), and the result is a randomly scatter mess of color without any coherent pattern.

This figure collection was provided mainly for consistency and inter-comparison with other plankton groups presented in this Special Issue. The referee is correct that breaking these into regions and sub-regions would better highlight the regional differences in seasonality and productivity. We have taken note of all of the referees many suggestions, and we plan to address them in the 2015 expansion of this work.

References Stromberg K. H. P., Smyth T. J. , Allen J. I., Pitois S., O'Brien T. D.: Estimation of global zooplankton biomass from satellite ocean colour. Journal of Marine Systems 78(1):18-27, 2009

Buitenhuis, E. T., Vogt, M., Moriarty, R., Bednaršek, N., Doney, S. C., Leblanc, K., Le Quéré, C., Luo, Y.-W., O'Brien, C., O'Brien, T., Peloquin, J., Schiebel, R., and Swan, C.: MAREDAT: towards a World Ocean Atlas of MARine Ecosystem DATa, Earth System Science Data Discussions, 1077-1106, 2012.

Interactive comment on Earth Syst. Sci. Data Discuss., 5, 893, 2012.