

## ***Interactive comment on “Ideas and perspectives: Biogeochemistry – Its Future Role in Interdisciplinary Frontiers” by Thomas S. Bianchi et al.***

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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 would like to change the title to be more reflective of what we consider to be a call to recharge and/or reassess of trends in biogeochemistry that are

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ongoing, rapidly developing, and/or in need of greater emphasis over the next decade. Nevertheless, there are indeed a few novel questions raised in our manuscript which we can clarify in this response. In essence, our revisions would entail the following: 1) a new title for the paper with some further clarification of our main goal; and 2) more clearly emphasizing the key points (discussed below) - with additional 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 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, would be good to mention as basis from which to continue building linkages between Earths’ history

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and future. This is one of the key points we emphasize in the paper, that 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 do discuss this in the article but will make sure this key point is clearly illustrated. 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, little progress has actually been made to date, 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 will certainly cite 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”. 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

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amongst the crowded pages on our computers that already sap our time and energy for forward progress.” As we have already responded to this comment (see below), we now acknowledge that perhaps we were not clear enough on this point, and will make the necessary revisions - as space permits. There is now ample evidence for rapid evolution, where rapid refers to contemporary evolution or evolution in ecological time. Multiple review papers on this topic have emerged (Collins and Bell, 2006; Fussmann et al., 2007; Hutchins et al., 2019; Schoener, 2011), as well as a first monograph (Hendry, 2017, “Ecoevolutionary Dynamics”, Princeton University Press). In brief, from micro-organisms to plankton, insects to plants, fishes, and birds, there are now hundreds of studies showing significant evolutionary changes in trait values over short time spans –just a few or a few tens of generations, leading to trait change during the course of a few weeks, a few months, or a few years. These evolutionary changes are rapidly gaining attention because they can influence ecological responses to, amongst others, global change. This implies that in our analyses of ecological responses and their biogeochemical implications, we should not assume that trait values of species are fixed in time. Depending on the taxon and the selection pressure, traits can significantly change, and these changes have been shown to influence ecosystem processes such as consumption, production, respiration and nutrient cycles. Given the importance of microbial organisms for biogeochemical cycles, this notion becomes even more important, because microbial organisms because of their short generation times can evolve significant different trait values in a matter of a few days or weeks. Just to illustrate with one example: Lawrence et al (2012) showed that bacterial strains that were competing with each other and had difficulties to grow together, when forced to grow together changed their physiology so much that they started to be partially dependent on each other, and thus reach higher densities when grown in the present of the other species. There are many ramifications through which eco-evolutionary dynamics can influence biogeochemical cycles and recommendations, yet few people in the field are aware of that. So, we view this as one of the next frontiers on which biogeochemistry can and should become even more integrative than in the past. Rev. 2. 1. “This paper has

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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.” We plan to make sure our points are more clearly listed. The reviewer, however, thinks the issues we discuss are valid and significant. We plan to revise the paper to enhance clarity by a change in the title and a more specific listing of our major topics. Overall, our view is the perspective we offer provides value for the biogeochemistry community through organizing and assessing 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.

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