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Reply on RC2

Madeleine Moyle et al.

Author comment on "Towards a history of Holocene P dynamics for the Northern Hemisphere using lake sediment geochemical records" by Madeleine Moyle et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-86-AC2, 2021

Thank you for your thorough review, we really appreciate the time you have put into reading through and commenting on the paper.

This paper aims to gather and analyse sediment P records by presenting reconstructed Holocene lake water TP and P yield using a newly developed model (Moyle and Boyle 2021). The records selected were those that covered as much of the Holocene as possible, as we were interested in examining Holocene-scale trends – which, as you noted, increases the temporal understanding of changes in lake water TP. The lakes selected also required sufficient data to apply the P model, limiting the sites that could be included in this study.

A central point of your commentary is that we should include a detailed comparison of our SI-TP records with published DI-TP records. We do not believe that this paper is the right place for that comparison. The reasons are detailed below, but in brief - a meaningful comparison between the two is not a straightforward matter, and is far beyond the scope of this paper and was not the focus of this study. We have been gathering information for a comparative analysis but that is another project, and requires direct contributions from the diatom research community.

As you mention, diatom-inferred reconstructions are the current tool for estimating Holocene timescale lake-water TP concentrations. This does not of course make them correct, and we are less certain than you that “the fundamental inferred changes in nutrient conditions are robust”. This is certainly demonstrated for recent change. However, when it comes to early Holocene records this is an untestable assumption. Consequently, our approach is more than just an opportunity to make up for the scarcity of whole-Holocene DI-TP records. Instead, based on a wholly different approach, the SI-TP approach offers new insights, an opportunity to validate long records, and a tool to apply at sites where diatoms are not preserved.

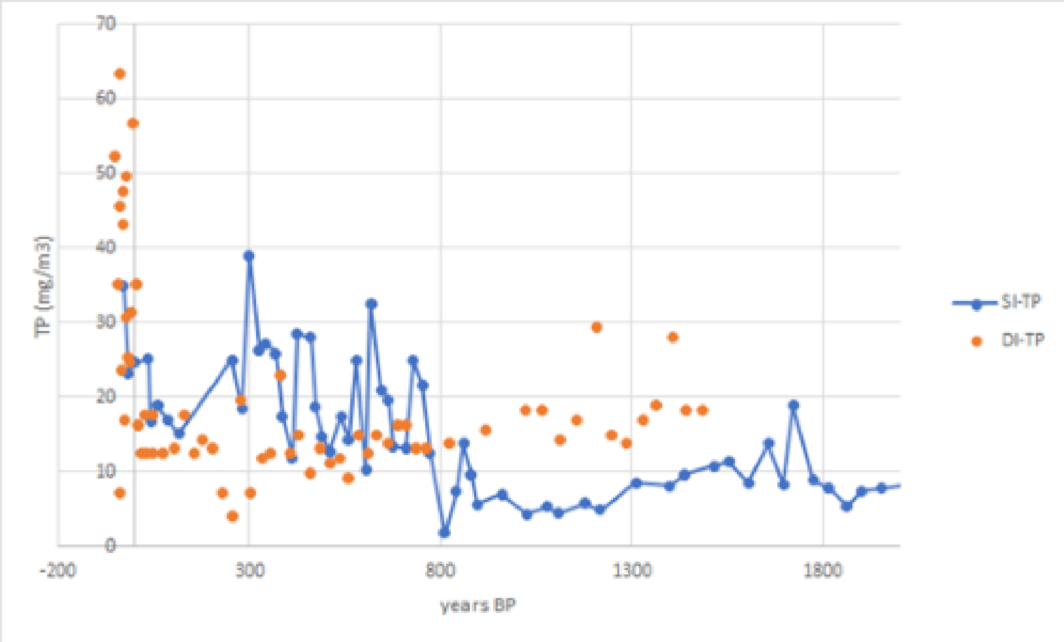
The question of whether DI-TP is valid for longer records is far beyond the scope of this paper, which aims instead to evaluate published long P records in terms of their mass balance implication for past P dynamics. Of course, the significance of the findings depend on the extent to which the inferred past lake water TP and catchment P yield values are reliable. In the paper we test this, as far as it is possible, by comparison with recent monitored values, which shows that our mass balance results concord with monitored values. In section 4.5 we also show that at three of the study sites (Schulzensee, Tiefer, and Dudinghauser) average values SI-TP agree with DI-TP. But given that these empirical models are calibrated on recent monitored TP, that is essentially the same thing. When it comes to longer records, interpretation of any comparisons of DI-TP with SI-TP is more complex. We fully agree that this needs to be done, but useful comparison requires not only optimal sediment records, but also expert input on diatom ecology and transfer functions, hence the brief comparison in section 4.5.

The sparse DI-TP record at SMP may be dissimilar in shape to our DI-TP - though more data points would help. The shape of the DI-TP and SI-TP records at Tiefer are different too. But how is this to be interpreted? Age model mismatch? And can we trust the DI-TP reconstruction? This requires an interrogation of both the SI-TP and DI-TP reconstructions.

Whilst we agree that comparing records of SI-TP to DI-TP would be valuable, we believe this would be done best as a separate study with a separate set of site selection criteria – which would not need to be restricted to Holocene scale records as in this study – and preferably on geochemical and diatom records from the same core with records from multiple sites. Here the aims were to look at Holocene scale patterns in SI-TP and P yield, rather than fully test the SI-TP reconstructions, and we show coherent patterns with matches to environmental history.

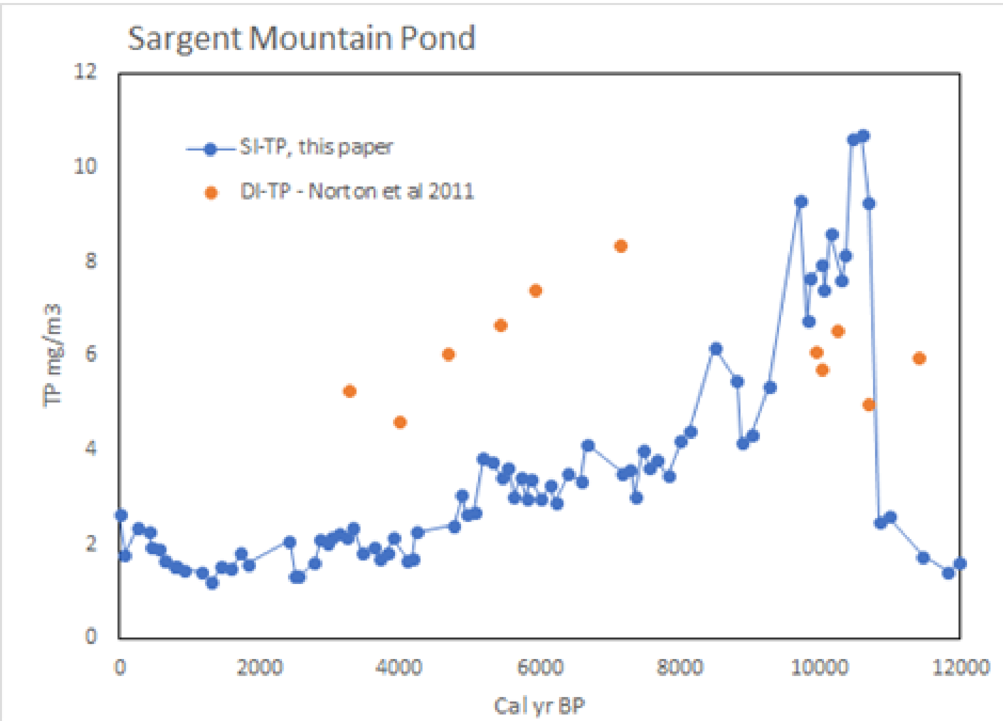
While we argue against adding this to the paper, we can of course comment on your two examples of mismatches between SI-TP and DI-TP, at Sargent Mountain Pond and Tiefersee in section 4.5. At Tiefersee (Image below) we find similar average magnitudes for the last 800 years, particularly for the most recent traces. Before that they are distinctly different. Estimation of SI-TP here is suboptimal because of the inferred dry density and low resolution age model. But, at the same time, there is no certainty that the mismatch cannot be attributed to DI-TP. Note: the very large shift in SI-TP we observe predates the base of the DI-TP record, and so isn’t compared.

Fig1: Comparison of DI-TP (Selig et al) and SI-TP (this paper) at Tiefersee



At Sargent Mountain Pond the situation is slightly different (Image below)

Fig2: Comparison of DI-TP (Norton et al. 2011) and SI-TP (this paper) at Sargent Mountain Pond



Here, we see a similar profile but different magnitude for the Mid Holocene, but with differing shapes for the early Holocene. The mismatches in magnitude are perhaps not such an issue - uncertainty of DI-TP alone can accommodate this. But the mismatches in shape must have another explanation. There seem to be three main possibilities. First, it might be attributed to post burial migration. Second, it might be attributed to a large change in the sediment P retention factor in the interval 7,000 -10,000 BP. Third, the DI-TP calibration might be incorrect for the early Holocene. There is simply no reason, as yet, to argue a strong case as to which of these is correct. More work on this is needed, but that does not detract from the fact that Holocene P profiles show coherent patterns of variation, the theme of this paper.

Finally, there is the question of sediment P fractions. As you have suggested, the inclusion or removal of certain P fractions will affect the reconstructions and we briefly touched on this in the model paper (Moyle and Boyle 2021). A strong case can be made for excluding biologically unavailable P from our sediment records, but of course there is no universal agreement on how to do this. We are definitely interested in exploring the possibility of using organic P concentrations, as these appear unaffected by accumulation of vivianite. However, that would involve adding an empirical step (the fraction of total "labile" contributing to the organic P record), which requires far more research. So, at present we base our method on totals and recognise that this provides an upper limiting value, though one typically close to the correct value. This approach has the advantage of requiring no local parameterisation of the model.

Again, the purpose of this study was to collect as many Holocene sediment P records as possible – and many of the studies here do not report fractions. This would be worth exploring with a separate dataset of lakes with P fractions – and not limited to Holocene scale records. We think this highlights the need for a bigger and global dataset of lake P records, including P fractions.

Thank you for the useful editorial comments, we will address most of these at a later stage but have a response to two points. First, the question of what mineral density to use in calculating dry density from water content is interesting, but relatively unimportant because the water content has such a strong effect. If we substitute 2.0 for 2.7 in our calculation the dry density changes by 5% (relative) for 70% water content, and by just 1.4% for a water content of 90%. Second, clearly µg/L and mg/m3 have the same numerical value. As modellers the latter seems preferable as the conversion to unit area in metres is more logical. Further comment on this by peer reviewers is welcome.

Thanks again for your supportive and thoughtful review, this paper is part of Maddy's PhD work and your comments have been useful and are very much appreciated!