

Response to Referee Comment 1

RC1: Referee comment 1, in gray

AC: Author comment, in black

AC: We thank Referee 1 for their helpful comments and suggestions to improve the manuscript. We have addressed each major comment below. We will incorporate all technical corrections listed by Referee 1 unless a comment is made below.

RC1: The paper titled, “Southern California margin benthic foraminiferal assemblages across a modern environmental gradient record recent centennial-scale changes in oxygen minimum zone” quantifies benthic foraminifera abundances and assemblages of surface multicore sections (0-2cm) and downcore (< 20cm). Overall, despite the shortcomings in the methodology, and lack of clarity in the writing style of this manuscript, the information offered in this study shows potential in its importance to current and future oxygen investigations using benthic foraminifera. I recommend this manuscript undergo Major Revisions including a significant re-write, standardization of data, and incorporate a more thorough literature review.

This manuscript is well organized and contains most of the necessary information, but would benefit from re-writing and shortening of certain sections for clarity and readability. Suggested edits, such as changes in the present and past tenses and excluding the first-person point of view writing are included in the “Technical Corrections” section below. As is currently written the manuscript needs to be tied to established literature references and include a much more comprehensive discussion section justifying methods and interpretations. There also needs to be a section acknowledging the limitations of the regional interpretations made here. The authors state “Our findings indicate that region (or environment) specific oxygen species associations may be necessary, as our findings do not align directly with previous categorization of species.” It is important that it is recognized that these results, although true in the Southern California Margin, may not show the same patterns elsewhere in the world’s oceans and/or for the authors to compare their results with those previously published. Based on the current manuscript an understanding of how strong the interpretations are is unclear. What additional data would be needed to test or refine the applications and interpretations? All of these issues, limitations, and confounding factors may be addressed in a Major Revision.

AC: We thank the reviewer for this feedback; as shown below, we will adapt the writing of the manuscript, address data standardization, and incorporate a more thorough literature review.

RC1: Specific comments regarding scientific questions/issues:

RC1: 1. How are raw abundance counts standardized? Are all abundances reported as raw numbers? If so, how do you account for inconsistencies in the amount of sediment examined in each interval? The data should be standardized to #/50cc or #/gram.

AC: Raw abundance counts

The abundance counts are done by volume of sediment relative to total, then multiplied to equal the “total” volume. Thus, these should represent the amount of foraminifera in the originally

sampled cylinder of sediment (core) 1 cm height x 9 cm diameter = 63.62 cm³. This will be updated in the Methods section of the paper and in Figure 2.

RC1: 2. It is unfortunate that samples were not able to be stained using Rose Bengal, however, I do still believe the data to be extremely valuable in that it is necessary to examine what surficial fossil assemblages are when using them down core. Rose Bengal stained samples here would have completed the picture, but the information available from this data set is valuable and needed for fossil interpretations. I am not sure how you make the assertion that examination of only the larger size fraction (>150micron) is suitable for paleoxygen investigations, at least, not with the text in its current form. Additional references and discussions are needed. Below is what I pulled from the manuscript and viewed as the line of thinking on the subject. Please reorganize and emphasize the statements to better clarify this argument. -Lines 200- Section 3.3:

-Lines 291: “species richness is greater in the >150 μm relative to the 63-150 μm fraction, yet there is no consistent relationship between diversity and size fraction”. Is this your argument for looking only at the >150 micron size fraction? If so, you need to include a better discussion of the relevant literature which suggests the >63 micron fraction is necessary to examine in environments with low oxygen and high carbon inputs.

-Line 297: “diversity is not driven by oxygen alone” And there is no clear pattern in diversity and size. So, what is the basis on which you are making the argument that only the >150 microns are necessary in oxygen related studies? I suggest referencing Keating-Bitonti and Payne, 2016 when writing this section. You include this as a reference, but you don’t really discuss or justify referencing it. -Lines 314-316: “Our findings show that spatial trends in the >150 μm size fraction generally reflect those found in the >63 μm size fraction or are muted by the inclusion of the 63-150 μm.” Have you presented this data for the readers to see? Is this Figure 3? If so, reference the figure here. If not, you need to provide supporting evidence.

-Lines 324-325: “...correlation between size of specimen and accuracy of identification, meaning that the inclusion of the smaller specimens in the >63 um fraction may reduce the accuracy of identification

...” This is a good point and should be discussed sooner for better emphasis.

AC: After submission of the manuscript, we realized that there was a graphical error that affected the plotting of some of the data in Figure 3. The interpretations of the figure in the text were accurate, it was the figure itself that did not display correctly. We have uploaded an updated version of Figure 3 in response to this comment and the updated figure should help to address the questions posed here by Referee #1. In this figure, it is apparent that “spatial trends in the >150 μm size fraction generally reflect those found in the >63 μm size fraction or are muted by the inclusion of the 63-150 μm.” This was unclear in the previous iteration of the figure but has now been made clearer. We will cite this figure in the text more heavily to reference for understanding.

RC1: 3. A better discussion of how agglutinated foraminifera are reported, or not, in the total foraminiferal counts should be included. I see no reason why not to include them in the abundances reported (is that what you are already doing?). Then simply report percentages of certain species within the calcareous population if that is what you are interested in (e.g., Agg sp. 1 comprises 10% of the total population; Cal sp. 1 comprises 30% of the total population and

50% of calcareous population). I think excluding agglutinated foraminifera populations will impede on future research of agglutinated species.

AC: We appreciate the interest in agglutinated species. While they were counted in this study, they were not speciated. Additionally, as is discussed further below, they are not well preserved so not utilized for investigations that reconstruct environments through time. For this reason, it is the industry standard to only utilize calcareous species in relative abundance analyses. We noted other papers have reported on agglutinated taxa in the same way (Venturelli et al 2018) or have excluded examination of all agglutinated (Balestra et al 2017, Kaiho 1994, and Myhre et al 2014). In an effort for our study to be comparable to other regional studies we chose to report relative abundance as percent of total calcareous taxa. We acknowledge that due to the lack of preservation of agglutinated foraminifera, fossil assemblages may capture an incomplete reconstruction of diversity and ecosystem function.

RC1: 4. A more complete literature review is needed in the discussion section in order to support the findings of the authors. I suggest two discussion/literature review sections: 1) examination of <150 micron (>63 or 63-150 micron) foraminifera in low oxygen/high carbon environments. Do an overview of who proposed it, what results have been seen, and how it relates to your data. 2) foraminifera test size in comparison with oxygen. Here would be a great chance to discuss Keating-Bitonti and Payne, 2016 in greater detail. Again, do an overview of who proposed it, what results have been seen, and how it relates to your data.

AC: We will incorporate a more thorough literature review of the distribution of foraminifera in low oxygen/high carbon environments and of foraminiferal test size in relation to oxygen. We will include Keating-Bitonti and Payne 2016, Keating-Bitonti and Payne 2018, Kaiho et al 1994, Kaiho et al 1999, Venturelli et al 2019, and others.

RC1: Technical Corrections

AC: We will incorporate **all** technical corrections listed by Referee 1 that are listed below

-Line 22: “San Diego Margin” is capitalized here and in the text, but not in the title.

Choose one and be consistent.

-Line 22: “Here, we” can be removed. Start the sentence with, “Five core tops were analysed .”

-Line 24: Assemblage changes downcore? If so, please state. -First-person point of view should not be used in scientific writing. Please modify the text accordingly.

-Line 30: “variability in [the] upper margin”

-Line 31: “stable in the last 1.5ka” add a space before ka to remain consistent with the formatting of other units.

-Line 42: “declines in dissolved oxygen,” awkward. Please rephrase.

-Line 43: determination of

-Line 49: “Low-oxygen zones typically contain both low abundance and low diversity of” change to “Areas of low oxygen availability typically contain low abundance and diversity of”

- Line 73: “2013), yet significantly fewer” remove “, yet”. Begin the sentence with “Significantly. . .” Do you have any examples to cite e.g.,? -
- Line 82: remove “current, the” or something I just don’t like how it is phrased.
- Line 85: too many back-to-back parentheses. –This entire paragraph should be shortened. Along the California margin, a large, intermediate-depth oxygen minimum zone (OMZ) and carbon maximum zone (CMZ; approx.. 500 – 1000 m water depth, Helly and Levin, 2004; Stramma et al., 2010) are formed and controlled through physical and biological processes including temperature-dependent diffusion from atmosphere, mixing, stratification, deep water circulation, primary productivity at the surface and respiration at depth (Gilly et al., 2013; Helly and Levin, 2004). Intensity and spatial extent of the modern California margin OMZ is influenced by physical mixing of well-oxygenated surface water, biological activity at the surface and at depth, and intrusion of lower oxygen bottom waters (Gilly et al., 2013).
- Line 107: change core to coring
- Line 119: (Grupe. . .2015) should not be italicized.
- Lines 123-128: The word sample is used too many times (5 in one sentence). Try to replace with another word to avoid monotony.
- Line 130: “present in the sample.” I’m assuming it is in the entire sample? If so, add “entire” before “sample”
- Lines 132-134: These two sentences should be combined with the previous paragraph as 2 sentences is not a paragraph on its own.
- Section 3.2: this section is written in present tense while the rest is in past tense. Change all “was” to “were”, “is” to “was”, etc. –Where is this information reported? A graph a table? Reference it in this section.

- Lines 169-172: “Foraminiferal abundance is low (<100 individuals) in some of the samples from 0-1 cm. Thus, in order to utilize sufficient numbers of individuals and because there were no significant differences in abundance of species between 0-1 cm and 1-2 cm, for the rest of the discussion we refer to the 0-2 cm fraction as the core top material.” This needs to be identified in Figure 3.
- Line 173: Remove “The site” and begin the sentence with “At”. Change “at the core of the OMZ” to “within the core of the OMZ, the”. Add “occurred” to the end of the sentence. Alternatively, this sentence could be shortened and combined with the previous sentence: Calcareous taxa dominated the assemblage at every site; agglutinated foraminifera made up 0 (e.g., XXX m) to 17.7% of the assemblage at 700 m, within the core of the OMZ.
- Line 179: “sp1” can this just be written as “sp.”?
- Line 181: “All other species each account for <4% of total assemblage across all core tops.” This sentence is confusing. Please rephrase.
- Line 200: “of” repeated. Could streamline to, “Comparisons of foraminifera abundances between. . .”
- Line 200: change 150 to >150 microns.
- Lines 202-204: “Three species have significantly different relative abundances between size classes; three are more likely to be found in the 63-150 μ m (Cassidulina carinata, Epistominella sp1 and G. subglobosa)”. When you repeat “three” are you referring to the same 3 species? If so, please rephrase.
- Line 207: I don’t think it is necessary to repeat “Shannon Index” after you describe it in the methodology.

- Line 296: Shannon Index -Line 341: remove DO as it is implied
- Line 262: “see Discussion section” can you refer to a specific section number e.g., 4.3?
- Line 263: “core top[s]”
- Lines 268-269: please rephrase this sentence for clarity. It is hard to understand your meaning.
- Lines 273- 279: shorten this section to make your findings more impactful. The word “document” is repeated and could be eliminated completely.
- Lines 338-339: “Infaunal species are more common within the OMZ, while epifaunal are more common in well-oxygenated areas.” True, but there are studies that illustrate that epifaunal abundances may be limited by substrate rather than a physiological limitation to oxygen availability (see comment above). You just alluded to this in the previous sentence, but I suggest incorporating something of this statement into this sentence or starting the sentence with, “In general”.
- Line 440: remove “the”; change “oxygenation” to “oxygen”
- Lines 442 and 443: change “classes” to “fractions” -Lines 444-445: “we conclude that analysis of the >150 µm assemblage for this site provides the most useful record for interpreting benthic foraminifera as a proxy for past change” This assertion needs a discussion or reference
- Line 447: “variability in upper margin of the OMZ” should be “variability in [the] upper margin of the OMZ”
- Lines 448-449: “We document expansion of upper margin of OMZ beginning 400 ybp on San Diego Margin that is synchronous with regional records of oxygenation.” Should be re-written. Perhaps, “In this study, upper margin OMZ expansion beginning 400 ybp on San Diego Margin is synchronous with regional records of oxygenation.”?
- Figure 2: Extra “)”;
- Figure 4: The *Bolivina spissa* and *U. peregrina* lines are very similar in color and hard to distinguish. Can the point shapes be changed to better facilitate reading?
- Table 1: Include salinity in the table
- Table 2: Contains a core not “used in this study” MV1217-4-1. If it is to be included in this table it would be helpful to also include depth and lat-long so readers have an idea of why you are including this in the manuscript. 14 in the 14C needs to be superscripted

RC1: Technical Corrections

AC: We have addressed or commented on the following suggested changes:

-Line 29: “diversity is not driven by oxygenation” In the core top materials? Is this pattern observed with Shannon Index downcore?

AC: Diversity is not driven by oxygenation in the core top samples. This statement is not referring to the downcore changes in diversity. We will clarify this in the text.

Line 75: “biological and chemical gradients are more extensively distributed” or more extensively variable?

AC: We will change the text to “more variable.”

-Lines 107-108: . . .”CTD (SBE9), with a dissolved oxygen probe (Seabird Electronics Sensor SBE43). . .”- CTDs typically have an oxygen probe. Is it necessary to state this?

AC: We included this to show that values for dissolved oxygen were acquired using a sensor rather than by bottle sampling and Winkler titration.

-Lines 110-111: “Bottom depths were measured acoustically at each site.” Is it necessary to state this?

AC: For completeness, we included how each of the environmental parameters were measured.

-Line 117-118: “frozen. Sediments were not stained upon retrieval; thus, we could not carry out an analysis of live vs. dead or depth habitat of these species” This is too bad. It would have made for a much stronger study if living and fossil assemblages were able to be extracted from core top samples. I don’t think the data presented here is useless, but having stained (recently living) samples to compare with the dead assemblages at the surface would have provided a much more powerful interpretation.

AC: We agree. This study would be stronger if the sediments had been stained at the time of collection.

-Line 132: I would not qualify 1-2cm as surface. It is shallow infaunal.

AC: We utilized both the 0-1 and 1-2 cm fraction as the “surface” for several reasons. These are discussed in section 3.2 Lines 168-172. We completed a comparison of the 0-1cm and 1-2cm “We do not identify any significant relationship between relative abundance of a species and depth interval (in all cases $p > 0.05$ or r^2 is < 0.001). Foraminiferal abundance is low (< 100 individuals) in some of the samples from 0-1 cm. Thus, in order to utilize sufficient numbers of individuals and because there were no significant differences in abundance of species between 0-1 cm and 1-2 cm, for the rest of the discussion we refer to the 0-2 cm fraction as the core top material.” (Lines 168-172).

-Lines 133-134: “. . . were examined at 1 cm intervals for cores MV1217-2-3 (528 m), MV1217-1-3 (800 m) and MV1217-4-3 (1175 m).” Ending at what depth in the cores?

AC: We will add in the depth (in cm) that we analyzed from each core.

-Line 156: no units on salinity. Remove “with a total” replace “range of” with “ranging from”

AC: We chose to report salinity in “practical salinity units.” We will make the additional language change.

-Line 157: (DO) once you have introduced an abbreviation you do not have to reference it again and you can then use the shorthand in the text. I suggest you do a search of the manuscript and identify duplicates of instances such as this. I suggest a rewriting of this section for clarity. Either report based on water column depth or minimums. As is, it is confusing. –Rephrasing

suggestion: —“Water column dissolved oxygen (DO) concentration documents a low oxygen zone, with a minimum occurring at 700 m water depth (0.26 ml/L; Figure 2, Table 1), compared to 1.54 ml/L at 300 m and 0.58 ml/L at 1175 m. Minimum pH is documented at 700 m (7.55) and is higher above (300 m, 7.65) and below (1175 m, 7.59) the intermediate depth low pH zone (Figure 2, Table 1).” —Water column DO measurements indicate areas of low oxygen availability from 300 m (1.54 ml/L) to 1175 m (0.58 ml/L) with lowest oxygen availability at 700 m (0.26 ml/L). Although not greatly variable, pH minima also occur at 700 m (7.55) and is higher at 300 m (7.65) and 1175 m, (7.59). In this section, why not report as hypoxic, anoxic, as outlined by Bernhard et al?

AC: We will improve upon the introduction of abbreviations earlier on in the text as suggested by both reviewers. We chose not to report oxygen as hypoxic, anoxic, as outlined by Bernhard et al because we later argue that in the environment we studied, these categories of foraminifera by oxygenation do not accurately reflect the foraminifera we sampled. Thus, it is more useful to describe each site using the measured dissolved oxygen.

-Line 175: “Due to their propensity for degradation and to remain consistent with other regional studies, we exclude agglutinated taxa and all values are reported as percent of total calcareous taxa for the remainder of the text.” I don’t disagree with this statement, but I think that ignoring the agglutinates is a mistake we will regret in the future. Why not keep the data (they were a significant portion of the population) and just report Calcareous populations in the graphs etc?

AC: In order to remain consistent with other studies (Kaiho 1994, Balestra et al 2017, Myhre et al 2014) that focus only on calcareous taxa, we exclude the agglutinated taxa from further discussion.

-Lines 180-181: “These dominant taxa make up more than 84% of all foraminifera counted across all core top samples.” Does this include the agglutinates or just 84% of the calcareous foraminiferal population?

AC: This only takes into account calcareous taxa. We will make this clear in the text.

-Lines 200- Section 3.3: Based on the results of this section why are you concluding that it is better to look at the >150micron size fraction as you state in the conclusion?

AC: We conclude that it is effective to look at the > 150 micron size fraction because we find that trends across depth are similar between the complete (>63 µm) and large size fraction (>150 µm) or are more pronounced in the >150 µm size fraction compared to the 63-150 µm size fraction. Further, we utilized this size fraction to remain consistent with other regional studies. These trends are further elucidated by the corrected Figure 3 we have uploaded as part of this response.

-Line 217: When you say above and below the OMZ do you mean on the seafloor? Not in the water column? Please clarify. *G. subglobosa* as oxic indicator- This assertion needs a discussion or reference. Skipped to discussion

AC: When we refer to above and below the OMZ we are referring to within the water column, not above/below the sediment surface. We are indicating that *G. subglobosa* is more abundant at the sites above (300m) and below (1175m) the OMZ. As such, it is from our own data that we identify this species as an oxic indicator, rather than from previous work. But, additionally, we can add citations showing this species as an oxic indicator (Kaiho 1999).

-Line 295-296: I'm not sure this was the findings of Venturelli et al., 2018. Which section of the paper are you referring to here? The focus of this paper was on comparing sediment grain size, oxygen, and foraminiferal abundances in the Southern California Bight. It was not an OMZ survey and therefore I am not sure they proposed seeing variations of foraminiferal abundances in size fractions "within" the OMZ vs outside the OMZ. If you just mean to say that 63-150 micron foraminifera were more abundant than >150 micron reported by Venturelli et al., 2018 I think this is true, but how different were the populations and would grain size difference influence these abundances?

AC: We will remove the citation for Venturelli et al 2018 and instead incorporate a more thorough discussion of the relationship between size and oxygenation in benthic foraminifera following the discussion in Keating-Bitonti and Payne 2016. See comment below on adding more thorough literature review and discussion of size.

-Lines 355-338: "The presence of oxic indicator species across all water depths may provide evidence for periodic flushing of high oxygen water or a selection for species that can tolerate a range of environmental conditions rather than a specific threshold of oxygenation." It may also be that the physiological tolerances of indicator species are not fully understood. They may be able to tolerate lower oxygen than previously thought provided another incentive such as substrate (e.g., Venturelli et al., 2018, Burkett et al., 2016), and or they may be able to tolerate short periods of low oxygen or inhospitable conditions (Bernhard et al., 2010).

AC: This is an interesting point. We will add further discussion and incorporate the references cited by Referee 1 (Venturelli et al., 2018, Burkett et al., 2016, Bernhard et al., 2010).

-Line 270: What do you mean by equal in magnitude? Can you elaborate on that? Perhaps by giving total abundance or percent abundance examples?

AC: In multivariate space, the difference between sites across space is greater than within any one site through time. We will clarify this in the text.

-Lines 300-302: Where can the readers see this stated relationship? "...and the >150 μm size fraction or 2) trends in the >150 μm size fraction are more pronounced than in the complete assemblage"

AC: This relationship can be seen in the updated Figure 3; due to the graphical error in Figure 3, this was not clear in the original submission.

-Lines 300-310: YES! I totally agree with some of the things you are saying in this section, but you have to do a complete discussion of the literature. I would suggest splitting it up into two

sections 1) examination of <150 micron foraminifera in low oxygen/high carbon environments. Do an overview of who proposed it, what results have been seen, and how it relates to your data. The second literature comparison should be 2) foraminifera test size in comparison with oxygen. Here would be a great chance to discuss Keating-Bitonti and Payne, 2016 in greater detail. Again, do an overview of who proposed it, what results have been seen, and how it relates to your data.

AC: We will incorporate a more thorough literature review of the distribution of foraminifera in low oxygen/high carbon environments and of foraminiferal test size in relation to oxygen.

-Line 447: by “core” do you mean center? Is there another word you can use here so as not to confuse it with sediment cores?

AC: In this sentence we are referring to the center of the OMZ, we will change the language so that it is not confused with sediment cores.

-Data availability: is the section with data files raw counts? Or is this standardized per volume? See discussion in the “scientific questions/issues” section.

AC: We have addressed this question in a comment above. The raw data are given as raw abundance by volume of original sediment core.

-Figure 3: “General observations discussed in the text are noted here, e.g., species that increase in abundance in the OMZ, appear associated with the “edge” of the OMZ, etc. Note difference in x-axis in *B. argentea* plot” is not very useful information for a figure caption. Please describe the structure of the graph and summarize what you observed or reference to the section of the paper where it is discussed. Please also clearly state in this figure that “core tops” are the 0-2cm intervals. -Based on the OMZ bounds of Figure 2 it seems the majority of the foraminiferal abundance plots resides in what you have defined at the OMZ. So how can you see increases if you have no “background” to compare it to? Please clarify. The key should be bounded by a box to better identify it.

AC: We will make the suggested graphical improvements. Further, by updating Figure 3 to eliminate the graphical error, we will fix these issues. We will more heavily cite Figure 3 in the text so that it is clear when interpretations are based on this data.
