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Interactive comment on "Nitrate assimilation and regeneration in the Barents Sea: insights from nitrogen isotopes" *by* Robyn E. Tuerena et al.

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We thank Dr Rafter for his time in completing this review. He has contributed some very useful points to help improve the manuscript. Here we include responses to all of the comments as follows: (1) Reviewer's comment (2) Author's comment (3) Suggested change to manuscript

(1) Overall, I found this to be a useful study of nitrate supply to the Barents Sea. Among the interesting results are the seasonal surface nitrate d15N across the Barents Sea Opening and the full water column nitrate isotopes and particulate matter d15N. I would like some clarification on a couple points. First, I don't think the particulate matter sampling strategy is ever detailed. This is key to interpreting the particulate d15N measurements in relation to the nitrate isotopes. Is this entirely euphotic zone particulate d15N? Are these the same sample locations and depths as the nitrate samples? Or sub-euphotic zone? This is important, critical for interpreting the particulate N measurements. I list other requests for clarification below. Given that these are necessarily suspended particulate N measurements, I found the strong relationship with nitrate d15N (and therefore connection to seasonal nitrate utilization) to be very surprising. This is because suspended N typically displays some degree of in- dependence from surface ocean nitrate utilization (see studies by Knapp et al., Fawcett et al., and others). This question about the particulate N measurements is important. I detail other points needing clarification below.

(2) Thank you for this point, the methods section has now been edited to show exactly what data have been used in the manuscript and why, and the DOIs for the associated data (nutrients, nitrate isotopes, particulate N isotopes) will be added in the following version. Only d15N-PN samples from the euphotic zone are used in Figures 6c and d, where the modelled data is presented. In 6a, upper 50m is presented and in Figure 6b only surface data are presented (as no depth profiles were collected). To further clarify, additional comments have been added to Section 4.2 and to the figure caption for Figure 6.

The integrity of the relationship between particulate and dissolved species following Rayleigh uptake systematics is dependent on the environment. The different time scales represented by the isotopic composition of dissolved and particulate species, relative degree of recycled production, and surface inputs from atmospheric deposition and N fixation, are all potential factors that can decouple this relationship. In the oligotrophic open ocean setting (eg. Knapp et al.,2016, Fawcett et al., 2011, 2014) these processes are relatively more important.

The strong relationship in our study indicates the importance of uptake processes determining the isotopic signals. This work takes samples from the euphotic zone of a highly productive, stratified Arctic shelf, where the euphotic zone nitrate concentration at the time of sampling, ranges from near source values (~9uM) to near zero. In summer months on the Barents Sea shelf, if the primary nutrient source is nitrate, the d15N signature is likely to follow the sharp changes in nitrate availability and these bulk measurements are unlikely to capture variability of separate algal assemblages as seen in Fawcett et al (2011) as the primary nutrient taken up by phytoplankton at this time, is nitrate, and not ammonium.

Our Barents Sea data also shows that the nitrate-particulate d15N relationship doesn't necessarily hold up with the same trend through the study area (different trend in low temperature Arctic Waters compared to warmer Atlantic Waters), through the full season (Figure 6b), or below the euphotic zone.

(3) Added paragraph at line 285: The integrity of the relationship between particulate and dissolved species following Rayleigh uptake systematics is dependent on the environment. The different time scales represented by the isotopic composition of dissolved and particulate species, relative degree of recycled production, and surface inputs from atmospheric deposition and N fixation, are all potential factors that can decouple this relationship (Knapp et al.,2016, Fawcett et al., 2011, Fawcett et al., 2014). Our finding that the large variability in nitrate concentration in the euphotic zone (from <0.5 to >8uM) is captured in the d15N -PN suggests that during the sampling period, nitrate was likely to be the principle N source to phytoplankton and the PN measured was largely of autotrophic origin.

Line by line notes (1) Title: It might be more accurate to describe this as insights from nitrate isotopes since it also includes nitrate O isotope measurements (2) Yes we found this difficult to choose (as the paper also uses particulate N isotope measurements), but agree that the nitrate isotope measurements are the key dataset for the paper. (3) Changed to: Nitrate assimilation and regeneration in the Barents Sea: insights from nitrate isotopes

(1) Line 38-40: I understand the sentence, but others might not. Would clarify. And

does the word "inflow" belong there? (3) Suggested edit: Further insight is required into how nitrate is supplied to Arctic shelves, the nutrient cycling processes that occur in-situ and their sensitivity to climate change. A further understanding of these processes will help to inform on future changes to Arctic primary production and food web dynamics.

(1) Line 54: Define "It" Line 68: Would insert more call- outs to figures throughout this description. (3) Suggested edit: As warm and saline AW inflow water is transported across the Barents Sea, it is modified by atmospheric cooling and is mixed with cold, fresh Arctic origin water (ArW) and the Norwegian Coastal Current (NCC) (Figure 1b). ArW found across the northern Barents Sea comprises fresh Arctic river runoff, sea ice melt and precipitation, and contains the remnants of the winter mixed layer (Rudels et al., 1996). Less dense ArW isolates the sea surface and ice cover from warm AW below (Lind et al., 2016) and during the summer is capped by a well-mixed surface layer of fresh melt water (Polar Surface Water) (Figure 2b). Sea ice import from the Nansen Basin and Kara Sea is the most important source of freshwater in the northern Barents Sea (Lind et al., 2016;Ellingsen et al., 2009). The transition between AW and ArW is marked by the Polar Front, which can be identified from the sea surface temperature gradient (Barton et al., 2018;Oziel et al., 2016) (Figure 1b).

(1) Line 73: I really like this description of the water masses and their influence.

(1) Line 93: Is this acronym used more than once? (3) acronym deleted

(1) 140: Wrong delta symbol? (3) changed to small delta

(1) 141-142: Might want to be more explicit about why the filtration persisted until "good colour was obtained on the filter". And where exactly are these samples? Are they at the same depths as the nitrate samples? (2) This section has been edited to be more specific and links to DOIs will be added in the revised version. (3) Dissolved inorganic nutrient concentrations were determined using a Bran and Luebbe QuAAtro 5-channel auto analyser (SEAL Analytical) and AACE operating platform (V 6.1) following standard colorimetric methods with a CRM precision of 0.3%, 0.8% and 1.9%

for nitrate+nitrite, phosphate and nitrite, respectively (Brand et al., 2020). Nitrate isotope samples were collected and filtered inline from the CTD using an Acropak and were frozen at -20°C until analysis. Of the 59 CTD casts in 2017, 23 were sampled for nitrate isotopes covering the full water column (Tuerena and Ganeshram, 2020). d15N-PN samples were collected by gently vacuum filtering through combusted GF/F filters (450 °C, 4hr, Whatman, 48 mm or 25 mm, nominal pore size 0.7 μm) until sufficient biomass was collected on the filter (8 to 12 L for the 48 mm diameter filters and 2 to 5 L for the 25 mm diameter filters). The filters were dried at 60 °C to remove all moisture and were stored folded and wrapped in combusted aluminium foil until return to the home laboratory where they were placed in a -80 °C freezer until analysis. d15N-PN samples were collected in the upper 200m (Norman and Mahaffey, 2020), however in this study, we only utilise measurements from within the upper 50m and for exploring Rayleigh fractionation, only samples from the euphotic zone were used.

(1) 190: Entire sentence is passive and can be clearer. Also, callout to figure (e.g., "far right in Fig. 2A & 2B) (2) Sentence has been edited to read: (3) Below 100 m depth, over the shelf break and continental slope of the Nansen Basin, high salinity (cooled) Atlantic origin water was observed within the Boundary Current that entered the Arctic via the Fram Strait (far right of Figure 2a &b).

(1) 210-216: Would begin with the "Therefore," sentence and be more active statement. (2) Thank you this has definitely made this paragraph clearer, now edited to read: (3) The origin of AW is important as pre-bloom nutrient concentrations, advected into the Barents Sea, set the upper limit on seasonal primary productivity. The nutrient concentration within AW is controlled by the relative contribution of nutrient-rich North Atlantic subpolar water and nutrient-poor subtropical waters that reach the Norwegian Sea together with the biological and physical transformations en-route. (Hatun et al., 2017;Rey, 2012;Johnson et al., 2013). Here we consider the contribution of subtropical and subpolar water to the AW sampled in the Barents Sea based on known nitrate isotope end members. We discuss the processes that the source waters are likely to

have undergone and consider historical and future long-term trends in d15N-NO3.

(1) 233: "in transit"? And does this refer to nitrate assimilation at depth? Or is the text calling on some earlier nitrate assimilation that was then mixed to depth? This latter seems the most likely considering seasonal North Atlantic mixing, right? There's a lot of questions here and I think this statement needs to be supported and/or described in more detail. (2) Yes this paragraph is describing earlier nitrate assimilation occurring in the subpolar north Atlantic where there is a high degree of seasonal mixing leading to d18O enrichments to depths of >200m which are then transported onto the Barents Sea shelf. Paragraph changed to: (3) An elevation in d18O-NO3 relative to deep water values from the North Atlantic demonstrates that partial nitrate assimilation followed by nitrification occurs in the subpolar North Atlantic which decreases d15N-NO3 to a greater extent than d18O-NO3 (Van Oostende et al., 2017; Peng et al., 2018). Seasonal mixing leaves an enrichment in d18O-NO3 to depths of >200m, a signal which is then transported onto the Barents Sea shelf.

(1) 291: These repeat transects are very cool.

(1) 308: I would want to qualify this statement with words like, "likely represents. . ." or "is consistent with. . ." (3) Changed to: This decline is consistent with N recycling and nitrification.

(1) 345: This equality between nitrate d15N and sediment d15N will only be the case where there is complete nitrate consumption. I think this is the case here, but this should be clarified. (2) Yes exactly. The full utilisation of nitrate was discussed in section 4.2, specifically lines 286-289:'As there is full utilisation of nutrients over the growing season, we suggest that the integrated source of organic matter to the sediments and food web is ~5‰ throughout the Barents Sea.' However we agree that it is worth also adding to this section. A new sentence has been added: (3) In section 4.2, we discuss the complete consumption of nitrate in the euphotic zone over a seasonal cycle. This finding suggests that over the course of the season, once all NH4+ that

has been released from the sediments and oxidised, d15N-NO3 should reflect the N source (in this study: 5.1 $\pm$0.1‰.

(1) 356: released in other regions? (2) Sentence now reads: (3) This process enriches NH4+ in 15N, a signature which is subsequently imparted on the overlying water column when NH4+ is released in other regions from the sediments and oxidized by nitrifiers (Brown et al., 2015).

(1) 380: This assumes that nutrient inventory is proportional to production, right? (2) Yes it does, although we argue that N availability is likely the primary limiter to productivity on Arctic shelves

(1) 385: "The N inventory is also dependent" right? (2) Yes, changed to: (3)The N inventory is also dependent on the NH4+ release from sediments and nitrification.

(1) 393: I feel that this last part of the manuscript is pretty speculative. I think it is ok, but can see how others might have a problem with it. (2) Although speculative, this part puts our findings into the context of wider Arctic research about changing Arctic nutrient supply and primary production. This has particular relevance in relation to recent work regarding the importance of Arctic nutrient supply in sustaining increases in Arctic primary production (Lewis et al., 2020). We have edited the wording of this section to highlight that this is speculative. (3) Previous work has suggested that increasing NPP on Arctic shelves would increase organic matter supply to sediments and thus increase sedimentary denitrification rates (Arrigo and van Dijken, 2015). As N is the primary limiting nutrient to Arctic phytoplankton (Mills et al., 2018), this would have downstream consequences to NPP in the central Arctic basin (Lewis et al., 2020). Given the Barents Shelf is not currently a locale that hosts significant sedimentary denitrification and NPP here is limited by N, the future changes are likely to be different from those envisioned for other Arctic shelves. We suggest that N supply through the Barents sea to the Arctic is likely to be determined by variability in AW inflow. Future changes in this inflow could impact the nutrient inventory transported through the Arctic Intermediate

Water, impacting productivity in the central Arctic Basins where AWs are transported.

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