# Response to Anonymous Referee #2

## General comments

Overall, this is a very nicely written paper that integrates remote sensing data with empirical biogeochemical and biological data to estimate ecosystem-scale N fixation in an oligohaline coastal lagoon. Using remote sensing data to study processes such as N-fixation, given the good empirical relationship between N-fixation and chl-a in the late summer, is a very nice application of these data in coastal systems. As the authors point out, blooms of N-fixing cyanobacteria can significantly alter the N-budgets of enclosed coastal water bodies. Importantly, this can lead to these systems serving as 'sources' of N to the coastal ocean rather than serving as reactors for removing DIN via denitrification.

**Answer:** we acknowledge the reviewer for their positive comments, which are appreciated.

One concern I have is the spatial distribution of the water sampling locations. I agree that using the remote sensing approach appears to provide much more resolved estimates of N-fixation (this ms) than simply scaling up from the two sample locations (Line 310-312). Still, the entire southern half of the lagoon was not sampled. For example, it is noted at Line 78 in this ms that, "Longer water residence time in the southern lagoon provides favorable conditions for cyanobacteria bloom development (Bartoli et al., 2018)." Without actually measuring N-fixation rates vs chl-a concentrations at those southern areas (which could differ if the phyto community composition differs), there is still uncertainty about whether or not the remote-sensing based approach is yielding biased results in those southern reaches. This is particularly true because most of the high N-fixation rate hotspots in Figure 8 are further south than the 'southern' sampling location. It seems unlikely that this particular concern can be addressed using the same dataset but it is an important caveat that should be acknowledged. If the authors have evidence that the phytoplankton community in the southern part of the lagoon is the same as the community in the middle of the lagoon (i.e., the 'southern' sampling location) either from previous literature or their own unpublished work, then this would be an important pattern to note for readers.

**Answer:** we agree that whole lagoon sampling would be an ideal, but access to the southern region, which is located within Russian territorial waters, is problematic. Here, we improve on our ability to scale up these measurements by using remote sensing of Chl-a to infer spatial and temporal variation in $N_2$ fixation. Our whole-lagoon estimates are based on data collected at stations within the northern and central portions of the lagoon, as access to the southern region is problematic. Hydrodynamic modeling studies have shown that water renewal times in the central and southern portions of the lagoon are comparable (Umgiesser et al. 2016). Monitoring data suggest that Chl-a and phytoplankton community composition is similar in the central and southern regions (Bresciani et al. 2014; Semenova and Dmitrieva 2011). Therefore, we felt it was appropriate to derive whole-lagoon estimates of N fixation based on in situ measurements from these two sites.

References:

Bresciani, M., Adamo, M., De Carolis, G., Matta, E., Pasquariello, G., Vaičiūtė, D., and Giardino, C.: Monitoring blooms and surface accumulation of cyanobacteria in the Curonian

Lagoon by combining MERIS and ASAR data. Remote Sens. Environ., 146, 124–135, doi:10.1016/j.rse.2013.07.040, 2014.

Umgiesser, G., Zemlys, P., Erturk, A., Razinkova-Baziukas, A., Mežinė, J., and Ferrarin, Ch.: Seasonal renewal time variability in the Curonian Lagoon caused by atmospheric and hydrographical forcing. Ocean. Sci., 12, 391–402, doi:10.5194/os-12-391-2016, 2016.

Semenova A. S., and Dimitrieva O. A.: Spatial and temporal aspects of toxic effect of harmful algae on zooplankton in the Curonian Lagoon (the Baltic Sea) in New series 1(4) by Trudy AtlantNIRO. AtlantNIRO, Kaliningrad, RUS, 56–69, 2017.

The methods are very sparse for the TN riverine data collection. While not a central part of the analysis, these data are used to place the remote sensing results in an ecosystem context and are therefore important to the manuscript. In the text, reference is made to a previous paper rather than providing methods, but in the referenced paper (Zilius et al. 2018), the methods reported in that paper are limited to the following: “For the mass balance analysis, water samples were collected at the inflow (Nemunas River) and outflow (Klaipeda Strait) of the lagoon, and from an off-shore site in the Baltic Sea (55◦55âAš13.1"N and 21 ˇ ◦02âAš39.4"E), to estimate riverine inputs, lagoon export, and December 2014 to November 2015, except at the inflow site (Nemunas) where additional samples were obtained (at 1–2 week intervals) during the period of highest discharge (January–April).” (Zillius et al. 2018) It is important to see some additional details, even if they are only provided in the Supplemental file. Were samples collected monthly or at higher resolution at certain times of the year (as in Zilius et al. 2018)? Was there any effort to collect during average flow conditions? Where were the samples collected – mid stream in the river, or from the shore? Is the collection location the same location marine inputs, respectively (Fig. 1). Samples were collected monthly at each of the sites from referenced in the Zilius et al. 2018 paper?

**Answer:** we have provided some additional details of methodology to reduce reliance on the Zilius et al. 2018 paper: “*We also monitored total nitrogen (TN) concentrations in the Nemunas River (Fig. 1) to derive riverine N loads for comparison with atmospheric N inputs via $N_2$ fixation*. River samples were collected twice monthly during peak discharge (January-April) and monthly throughout the rest of the year (16 collections). *Water samples (2 L) were collected in triplicate, integrating the whole water column with repeated Ruttner bottle sampling at the surface (0.4 m depth) and bottom layers (3.0 m depth) as described in Vybernaite-Lubiene et al. (2018). Integrated water samples were transferred to opaque bottles, cooled with ice packs, and transported to the laboratory within the hour for subsequent analyses (see section 2.3 for details). Riverine N concentrations were used in combination with daily discharge measurements (provided by Lithuanian Hydrometeorological Service) to derive monthly N loads to the lagoon as previously described in Zilius et al. (2018).*“ (line 98-105).

## Specific comments

Figure 1. Please provide definitions for abbreviations (RUS, LT) and increase font size on some of the smaller figure elements such as the scale bar. There is a grey rectangle just above the Nemunas River. Is that meant to be there and if so, what is it? Please show the river sampling location on the map.

**Answer**: thanks for suggestions. We have updated figure accordingly.

Line 114 – please provide a long-term estimate of d15N analytical precision for the UC Davis facility. They should have these numbers readily available. Otherwise, you could also report summary statistics on sample duplicates that were (presumably) interspersed with the submitted samples.

**Answer**: we have added missing information "*The long-term standard deviation is <0.3 ‰ for $\delta^{15}N$.*" (line 128-129)

Figure 3 – it is confusing to list *Anabaena* in the figure while referring to it as *Dolichospermum* in the text. There is a note in the figure legend that the two are the same but why not simply use *Dolichspermum* in the figure (or at least an abbreviation)?

**Answer**: thanks for suggestion. We have corrected figure accordingly (see below).

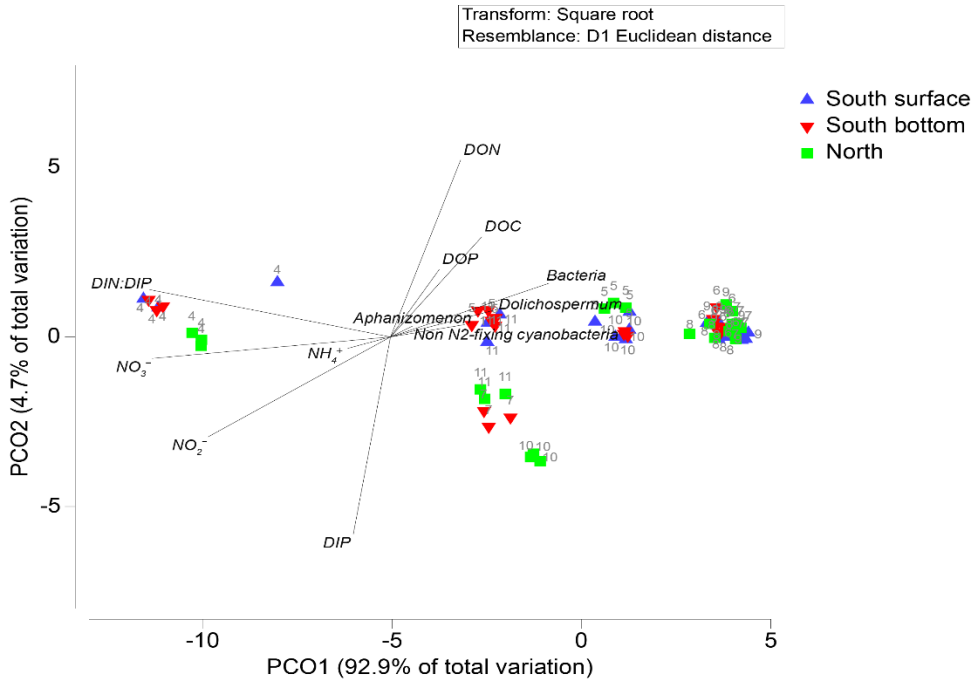


**Figure 3:** Principal coordinate biplots generated on Euclidean distances of normalized and forth-root transformed nutrient concentrations (DOC, $NH_4^+$, $NO_2^-$, $NO_3^-$, DON, DIP, DOP, and DIN:DIP). Overlaid vectors show individual chemical variables (those significantly correlating with either of the two primary axes, with Pearson correlations > 0.5) and plankton community biomass (*Aphanizomenon, Dolichospermum,* non-$N_2$-fixing cyanobacteria and heterotrophic bacteria).

Figure 4 – are the southern site values averaged between surface and bottom or are these only surface (or bottom) values? Can you please clarify in the figure legend?

**Answer**: revised caption is "*Figure 4: Temporal patterns in temperature, dissolved organic carbon (a, b), dissolved and organic nitrogen (c, e), phosphorus (e, f), and DIN:DIP ratios (g, h) at southern (surface layer; left panel) and northern (right panel) sites in the Curonian*

*Lagoon during 2018 (error bars denote standard error based on 3 replicates; some not visible)*."

Line 346-360 – also see papers by Karlson et al. (2015), Woodland, Cook and others (2013, 2014) for evidence of diazotrophic N from cyanobacteria contributing to brackish food webs.

**Answer**: thanks for suggestion. We have included these references in manuscript.

**Technical corrections**

Line 182 – what do you mean by 'process' here? Is that word out of place or does it reference to a specific type of measurement taken in the surface and bottom waters? Can you please rephrase to make this more interpretable?

**Answer**: this is a redundant and has removed from the text.

Line 248 – add a comma after '0.88'

**Answer**: Done.

Line 249 – add a space between '=' and '0.07

**Answer**: Done.

Line 356-357 – replace 'their' with 'these blooms to have a' or something similar. The current phrasing is awkward.

**Answer**: this comment is not clear as indicated line reads "…abundance of *Microcystis* spp. and *Planktotrix agardhii*. Measured low $\delta^{15}N$ values (0.5 ± 0.2 ‰) in suspended living material suggest that fixed N can temporally support most of the nutritional needs for plankton (bacteria + phytoplankton) growth".

We may think that the reviewer had indicated line 365-367, "*Since intensifying blooms of cyanobacteria have already been observed in coastal areas of the Baltic Sea (Olofsson et al., 2020b), we may expect their stronger effect on ecosystem functioning in future*". We have rephrased this sentence, "*Since intensifying blooms of cyanobacteria have already been observed in coastal areas of the Baltic Sea (Olofsson et al., 2020a), we may expect these blooms to have a stronger effect on ecosystem functioning in future*".