Revised title: Living and nonliving particulate iron in the subtropical North Pacific Ocean

Manuscript # egusphere-2025-6068

RC1: 'Comment on egusphere-2025-6068', Anonymous Referee #1, 14 Jan 2026

Review of egusphere-2025-6068 "Biogenic and nonliving labile particulate iron in the subtropical North Pacific Ocean by Bates and Hawco.

Summary

This manuscript explores the composition and dynamics of labile particulate iron (pFe) in the subtropical North Pacific, focusing on the split between biogenic and nonliving fractions. To achieve this, the authors undertook iron (Fe) uptake experiments (using the Fe isotope double spike method) and carbon (C) uptake to estimate how much Fe and C are incorporated into cells. They then use Fe:C uptake ratios in combination with particulate organic carbon (POC), particulate organic phosphorus (PP) and ATPase to estimate biogenic pFe. To estimate labile iron, Bates and Hawco used the chemical leach method of Berger et al. (2008) to estimate easily mobilised Fe from biogenic and non-living material. Finally, they connect the two and determine that biogenic Fe accounts for approximately 60% of labile Fe in the mixed layer, with the rest being associated with nonliving matter.

Overall, the manuscript is generally well written. One bugbear is that the manuscript keeps directing the reader to other papers for DFe and associated data (see examples below). I realise that the data has been published, but it would be useful to include plots in the supporting materials; otherwise, the reader has to sift through articles to check the claims.

We appreciate the reviewer's consideration of our manuscript. We will add the associated Fe data published in our other manuscripts to this work.

Specific comments

Line 96: Are you saying that at the end of the incubation, there was ~a 50:50 split of the FeDS between the dissolved and particulate phases? Or is this total - probably the total as you added ~ 50 pM.

This is the total mean concentration of FeDS that was recovered at the end of the incubation; we have clarified this in the text which now reads:

“The total mean FeDS recovered from the dissolved and particulate phases was 55 ± 21 pM, …”

Line 119-120: Where is the evidence to support this? Please reference a figure or table here - as a reader, I really don't want to have to search through other references for the data. It's your data (Bates and Hawco, 2025), so this should be easy to generate. Perhaps you could add an extra couple of panels to Fig 1 showing the iron data or add a new figure. Or you could add a figure to the supplementary information showing the DFe data and reference it came from Bates and Hawco, 2025.
Line 122-123: Again, please don't make me read other papers to see the primary data you are referring to - show it here and then reference where it came from.

We thank the reviewer for identifying how to make our work more accessible for readers. We will add the seasonal variability for euphotic zone dFe and labile pFe to Figure 1. We will also add the seasonal variability of lithogenic pFe and particulate Fe export to a Supplemental Figure so the reader does not have to seek out the other references.

Line 129: What about Synechococcus? was that measured? It can also be an important player in tropical and subtropical waters. Certainly, it is often found at shallower depths than Prochlorococcus (Flombaum et al., 2013).

Yes, we were also interested in the potential role of *Synechococcus* in Fe uptake. However, it did not show a strong correlation with Fe uptake rates (line 133). This is likely because *Synechococcus* cell numbers are relatively low at Station ALOHA, comprising just 2-8% of picophytoplankton biomass in both the upper and lower euphotic zones and ~2% of total ^{14}C productivity integrated across the euphotic zone (Rii et al. 2016).

Rii, Y., Karl, D. M., and Church, M.: Temporal and vertical variability in picophytoplankton primary productivity in the North Pacific Subtropical Gyre, Mar. Ecol. Prog. Ser., 562, 1–18, https://doi.org/10.3354/meps11954, 2016.

Line 134: Table S1 only show correlation data; perhaps you could show the population data for Prochlorococcus, Synechococcus, and picoeukaryotes at 25 m. That will allow the reader to check the data and the points about abundance made in the text.

We will add a supplemental figure showing the temporal variability of *Prochlorococcus*, *Synechococcus,* picoeukaryotes, and heterotrophic bacteria populations over the course of this study.

Line 134: How about presenting the 14C data. It would be nice to see how it varied temporally. We only have the Fe:C ratio data.

We appreciate the reviewer noting this and will add the HOT ^{14}C data to Figure 1.

Figure 1. Because you say that Prochlorococcus and picoeukaryotes dominate, is it possible to normalise the iron uptake to cell number to get an idea of uptake per cell? As you show in panels c-e, the strong coupling between uptake and Prochlorococcus and picoeukaryotes abundance indicates that it is driven by cell abundance, which is likely to vary seasonally. Based on the comments about the 14C data on lines 133 to 134, I assume that primary production (14C) and cell abundance are not coupled? It might be worth showing this as well.

We appreciate the reviewer's suggestion to calculate an uptake per cell. Due to co-occurrence of both groups with vastly different cell sizes, we do not feel that it is appropriate to cell number without creating new problems. However, we can use the slopes of the multiple linear regression model (Fig. 1e) to approximate an apparent Fe uptake per cell for *Prochlorococcus* and picoeukaryotes.

For *Prochlorococcus,* which dominate phytoplankton cell counts (but not necessarily biomass), our regression indicates a slope of 0.00045 pM Fe uptake per cell/mL per day. We can convert this to an apparent *Prochlorococcus* uptake rate of 45 x 10^{-19} mol Fe $cell^{-1}$ d^{-1}, or 0.45 amol Fe $cell^{-1}$ d^{-1}. This is in reasonable agreement with group-specific Fe uptake rates for *Prochlorococcus* from the South Pacific Ocean (Lory et al., 2022). A similar analysis for picoeukaryotes yields an apparent uptake rate of 39 amol Fe $cell^{-1}$ d^{-1}. The ~100-fold difference in cell-specific Fe uptake rates is reasonable considering the ~100-fold difference in cell-specific C productivity for picoeukayotes (~30 fmol C $cell^{-1}$ d^{-1} in the mixed layer; Rii et al., 2016) compared to *Prochlorococcus* (~0.3 fmol C $cell^{-1}$ d^{-1} in the mixed layer; Rii et al. 2016). We have added the following text to paragraph two of section 3.1:

"From the slope of the multiple linear regression, we can calculate apparent cellular uptake rates of 0.45 amol Fe $cell^{-1}$ d^{-1} for *Prochlorococcus* and 39 amol Fe $cell^{-1}$ d^{-1} for picoeukaryotes. The *Prochlorococcus* rate agrees with previously reported *Prochlorococcus*-specific Fe uptake rates (Lory et al., 2022), while the ~100-fold difference between the two groups is consistent with the ~100-fold difference in group-specific ^{14}C productivity rates (Rii et al., 2016)."

^{14}C and cell abundances were not well correlated and we have amended line 133 to:

“^{14}C-based primary production was less variable than Fe uptake rates over these cruises (RSD = 0.13 for primary production compared to 0.40 for Fe uptake) and did not correlate well with cell abundances ($R^2 < 0.1$ for *Prochlorococcus*, *Synechococcus,* picoeukaryotes, and heterotrophic bacteria).”

Lory, C., Van Wambeke, F., Fourquez, M., Barani, A., Guieu, C., Tilliette, C., Marie, D., Nunige, S., Berman-Frank, I., and Bonnet, S.: Assessing the contribution of diazotrophs to microbial Fe uptake using a group specific approach in the Western Tropical South Pacific Ocean, ISME Communications, 2, 41, https://doi.org/10.1038/s43705-022-00122-7, 2022.

Rii, Y., Karl, D. M., and Church, M.: Temporal and vertical variability in picophytoplankton primary productivity in the North Pacific Subtropical Gyre, Mar. Ecol. Prog. Ser., 562, 1–18, https://doi.org/10.3354/meps11954, 2016.

Line 175: The assumption here is that the Berger method is getting all of the biogenic Fe - did you check the Fe/Al ratio for the labile and total pools to see if they jive with each other? Also, perhaps it should be mentioned that the Berger method was designed to look at labile iron from the Columbia River plume and coastal waters off the West Coast of the US. The values in that study were in the high nanomolar range for iron, whereas concentrations in the present work are subnanomolar. Since most of the iron in the present work is likely within organic molecules, dead and alive, it is possible that the Berger leach does not access this as molecules may need to be oxidised (noting the Berger leach is reducing) to break them down before iron can be accessed. Just a thought.

We appreciate the reviewer’s note of the complexity of interpreting results from the Berger leach. The mean mixed layer Fe/Al ratio of the refractory pool was 0.50 mol:mol, notably lower than the Fe/Al of the total pool (mean 0.69 mol:mol), but in agreement with the total Fe/Al ratio found in North Pacific aerosols (0.53 mol:mol, Buck et al. 2006). This suggests the Berger leach removed biogenic Fe but did not solubilize lithogenic Fe (which would have released Al). Rauschenberg & Twining (2015) also compared the Berger leach to direct measurement of phytoplankton cellular Fe and found good agreement in the subnanomolar range (including samples from the center of the North Atlantic subtropical gyre). We also note that the leach includes a heating step for the purpose of denaturing proteins (Berger et al., 2008), which we believe is effective for releasing Fe from colloidal biomolecules.

We have added the following sentence to the first paragraph of 3.2 Estimating pFe in biomass using three different approaches (line 160):

"The Berger et al. (2008) leach was originally developed to estimate labile pFe in a river plume and coastal waters, but subsequent applications in oligotrophic waters have shown that it can effectively solubilize biologically relevant pools of pFe (Rauschenberg & Twining, 2015)."

Berger, C. J. M., Lippiatt, S. M., Lawrence, M. G., and Bruland, K. W.: Application of a chemical leach technique for estimating labile particulate aluminum, iron, and manganese in the Columbia River plume and coastal waters off Oregon and Washington, Journal of Geophysical Research: Oceans, 113, https://doi.org/10.1029/2007JC004703, 2008.

Buck, C. S., Landing, W. M., Resing, J. A., and Lebon, G. T.: Aerosol iron and aluminum solubility in the northwest Pacific Ocean: Results from the 2002 IOC cruise: AEROSOL FE AND AL SOLUBILITY, Geochem. Geophys. Geosyst., 7, n/a-n/a, https://doi.org/10.1029/2005GC000977, 2006.

Rauschenberg, S. and Twining, B. S.: Evaluation of approaches to estimate biogenic particulate trace metals in the ocean, Marine Chemistry, 171, 67–77, https://doi.org/10.1016/j.marchem.2015.01.004, 2015.

Figure 3, panel b. The unit nM needs to be removed as this is a fraction calculation.

We thank the reviewer for catching this, it has been fixed.

Figure 4 caption. "...authigenic (navy).." is mentioned, but the figure key is "Labile nonliving pFe".

We thank the reviewer for catching this, it has been fixed.

Line 303 – I like this, it's always good to compare to other regions.

Thank you, we agree this is an important section for contextualizing our work.

References

Bates, E.S., Hawco, N.J., 2025. Dissolved Iron Seasonal Cycle and Residence Time in the North Pacific Subtropical Gyre. Geophysical Research Letters, 52(21): e2025GL118095.

Berger, C.J.M., Lippiatt, S.M., Lawrence, M.G., Bruland, K.W., 2008. Application of a chemical leach technique for estimating labile particulate aluminum, iron, and manganese in the Columbia River plume and coastal waters off Oregon and Washington. Journal of Geophysical Research-Oceans, 113.

Flombaum, P. et al., 2013. Present and future global distributions of the marine Cyanobacteria Prochlorococcus and Synechococcus. Proceedings of the National Academy of Sciences, 110(24): 9824-9829.

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