

Bianchi et al.: Response to Reviewers:

We appreciate the suggestions from both reviewers and outline here a path forward that we believe will improve the paper. In particular, we acknowledge that not all of the issues raised in our paper are novel, and this is not what we had intended. Perhaps the main objectives of this exercise, which we carefully thought about through revisions and discussions, have been misconstrued by our choice of the title of the paper (*Biogeochemistry: Its Future Role in Interdisciplinary Frontiers*). We have now changed the title to: *Ideas and perspectives: Biogeochemistry – Some Key Foci for the Future*. The revised article now reflects what we consider some key topics in biogeochemistry that are rapidly developing, and/or in need of continued emphasis over the next decade. In general, our revisions are as follows: 1) a new title for the paper with some further clarification of our main goal; 2) a shorter and more focused document, with omission of the section of spatial/temporal advancements; and 2) more clearly emphasized the key points on new linkages with modern and past eco-evolutionary processes and continued emphasis on the social sciences (discussed below) - with additional supporting references.

Rev. 1.

1. "I have mixed reaction to this paper. On the one hand, how can one criticize a plea for more interdisciplinary perspectives, especially into genomics and the social sciences? And one certainly cannot criticize pleas for better communication of our results to improve science-based policy. On the other hand, all this has been said before, widely and frequently, so I really didn't learn much from this perspectives piece, nor did it offer new excitement."

The issues raised in this paper were not meant to be exclusively novel, but more a reminder of where biogeochemistry needs to keep moving and where enhanced development and greater efforts are needed, which some specific examples of where past efforts have not yet succeeded. The audience is also intended to be broad including not only established biogeochemists but also early career scientists new to the field who may be particularly interested in its societal relevance. As we mention in our perspective, the Biogeosciences were only marginally prepared to understand how changes in economic activity associated with COVID19 affected air and water quality and carbon fluxes. Similarly, the necessary multidisciplinary interactions are still not well represented in new funding programs in such areas as Critical Zone science and Biological Integration in the U.S. and elsewhere. These along with other key topics in our paper are reminders of what this team of biogeochemists' view as key areas and something we feel is worthy of publication.

2. "The very name: Bio-Geo-Chemistry, reflects the interdisciplinary roots of this field of endeavor. In several papers, Paul Falkowski and Diane Newman have reviewed how the evolutionary biochemistry of prokaryotes has left its mark on the Earth's chemical conditions."

Yes, and the paper by Falkowski, which is a key figure in a recent paper published by Bianchi (2020), on the history of biogeochemistry, along with work by Newman, are now cited as key papers that links Earths' prokaryotic history and future biogeochemistry. A key point we now emphasize in the paper, is the importance of using proxies and fossil communities to better understand not just changes in community structure, but the impact these metazoan (not just microbial) changes have had, and will have, on key biogeochemical drivers, such as redox. While range expansion has been a notable topic in recent years, much of the emphasis has been on the consequences of changing diversity and microevolution, and not how these changes affect community structure along with associated biogeochemical properties and processes, for example, redox and changes in bioturbation and/or bio-erosion. We have added some clarity to this in the paper.

3. *“Even the importance of integrating the social sciences in environmental science is widely recognized program of coupled human and natural systems at NSF and a requirement by the agency for social science linkages in its long-term ecological research programs. Better transmission of our results to policy makers was named Translational Ecology by Schlesinger in a 2010 editorial in Science and now the focus of a working group at the National Socio-Environmental Synthesis Center (SESYNC) at the University of Maryland.”*

While these points about multidisciplinary interactions, especially with social science, have been made before, there are still both vast unexplored opportunities and an urgent need for more interactions, and a reassertion these issues along with other newly developing complexities are needed. For example, while translational biogeochemistry was certainly a notable and timely concept, something we clearly missed and have cited in our revisions, we have witnessed recently protests related to carbon taxes that indicate need for new approaches and integration of biogeochemistry in relation to social science, and in particular the feedbacks with human behavior. The latter is a very embryonic line of research which we feel may be new to many in the scientific community. Once again, a reassessment and unification of ideas in our paper looking ahead for the next decade or so seems important, especially with broad the diversity of fields identify themselves under the Biogeosciences “umbrella.” We have now referenced the earlier views on *Translational Ecology* to add better historical context to what we are saying here. We have also suggested that previous lack of progress on integration between social and natural sciences has been stymied by lack of data on the coupling between the two types of systems, and we argue that digital social data may serve as a source of data to ‘jump-start’ closer integration of these fields.

Commented [MOU1]: Should this be ecology?

4. *“I have a fear that the statements about rapid evolution (page 3, line 79ff) are at odds with the recognized inefficiency of eugenics. So, I have no real criticisms of this piece; I just question its novelty and potential impact amongst the crowded pages on our computers that already sap our time and energy for forward progress.”*

We acknowledge that perhaps we were not clear enough on this point, and have made the necessary revisions.

Rev. 2.

1. *“This paper has an excellent group of authors. However, I agree with the comments of Bill Schlesinger – it’s not clear what hasn’t already been said many times before. The abstract drives that home. What is really new in this paper?”*

See our aforementioned response to Reviewer 1 on this issue of novelty.

2. *“So what might be a way forward? One suggestion is to develop a list of what are the new insights in this manuscript, and write the text around those instead of trying to cover so many different angles (scales, topics, etc). That said, the paper is well written in that it was very easy to read. I just didn’t come away with new insights.”*

These are excellent suggestions by the reviewer. Consequently, we have now changed the title and focused on key topics with more clarity. In particular, we have omitted the spatial-temporal advances made in sampling capabilities etc., and now focus just on the need for new biogeochemical linkages in modern and past eco-evolutionary processes and continued emphasis on social sciences – in light of global change such as human population growth and zoonotic pandemics, range expansion by organisms (including human emigration/immigration patterns), weather disasters etc.

We believe the perspective we offer now provides value for the biogeochemistry community through organizing and assessing a few key areas for progress. We intend that our essay stimulates assessment. We advocate for advances in areas we currently recognize, and we anticipate that via discussion and debate differing perspectives held by others will emerge to drive the field forward.