

# ***Interactive comment on* “Technical Note: Constraining stable carbon isotope values of microphytobenthos (C<sub>3</sub> photosynthesis) in the Arctic for application to food web studies” by L. E. Oxtoby et al.**

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Received and published: 18 February 2014

Interactive comment on “Technical Note: Constraining stable carbon isotope values of microphytobenthos (C<sub>3</sub> photosynthesis) in the Arctic for application to food web studies” by L. E. Oxtoby et al.

Dear Reviewer 2,

We thank you for your valuable comments, which we have addressed as follows:

1) Comment: There are substantial problems with the DIC composition that was used

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as a starting point in the calculations. Stable isotopic composition of DIC was determined 5 meters above the seafloor, and it is very unlikely that the benthic microalgae would see DIC with this isotopic composition. The  $\delta^{13}\text{C}$  ratio of DIC in the sediment-water interface is affected by DIC from mineralization processes and benthic photosynthesis. As a result, porewater DIC can be substantially more different than overlying waters.

Author Response: In our study, we measured the isotopic composition of dissolved inorganic carbon (DIC) in bottom water located within five meters of the seafloor. Our dataset adds to a very limited set of isotopic measurements of DIC in the Arctic (e.g. Gruber et al. 1999) and to an even smaller set of those measurements conducted at depth (e.g. Griffith et al. 2012). In addition to expanding spatial coverage for  $\delta^{13}\text{C}$  DIC measurements at depth in the Arctic, our measurements close the sampling gap represented by those from surface waters and those from porewater (Coffin et al. 2013).

The reviewer raises an important concern about DIC composition. Using the isotopic composition of bottom water DIC to estimate that of microphytobenthos (MPB) could bias estimates for carbon stable isotope compositions of microphytobenthos ( $\delta^{13}\text{C}$ MPB) if there is minimal exchange between porewater and bottom water DIC pools and if these two sources are isotopically distinct. While we are unable to comment on exchange between DIC pools, existing evidence shows that porewater DIC in our study region is not isotopically distinct from bottom water (Coffin et al. 2013). We have recently (since our manuscript was submitted) been made aware of a study in which porewater  $\delta^{13}\text{C}$  DIC measurements were made at sites along the Alaskan shelf of the Beaufort Sea during the same time of year as our study (Coffin et al. 2013). Coffin et al. (2013) observed that, in all locations, porewater  $\delta^{13}\text{C}$  DIC near the sediment water interface, where MPB would be growing, were similar to that of typical seawater values. The range of  $\delta^{13}\text{C}$  DIC values reported for porewater from varying sediment depths are the same as, or lower than, our DIC values from bottom water. This gives us confidence that our measured values for the  $\delta^{13}\text{C}$  DIC values we used

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in our manuscript are appropriate to constrain estimates for MPB biomass. Additional porewater and bottomwater sampling in the Arctic would bolster our estimates and elucidate a poorly studied compartment of the benthic carbon cycle.

2) Comment: The model that was used for estimating isotopic fractionation factors in marine microalgae, has been developed for phytoplankton i.e. cells suspended in water. Benthic microalgae are however growing in dense biofilms that operate more as a closed system. As a result, CO<sub>2</sub> availability will be restricted and actual isotopic fractionation factors reached in benthic microalgae may therefore be much lower than for phytoplankton.

Author Response: The referee makes a valuable point. This is one drawback of our model that we will acknowledge in our discussion of the strengths and weaknesses of our modeling approach. However, application of this method (and use of a similar, less developed modeling equation), has been used to constrain values of hydrocarbons in sediments (Freeman et al. 1994). With respect to benthic microalgal fractionation factors, we do not expect isotopic discrimination to be the same for benthic microalgae from high and low latitude systems. In cold environments, algal growth rates are depressed by cold water temperature, and low nutrient and light availability (Kirst and Wiencke 1995). Consequently, we expect isotopic discrimination for polar MPB at typical Arctic growth rates to be higher relative to MPB growing in warm water provided there is sufficient nutrient and light availability. 3) Comment: Although  $\delta^{13}\text{C}$  data may not be available for the Arctic, the data available for more temperate systems suggest that benthic microphytobenthos is heavier (say -11 to -18 ‰ than phytoplankton (around -21 ‰. Several approaches have been used to study the isotopic composition of benthic microalgae: several studies isolated mobile diatoms (e.g. Riera and Richard (1996) *Estuarine Coastal And Shelf Science* 42: 347-360) and others studied FA biomarkers (as proposed by the authors, e.g. Evrard et al (2012) *Marine Ecology Progress Series* 455: 13-31). None of this literature is used in this paper, and would directly indicate that the approach used here is probably flawed.

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Author Response: In this short technical note format we intentionally limited our discussion of previously published values of  $\delta^{13}\text{C}_{\text{MPB}}$  from temperate and tropical regions, of which there are many (Oakes et al. 2005 and references therein), because we feel it would be inappropriate to compare Arctic values with those from temperate and tropical environments. Differences in water temperature, seasonal light availability and nutrient regimes between high and low latitude environments are substantial and would have an influence on growth rate and species composition of MPB. Additionally, in our study region, porewater DIC can be influenced by methane that may decrease its isotopic composition in regions of high methane availability. At sites on the Alaskan Beaufort shelf,  $\delta^{13}\text{C}_{\text{DIC}}$  was as low as  $-36\text{‰}$  which would result in even lower isotopic compositions of MPB biomass relative to lower latitudes. Any influence of a methane-derived carbon source on the  $\delta^{13}\text{C}_{\text{DIC}}$  and subsequently the  $\delta^{13}\text{C}_{\text{MPB}}$  would only reinforce one of the conclusions of our original manuscript that estimated  $\delta^{13}\text{C}_{\text{MPB}}$  values in the Arctic would be distinct and lower than sea ice derived organic matter, including fatty acid biomarkers (Wang et al. 2013).

We do not have sediment isotopic data from the Beaufort or Chukchi Seas. However, we have analyzed sediments from an extensive spatial and temporal range of the Bering Sea shelf for  $\delta^{13}\text{C}$  values of bulk total organic carbon (TOC) and compound-specific fatty acid (FA) biomarkers (Oxtoby et al. unpublished).  $\delta^{13}\text{C}$  values for MPB TOC and FA from sub-Arctic sediments are consistent with those that we modeled for MPB here. If we expect Arctic  $\delta^{13}\text{C}_{\text{MPB}}$  values to resemble temperate and tropical MPB ( $\delta^{13}\text{C}_{\text{MPB}} = -11$  to  $-18\text{‰}$ ), then mixing models to determine relative contributions of MPB into Bering Sea sediments indicate that MPB was not present at any of our sites under varying sea ice regimes. We would be willing to include a table containing previously unpublished  $\delta^{13}\text{C}_{\text{TOC}}$  and  $\delta^{13}\text{C}_{\text{FA}}$  from Bering Sea sediments to corroborate the results of our predictive model. 4) Comment: Algal growth rates that were used in the model are derived from phytoplankton. Are these relevant for benthic microalgae?

Author Response: The referee is correct in stating that the growth rates used in the

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model proposed by Laws et al. (1995) are derived from phytoplankton. However, on page 18159 Lines 1-7 (included below), we make reference to additional studies (Karsten et al. 2006, Longhi et al. 2003) that show algal growth rates for polar MPB that are well within the range of those used by Laws et al. (1995) and within the range of the maximum growth rates observed in the natural environment (Laws et al. 1987):

p. 18159 Lines 1-7: “We investigated changes in  $\varepsilon_p$  over a range of typical growth rates given low levels of irradiance and cold temperatures in polar environments (Karsten et al., 2006; Longhi et al., 2003). Although growth rates for polar benthic diatoms are typically  $\mu=0.3\text{--}0.5\text{ d}^{-1}$ , growth rates as high as  $\mu=1.24\text{ d}^{-1}$  have been observed (Karsten et al., 2006; Longhi et al., 2003). We selected  $\mu=1.4\text{ d}^{-1}$  as the upper limit for algal growth rate following Laws et al. (1995) because  $\mu$  rarely exceeds two doublings per day in the natural environment (Laws et al., 1987).”

As we discussed in our response to a comment provided by Referee 1 (comment number 3), the maximum algal growth rates in the Arctic observed during a highly productive under ice phytoplankton bloom was  $1.44\text{ d}^{-1}$  in the Chukchi Sea (Arrigo et al. 2012). We felt  $\mu=1.4\text{ d}^{-1}$  was a conservative upper bound for our range of modeled values for  $\delta^{13}\text{C}$  values given reduced light attenuation at depth and due to high sediment loading on the Beaufort Shelf. However, we would be willing to include an additional column of data to Table 1 extending the upper bound for  $\mu$  to show how  $\delta^{13}\text{C}$  values of MPB are affected. For example, even by increasing the maximum growth rate to a high (and less probable) level of  $\mu=2\text{ d}^{-1}$ , we find a very minimal shift of 1 ‰ for *P. tricornutum* (given average values of  $30\ \mu\text{mol kg}^{-1}$  and  $0.8\text{ ‰}$  for aqueous carbon dioxide concentration and  $\delta^{13}\text{CDIC}$ , respectively, taken from Table 1). This shift is still insufficient to create a  $\delta^{13}\text{C}$  value for MPB that resembles that of sea ice derived organic matter and is therefore consistent with the conclusions of our manuscript.

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Interactive comment on Biogeosciences Discuss., 10, 18151, 2013.

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