Referee 1 Interactive comment on "Drivers of the spatial phytoplankton gradient in estuarine-coastal systems: generic implications of a case study in a Dutch tidal bay" by Long Jiang et al. Tom Fisher (Referee) fisher@umces.edu Received and published: 6 March 2020

This is a well-written, multi-disciplinary manuscript addressing the distribution of phytoplankton and primary productivity in a Dutch estuary. The three approaches (observational, modeling, remote sensing) provide a strong basis for describing phytoplankton distributions and the causes of the patterns. The literature synthesis at the end of the manuscript sets the results of this manuscript in global context. Overall, a strong addition to the estuarine literature.

Response (1): We appreciate the referee's efforts in reading our manuscript and positive comments. The manuscript has been revised based on the following suggestions.

I suggest that the authors address a few issues that I think are missing: 1. Light limitation of phytoplankton growth is common in estuaries and often occurs in turbid, nutrient-rich, low-salinity waters with no vertical stratification. No data are presented on salinity or density in this manuscript, and the authors simply state that there is no stratification, citing another paper. They could be right, and water depth may limit vertical mixing. However, my experience suggests that vertical stratification in spring under high river flow conditions initiates the spring bloom. Even if there are no CTD data available to calculate vertical variations in density, the authors should at least mention the possibility that the low salinity areas with high nutrients and turbidity may be light-limited regions of the estuary.

Response (2): Thanks for the comment. The Oosterschelde used to be a coastal plain estuary, but not any more since the safety-oriented Delta Works in the late 1980s (https://en.wikipedia.org/wiki/Delta_Works). Many dams and sluices were built at approximately the same time cutting the freshwater input of the Oosterschelde, which became isolated from other delta networks (Ysebaert et al., 2016). The overall freshwater inflow into the bay is below 10 m³ s⁻¹ (Ysebaert et al., 2016). For example, it was $3.2 \text{ m}^3 \text{ s}^{-1}$ and $4.5 \text{ m}^3 \text{ s}^{-1}$ in 2009 and 2010, respectively (Rijkswaterstaat data). This is a negligible amount compared to the flushing of the basin by tidal exchange, which is ~2 × 10⁴ m³ s⁻¹, estimated from a typical tidal prism of 9 × 10⁸ m³ in a 12-h tidal cycle.

Due to the greatly reduced freshwater input, the post-barrier Oosterschelde is well mixed most of the time. Based on our CTD casts in spring and summer, the surface-to-bottom salinity difference in a 10-m water column is below 0.1 psu (Figs.

R1 and R2).

Turbidity in the Oosterschelde does not resemble the typical distribution in an estuary. The suspended matter concentration is highest near the bay mouth and lowest near the northern branch where the aforementioned limited amount of freshwater enters (Wetsteyn and Kromkamp, 1994). In other words, the largest source of suspended sediment is the North Sea, rather than the landward end.

The Westerschelde, south to the Oosterschelde, is a true estuary with large freshwater and terrestrial of suspended sediment input, secchi depth of 0.2–2 m and salinity ranging 0 to 30. In contrast, the Oosterschelde is featured by greater transparency (secchi depth 3–5 m) and marine salinity conditions (salinity 30–33). Primary production in the Oosterschelde is much more limited by grazing and marine nutrient sources as discussed in the manuscript than light. Data in this paragraph are unpublished and measured by Jacco Kromkamp. We have clarified it in Section 2 (Page 3 Lines 23–25 in the "accept-changes" version) of the revised manuscript.



Figure R1: Observed (a) water level and (b-f) salinity and temperature at OS2. The station location is showed in Figure 2. The observational periods during flood (6 March 2018) and ebb (8 March 2018) tides are marked with blue and red dotted lines, and the corresponding observational data are shown in the lower left and right panels, respectively.



Figure R2: Observed salinity and temperature at OS7 during one full tidal cycle on 4 June 2019. The station location is showed in Figure 2. The water level is shown with the dotted line.

References

- Wetsteyn, L. P. M. J., and Kromkamp, J. C.: Turbidity, nutrients and phytoplankton primary production in the Oosterschelde (The Netherlands) before, during and after a large-scale coastal engineering project (1980–1990), Hydrobiologia, 282/283, 61–78, http://doi.org/10.1007/BF00024622, 1994.
- Ysebaert, T., van der Hoek, D. J., Wortelboer, R., Wijsman, J. W., Tangelder, M., and Nolte, A.: Management options for restoring estuarine dynamics and implications for ecosystems: A quantitative approach for the Southwest Delta in the Netherlands, Ocean Coast. Manage., 121, 33–48, https://doi.org/10.1016/j.ocecoaman.2015.11.005, 2016.

2. I am surprised that there are no data presented on salinity, temperature, river discharge, and river nutrient concentrations. The authors nicely show that advective inputs of shelf nutrients and phytoplankton is likely to be small, but never explore the role of river inputs. This could be a whole other paper, but they could at least mention that riverine inputs, both freshwater and nutrients, are likely driving the spring bloom. They could do additional model runs with half of the river discharge or half of the river N concentrations, but this might be more work than reasonable. I suspect that vertical stratification in the inner half of the estuary allows algal biomass to accumulate following high winter-spring river discharge. What would the model show if freshwater flow and/or river nutrient concentrations were halved? Can any of the temporal variations in the spring bloom be related to river flow?

Response (3): Thanks for the suggestion. The data on salinity, temperature, and river discharge is presented in the last response. The river nutrient is not significantly different from that in the Oosterschelde.

We conducted sensitivity test on the river discharge as suggested. A model run switching off the river discharge is compared with the baseline run. As we can see from the results (Figs. R3 and R4), dissolved inorganic nitrogen and chl-a are slightly higher in the baseline simulation including freshwater input, but the difference is minimal. The impact of freshwater is visible at OS5 but cannot reach the mainstem station OS2. These findings verify that freshwater input does not play a dominant part in the phytoplankton distribution in the Oosterschelde, as mentioned in the last response.

As readers may similarly wonder about the role of freshwater input, we have briefly added the above outlined explanation in Section 3.2 of the revised manuscript (Page 6 Lines 4–6 in the "accept-changes" version).



Figure R3: Comparison between modeled and observed dissolved inorganic nitrogen (DIN) in 2009 at stations(a) OS5, (b) OS4, and (c) OS2. The panels are arranged based on their respective distance from the freshwater source. See Figure 2 for station locations. The two model scenarios include the baseline scenario and switching off freshwater input.



Figure R4: Comparison between modeled and observed chlorophyll-a in 2009 at stations (a) OS5, (b) OS4, and (c) OS2. The panels are arranged based on their respective distance from the freshwater source. See Figure 2 for station locations. The two model scenarios include the baseline scenario and switching off freshwater input.

3. I made a few minor grammatical or wording suggestions to the pdf of the text and for improvements in the figures that will be easy to address. This isn't a long manuscript, and the above two issues can probably be addressed briefly in 1-2 pages.

Please also note the supplement to this comment: https://www.biogeosciences-discuss.net/bg-2020-40/bg-2020-40-RC1-supplement.pdf

Response (4): The supplement is well received. Thanks for the minor suggestions, which are addressed as follows.

Page 4 Line 3-4: Not clearly stated. Bivalve grazing must also be burying and/or denitryfying phytoplankton N and P if grazing decreases prim prod. With no N and P losses, chla might decrease but primary production could be the same due to higher turnover.

Response (5): By grazing, bivalves remove N and P from the water column and keep the phytoplankton biomass low. On the other hand, bivalves release a smaller amount of inorganic nutrients into the water column by excretion and respiration, which may stimulate phytoplankton grown in the nutrient-limited summer months. We have removed the second half of the sentence for clarification. Please see Page 4 Line 9 in the "accept-changes" version of the revised manuscript.

Page 5 Line 10: validation? error rate or model accuracy? ok, I see it on p7. Add a sentence to Methods.

Response (6): We have changed it to "validation" and added this to the manuscript addressing the validation of the FABM model. Please see Page 5 Line 15 in the "accept-changes" version of the revised manuscript.

Page 5 Line 15: provide citation on sinking rate.

Response (7): We have added a reference (Eppley et al., 1967) here. Please see Page 5 Line 20 in the "accept-changes" version of the revised manuscript.

Reference

Eppley, R. W., Holmes, R. W., and Strickland, J. D. H.: Sinking rates of marine phytoplankton measured with a fluorometer, J. Exp. Mar. Biol. Ecol., 1, 191–208, https://doi.org/10.1016/0022-0981(67)90014-7, 1967.

Page 5 Line 26: specify weight ratio or give units. Also give a general range of PO4 concentrations to justify the N based model. Phytoplankton can be P and light-limited in the fresher parts of estuaries. Light limitation often occurs in the turbid 0-5 psu range, but no information seems to be available on vertical density and may not be available.

Response (8): Thanks for the comment. The unit of Chl:N ratio is mg Chl mmol N⁻¹, and the value (2) is prescribed based on the estimation of local species by Soetaert et al., 2001. Please see Page 5 Line 31 in the "accept-changes" version of the revised manuscript.

The PO₄ concentration ranges 0-2 mmol m⁻³ (Fig. R5). Most time of the year, phosphorus is not limiting, except for a short period after the spring bloom. We have mentioned it in the Discussion that not including P limitation may result in the underestimation of DIN in this period. Please see Page 9 Lines 6–10 in the

"accept-changes" version of the revised manuscript.

As described in Responses (2) and (3), the freshwater inflow is extremely low. The turbid fresh (0-5 PSU) region and strong vertical salinity gradients hardly exist in the Oosterschelde.



Figure R5: Time series of phosphate concentration during 1995–2013 at NIOZ stations OS1, OS3, and OS8.

Reference

Soetaert, K., Herman, P. M., Middelburg, J. J., Heip, C., Smith, C. L., Tett, P., and Wild-Allen, K.: Numerical modelling of the shelf break ecosystem: reproducing benthic and pelagic measurements, Deep-Sea Res. Pt. II, 48, 3141–3177, http://doi.org/10.1016/S0967-0645(01)00035-2, 2001.

Page 6 Line 21: winter phytoplankton blooms can occur in estuaries at low temperatures. Vertical stratification, sometimes defined by <0.5 psu, is the dominant control by limiting the depth of mixing in turbid waters especially with high FW flows.

Response (9): This comment also relates to our unclear description of the limited freshwater contribution. The Oosterschelde is not a typical estuary with high freshwater input. We have made the clarification here. Please see Page 6 Lines 26–27 in the "accept-changes" version of the revised manuscript.

Page 6 Lines 29-30: Was there any relationship between peak or integrated biomass and total river flow into the estuary? I'm guessing that the big or sustained peaks are positively associated with river discharge during the bloom period.

Response (10): Yes, the phytoplankton biomass at station RWS1 (at the mouth of the Westerschelde Estuary) is mostly influenced by the discharge of the Westerschelde. But for the most parts of the Oosterschelde, as presented in the manuscript, grazing pressure is the dominant control on phytoplankton biomass.

Page 8 Lines 22-25: Mention in methods that this issue is addressed in Discussion.

Response (11): OK. This relates to Response (8).

Page 8 Line 31: add a little more detail on how this was calculated here.

Response (12): Thanks for the suggestion. There are many ways to calculate residence time, and it is necessary to indicate the calculation here. The residence time is estimated by two methods in a model tracer experiment (Jiang et al., 2019). Briefly, each grid cell is filled with tracer and these two methods quantify the decay rate of tracer. The first method integrates the remnant function to calculate residence time

 $T_r = \int_0^\infty C(t)/C_0 dt$, where C(t) and C_0 are the instantaneous and initial tracer

concentration in each grid cell. The second method quantifies the time when $C(t) = e^{-1}$ C_0 , since the tracer concentration decreases exponentially in a well-mixed system. Based on our estimate, these two methods result in similar residence time in our system. We have added these two methods to the sentence. Please see Page 9 Lines 17–18 in the "accept-changes" version of the revised manuscript.

Reference

Jiang, L., Soetaert, K., and Gerkema, T.: Decomposing the intra-annual variability of flushing characteristics in a tidal bay along the North Sea, J. Sea Res., 101821, https://doi.org/10.1016/j.seares.2019.101821, 2019.

Page 9 Line 21: but nutrients are probably increasing towards the river end member due to light limitation of algal growth in the inner estuary.

Response (13): Because of the "missing" or weak river end member, the spatial gradients of nutrients and turbidity are not as strong as those in typical estuaries. Thereby, we differentiate the Oosterschelde, representing coastal bays with limited freshwater input but dominant marine influences, from river-dominated systems and other types in Section 6.

Page 9 Line 32: substantial land-derived nutrients, and light limitation of phytoplankton in turbid, low salinity areas of the estuary.

Response (14): This comment also relates to our unclear description of the limited freshwater contribution in the Oosterschelde. Because of that, the largest nutrient source is the marine import, contributing to the seaward increasing chl-a distribution.

Page 10 Line 10: is maintained

Response (15): Corrected. Please see Page 11 Line 9 in the "accept-changes" version of the revised manuscript.

Page 11 Line 26: trophic levels.

Response (16): Thanks for the correction. This sentence is rephrased. Please see Page 12 Line 27 in the "accept-changes" version of the revised manuscript.

Page 11 Line 28: This is barely addressed. Either add likely climate effects to Discussion or remove this statement here and in Abstract.

Response (17): Thanks for the suggestion. The climate effect is deleted here and in Abstract. Please see Page 12 Lines 22–28 and Page 1 Lines 24–25 in the "accept-changes" version of the revised manuscript.

Figure 5: The time axis of Figs 4 and 5 is not sufficiently clear to tell when the blooms occur. They said it was spring, but it would be easy to add month or half-year tics to show this more clearly.

Response (18): Thanks for the suggestion. We have changed the interval of grid lines to two months in Fig. 4, and Fig. 5 has been replaced with a monthly average graph.