

## ***Interactive comment on “Anthropogenically induced environmental changes in the northeastern Adriatic Sea in the last 400 years (Panzano Bay, Gulf of Trieste)” by Jelena Vidović et al.***

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Received and published: 19 September 2016

Responses to the Referee 1 comments (colored blue in the manuscript):

1)

Referee 1: "Many statistical analyses make the manuscript complex and confusing. Indeed, the result of NMDS is not fully discussed. What foraminiferal species are related to NMDS 1 and 2, and what can we learn from the temporal changes of NMDS 1 and 2? Figure 7 is not fully used in discussion. So, I think there is no need to show figure 7 in this manuscript".

C1

We think that unconstrained ordination - NMDS (Figure 7) - is important because it directly depicts the differences between foraminiferal assemblages from different stratigraphic intervals/time periods, independently of environmental data. We note that the stratigraphic order is rather lost in both RDA and clustering - they just show two distinct groups, with no trends and no continuous compositional gradient. We have rather decided to move Figure 8 with constrained ordination to the Supplement (see also below). We have expanded the description of NMDS in results, related it to the information on what taxa are associated with positive and negative scores, and have now provided some further explanation in the chapters Results and Discussion:

Chapter Results, page 14: "In the NMDS space, samples from the lower and middle part of the core (150-35cm) are associated with positive scores along the first axis and are tightly grouped, indicating relatively homogeneous faunal composition... In contrast, the samples from the upper 35cm of the core are associated with negative scores along the first axis and are widely distributed in the ordination space. The separation of the uppermost part of the core from the rest of the core in the ordination space suggests a continuous, but a relatively strong shift in the assemblage composition at the onset of the 20th century (Fig. 7)."

Chapter Discussion, page 19: "However, the overall assemblage composition in the 20th century changed markedly relatively to the pre-20th century assemblage composition. The uppermost parts of the core show a very strong and directional change in composition lasting up to the present (Fig. 7), whereas the lower and middle parts of the core were characterized by a relatively constant taxonomic composition, with a much smaller multivariate dispersion in NMDS (Fig. 7)."

Referee 1: "I think that figure 6 (b) and (c) are enough for the conclusion of the manuscript. It is also same to figure 8. What is PC1 in figure 8? I think PC1 is the result of PCA of geochemical data (Fig. 4). However, the values are not equal".

As explained above, the results of NMDS analysis directly show stratigraphic order of

C2

foraminiferal assemblages and thus we would like to keep it as a part of the manuscript. The component PC1 in the Figure 8 (RDA plot) is based on relative abundances of foraminifera, while the geochemical data are reduced to total nitrogen concentration along RDA1. Because there is only one environmental variable selected by the forward model selection in the redundancy analysis (nitrogen), there is only one RDA axis. We have clarified the caption to Figure 8 (in the revised version Figure S1) as follows: "Given that only one environmental variable is used, the second axis corresponds to the first principal component that visualizes the residual compositional variation unconstrained by geochemical data. "

We moved the Figure 8 to supplementary data and added the Table S4 to the main part of the manuscript (The results of the forward model selection in the redundancy analysis; in the revised version named Table 1), because it provides detailed information about elements that explain the highest proportion of variation in assemblage composition. The results shown in this table are important for the conclusions of the manuscript, as previously explained on the page 20, lines 503-505, page 22, lines 543-544).

2)

Referee 1: "The authors concluded that the foraminiferal community has adapted to naturally elevated trace element concentrations, but such adaptation cannot be evaluated from this study because anthropogenic impact is found even in the bottom of the core".

To avoid confusion, we have omitted "naturally".

3)

Referee 1: "There are no explanations about dash line, solid line, and grey circle in figure 2. The explanations are needed in caption. I think dash line means the range between maximum and minimum ages of shells. If so, the range of ages between 90cm and 120cm are very wide (i.e. it shows "modern" to "old" ages)."

C3

We have added our clarification to the caption of the Figure 2 as follows: "The dashed line represent the total range of ages of *Varicorbula gibba*, i.e., bounded by the minimum and maximum age, the solid line represents the inter-quartile range of ages, i.e., it is bounded by the 25th and 75th quantiles, and the grey circle refers to the median age. We note that age range and inter-quartile age range increase downcore and death assemblages in the basal core increments are time-averaged to few centuries, most likely due to bioturbational mixing. Therefore, although median age of *V. gibba* in the lowermost (145-150 cm) increment is 1616 AD, interquartile range of ages of *V. gibba* in this increment includes shells that died in the 16th century."

Additionally, as the lowermost sample includes shells that died in the 16th century, the core effectively captures the past 500 years of environmental history in the Bay of Panzano. We added an explanation about this on page 12, lines 290-294, and we corrected this within the title and the manuscript.

Referee 1: "Moreover, calculated sedimentation rate between 120cm and 140cm is very high (ca. 2cm/yr). The concentration of Al decreases abruptly during this period. This may indicate the change of depositional environment. Evaluations about these points are needed".

If we use median age in each increment, the difference of ~100 years between 120 and 140 cm would imply sedimentation rate ~0.2 cm per year, not 2 cm per year. Although some elements (like Al) show some fluctuations that are in phase with grain size variations, absolute changes in sediment grain size are very minor (as already described in manuscript at page 12, lines 297-301) and we thus think that it is difficult to infer changes in environment based on it. We additionally discuss this on page 16: "In the Panzano Bay sediments, trace (Cr, Cu, Ni, Cd, Mn) and conservative elements (Fe, Al) have relatively higher concentrations in the lower part of the core and a pronounced decrease in the upper 35cm. The only discrepancy of this trend occurred in the latest 17th century, when the concentrations of all these elements declined, with simultaneous change in grain size (Fig. 3). Although these elements show some fluctuations

C4

that are in phase with grain size variations, absolute changes in sediment grain size are very minor and it is thus difficult to infer changes in environment based on it."

Referee 1: "The authors argue that short term decline of *Ammonia* sp. in the latest 17th century may have caused by the increases of pollutants, because *Ammonia* sp. is sensitive to pollutants (p. 17 line 410 to 413). However, this short term drop is only one sample, and the drop of Al during this period may indicate the change of depositional environment as mentioned above. It may be the taphonomic effect. Indeed, it seems that the change in grain size distribution occurs simultaneously with Al drop. So, we cannot discuss the decrease of *Ammonia* in relation to anthropogenic impacts. Moreover, the authors describe that the increase of *Ammonia* sp. during the late 20th century is correlated with the increase of persistent organic pollutants (p. 21 line 511 to 516). These two interpretations of *Ammonia* species are inconsistent (*Ammonia* sp. is sensitive or tolerant to pollution? *Ammonia* sp. increases after 1950 when some pollutants increase rapidly.)".

To avoid ambiguity and avoid difficulty with disentangling sampling issues and taphonomic effects, we have omitted the inference about the decline in *Ammonia* sp. in the lower part of the core. We keep the information that most *Ammonia* species are tolerant to pollution.

4)

Referee 1: "Major foraminiferal change during 1700s to 1800s is fluctuation of *Valvulineria* species (Fig. 5). The authors argue that the distinct peak of *Valvulineria* in the early 19th century coincides with the coldest and most humid phases of the LIA by citing previous study. However, the same distinct peak of *Valvulineria* also occurs in the early 18th century. The authors also describe that *Valvulineria* is adapted to large seasonal variability of organic matter, periodic hypoxic conditions, increased fluvial runoff and increased turbidity. However, nutrient concentrations and grain size are relatively stable rather than variable. The authors do not discuss this point".

C5

We have downplayed the inference about seasonality, mainly because of the likely effect of time averaging and mixing. The constancy of nutrient concentrations can be further explained by less dense spacing of samples where nutrients were measured. In the Discussion (page 18), we have added: "In contrast to fluctuations in abundance of these foraminiferal taxa, vertical changes in the concentration of nutrients in the lower and middle part of the core are mild. However, the spacing of increments that were analyzed for nutrients is larger than dense spacing of increments analyzed for the composition of foraminiferal assemblages. In addition, concentrations of nutrients, grain size distribution and vertical changes in foraminiferal assemblages are likely further affected by vertical homogenization by bioturbation, as evidenced by decadal to centennial time averaging of *Varicorbula gibba* (Fig. 2), thus making difficult to detect the effects of environmental fluctuations occurring at higher (seasonal or yearly) temporal resolution"

5)

Referee 1: "The authors describe that high abundances of Non keeled *Elphidium*, *Valvulineria*, and *Ammonia* during the 17th to 19th century suggest strong seasonal variations of river runoff and organic matter input based on the result of RDA (p. 17 line 425 to 429). However, I think that RDA results are strongly influenced by top 20cm (20th century) data of the core, because *N. tot* is relatively stable below 20cm. Gradual decrease of *N. tot* may indicate decomposition process. Indeed, if my understanding is right, high positive correlations occur within top 20cm (Figs. 4 and 8) ".

Yes, this is correct; we have removed reference to RDA in this part of the Discussion. Our inference here is primarily based on known ecological requirements of these taxa. Regarding nitrogen concentrations, we have added this statement into Discussion (page 19): "Although upward increasing concentrations of TOC and TN can be partly related to their recycling dynamic, the corresponding increase in pollutants (PAH and PCB) and other observations of major increase in pollutants and organic enrichments in the Gulf of Trieste (Heath et al., 2006) imply that the nutrient increase also

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reflects intensifying agricultural and maricultural activities in the Gulf of Trieste during the 20th century. "

6)

Referee 1: "The authors propose the three hypotheses in introduction section, so inspection result of the hypotheses should be written in conclusion section. Especially, hypothesis three (relationship between foram diversity and pollutants) was not incompatible with the result. Many previous studies have already suggested that early phase of eutrophication cases increase in foram diversity".

We added the inspection of the hypotheses in the conclusions (page 24): "This is reflected in increasing concentrations of trace elements and persistent organic pollutants (PAH, PCB), as well as in progressive nutrient enrichment, as it was presumed within the first two hypotheses. However, mining activity did not produce a progressive enrichment of mercury as anticipated in the second hypothesis, due to the improvement of the methods for the metal recovery. Increased pollutants did not cause a decline of species abundance and diversity as suggested by the third hypothesis, as foraminiferal response to such anthropogenic impacts in Panzano Bay are shaped by their long history of adaptation to elevated trace element concentrations, but also as initial stages of eutrophication can positively affect species richness."

In the Discussion, page 19, we have added this statement: "The increase in diversity observed in the uppermost parts of the core not only correlates with nutrient enrichment (in accord with observations that early stages of eutrophication can increase species richness, Martinez-Colón et al. 2009) but also with higher concentrations of pollutants, thus rather contrasting with the hypothesis that pollution inevitably decreases species richness."

7)

Referee 1: "p. 18 line 453 to p. 19 line 473: The authors associate the increases

C7

in the abundances of *Miliolinella*, *Triloculina*, and *Haynesina* with enhanced microalgal biomass (mainly diatoms) as a consequence of nutrient enrichment. However, certain *Elphidium* species feed diatoms and prefer organic rich sediments. *Ammonia tepida* decreases during this period, but *A. tepida* is herbivorous and tolerant to all kinds of stress conditions, including organic enrichment as the authors describe in the manuscript. So, this faunal change cannot be explained only by enhanced microalgal biomass and nutrient enrichment".

It is true that certain *Elphidium* species feed on diatoms. However, those are only keeled species, known to be epifaunal and herbivorous, while non-keeled *Elphidium* species prefer an infaunal mode of life and can be associated with food enrichment of the sediments. In sediments of Panzano Bay, only non-keeled *Elphidium* species dominate in the lower part of the core and we relate their abundances with the LIA, increased river run-off and organic matter input. In the 20th century, taxonomic change of foraminiferal communities happened, including the decrease of non-keeled elphidiids and increase of herbivorous taxa. Such a shift in the trophic mode of foraminiferal species we interpreted as an indication of enhanced phytoplankton, reflecting higher nutrient levels. Therefore, non-keeled elphidiids decline here probably because of the shift in the available food. This inference is explained in the manuscript (page 17, lines 424-429, page 20, lines 487-494, page 20, lines 495-503). Yes, *A. tepida* slightly decreases during this period and does not fit this trend. However, *Ammonia* sp. and *A. inflata* increase here. We added a comment about it on page 20: "Additionally, in the second part of the 20th century herbivorous genus *Ammonia* also slightly increases its abundances, with only *A. tepida* not following this trend."

9)

Referee 1: "p. 20 line 504 to p. 21 line 506: The authors describe that the presence of PAH is probably related to industrial activities, and it started to increase from the middle of the 20th century. However, it seems that PAH concentration start to increase from the latest 18th century, although it increases rapidly from the middle of the 20th

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century. So, industrial activities was advanced from the latest 18th century“.

We have modified our statement as follows: “The presence of PAH and PCB in Panzano Bay sediments is probably related to industrial activities in the port. Their concentrations are low throughout the core and start to increase in the 19th century and especially since the middle of the 20th century (Fig. 3)...,”

10)

Referee 1: "Foraminiferal discussions in subsection 5.1 and 5.3 are same although different pollutants are described in each section. So, subsection 5.1 and 5.3 should be combined to avoid confusion."

Subsections 5.1. and 5.3. concern each source of pollution separately, namely maricultural and agricultural in the chapter 5.1. and port activities in the chapter 5.3. We estimate the effects of maricultural and agricultural activities based on trace element concentrations and nutrients. Consequently, we provide the information on the responses of foraminiferal assemblages to elevated trace element concentrations and nutrients. In the chapter 5.3. we evaluate the effects of port activities by using the concentrations of persistent organic pollutants: polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyl (PCB) and we discuss possible effects of these pollutants on foraminiferal assemblages. Therefore, we would like to retain these subsections as they are. Additionally, we further split the Discussion into pre-20th and 20th century changes in foraminiferal assemblages.

Referee 1: "Figure 4: In the text, the authors describe “the first two axes explaining 75.8% of the variance”, but the value of PC2 is 14.8% in the figure 4 (sum of axes is 74.8%). Which is correct? Names of each arrow are piled and indistinct. Please redraw in the clearest way possible. Figure 5 : “sp.” is not italic. "References: Di Leonardo et al. (2006) and Solis-Weiss et al. (2001) are not cited in the text. There are discrepancies of publish year between the text and the references. P. 18 Line 440: Naeher et al. (2014) P. 11 Line 270: R Core Team (2015) P. 4 Line 104: Xuschin and

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Piller (1994)“.

Figure 4: The correct number is 74,8% of variance. We redrew the Figure 4 as suggested and corrected all listed spelling mistakes.

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Interactive comment on Biogeosciences Discuss., doi:10.5194/bg-2016-273, 2016.