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Interactive Comment

Interactive comment on "Seasonal cycling of phosphorus in the southern bight of the North Sea" *by* C. van der Zee and L. Chou

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The authors would like to thank Anonymous Referee #2 for his/her comments and suggestions to improve the manuscript. Please find our responses here below. The editorial office of Biogeosciences will provide the figures A and B to you.

Reply to General comments

We changed "southern bight" to "Southern Bight" in the title and elsewhere in the manuscript.

Ref #2: "I would suggest the authors to further explore the seasonal cycle of the POP (Particulate Organic Matter) concentration (in μmol/l) in order to compare the different P fractions." Answer: We did not include the particulate organic phosphorus (POP) data expressed in μM, because the seasonal POP concentration in μM is not very informative due to the large variations in suspended particulate matter (SPM) concentration in the water column (Fig. A). Therefore we have chosen to show the POP data

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in terms of particulate organic phosphorus content expressed in μmol/g and we have attributed the POP enrichment of the SPM in spring to a phytoplankton bloom. We did check that this was not solemnly due to enhanced resuspension. But we did not discuss that in the manuscript. We will keep the figure as is (e.g. with the POP expressed in μmol/g), but add another figure where we compare the "corrected" POP concentration with the POP content. With "corrected" we mean the POP concentration minus the PIP concentration times the POP/PIP ratio in winter (average of Dec-02, Jan-03, Feb-03 and Dec-03), as suggested by Anonymous Referee #2. This method assumes that in winter there is only SPM with the same POP/PIP ratio as the resuspended sediment has and that this ratio is constant throughout the year. This is not necessarily so, for example, surfacial sediment will contain relatively more POP after the settlement of the spring bloom and subsequent resuspension will lead to SPM with a higher POP/PIP ratio. Both representations have their own drawbacks, but when they give largely similar results (and they do), we may conclude that the peak in POP content in spring is due to the phytoplankton bloom. We revised section 3.3 in this light.

Ref #2: "The last conclusion (concerning the autumn decay of algae and release of DOP) could be possibly be further substantiated by the data by showing that the increase of DOP is accompanied by a loss of POP. Answer: This has been done.

Ref #2: "The first conclusion (concerning the P limited spring bloom with enhanced P cycling) might be further supported by showing that the total amount of P is constant (i.e. only a phase shift has taken place from the inorganic to the organic form)." Answer: In order to show the total amount of P, we need again to correct for resuspended sediment. When we sum up the P concentrations in PO4, dissolved organic phosphorus (DOP) and the "corrected" POP, we find a lack of P in spring or an excess of P in fall and winter at all stations (Fig. B). This may be due to export of organic matter in spring or differences in riverine input during the season. The sediment may be a source of PO4 and a sink of POP. It is likely that after settling of the spring bloom, remineralisation of organic matter at the sediment-water interface will liberate phosphate, which at least partially will diffuse into the overlying water column.

Ref #2: "I would welcome a summarizing graph of PO4, DOP and POP (in μmol/l) showing a generalized seasonal cycle of the different P components. If necessary, a differentiation between the various settings can be added (e.g. coastal vs. off-shore; low vs. high salinity; high SM vs. low SM)." Answer: As can be seen from Figure A, there is not much to summarize from the graphs with POP in μM. The problem is not only that some stations have higher SPM loads than other stations, but also that between months the amount of SPM varies greatly, which is reflected in the POP concentration.

Reply to specific comments

682/14. "Recycling activity" has been changed to "release". A conclusion on the polyphosphates has been added.

682/23 The first paragraph of the introduction has been amended to include the fact that changes of Si loads in the Rhine have occurred.

683/7 That was not a reference. London (1987) indicated that the meeting was held in London in the year 1987. We have added a reference.

683/15 We have rephrased this sentence.

683/27 The missing reference (Cadee and Hegeman, 2002) has been added.

684/5 We decide not to give the TP loads to match the TN loads given, but instead the nitrate loads to match the phosphate loads given. The values are now expressed in moles (see Ref #3). As we do not present TN data in our paper, we thought it was more appropriate to present the nitrate load.

684/12 Tungaraza et al. (2003) did not supply any information on salinity. We have removed the phosphate concentrations, because they are difficult to interpret without salinity information. Now the sentence only states that the PO4 concentrations did not show a seasonal trend.

685/6 We have added information about the water depth, the completely mixed water column and the annual primary production in section 2.1.

686/20 The precisions of the DOP and DON analyses have been included in the methods section.

687/7 The missing reference (Solorzano and Sharp, 1980) has been added.

687/16 The sentence has been rephrased.

687/21 We have changed Fig. 2 to include Chl a concentration and POC concentration and added a new figure with the POC:Chl a ratio and POC:SPM ratio (or the POC content). In our case plotting the POC as per liter did not make it better comparable with the chlorophyll data. We have thus added the two other parameters that showed an important contribution to POC of resuspended sediment in winter (low POC:SPM and high POC:Chl a) and of phytoplankton in spring and summer (high POC:SPM and low POC:Chl a). The text in the result section (3.1) has been amended to include the new data.

688/4 We will add all DOC data or leave all of them out in our revised manuscript.

688/7 A new figure with the Si, NO3, NH4 and DON versus salinity plots in winter has been added as well as a new paragraph about this figure at the end of section 3.2.

688/11 When comparing Si and salinity at the ten stations in January-03, there is a clear correlation between the Si concentration and salinity. But when comparing the winter months with each other, salinity is not the only factor determining the Si concentration. See also point 688/7.

688/24 The nitrate versus salinity plot shows that individual months exhibit conservative behaviour, but that their slopes are not the same. Therefore, salinity can explain difference between stations in one month, but cannot explain differences between winter months for one station. See also point 688/7.

688/25 The ammonium versus salinity plot shows that only in January-03 a correlation exists between the ammonium concentration and the salinity. During the other winter months, no such correlation could be observed. See also point 688/7.

689/1 See point 688/7.

689/22-24. The sentence has been rewritten.

690/4 We have tried to obtain the paper of Beusekom & Brockmann (1998), which was published in Estuaries, but could not. Therefore we have used our own wintertime POP/PIP ratios.

690/7 See point 688/7.

690/12 The sentence has been amended.

690/18 The paragraph discussing the DOP and DON data has been revised completely. A riverine source of DON could be important, whereas this does not seem likely to be the case for DOP.

690/23 The P versus salinity plot has been moved to the result section. The extrapolation of the property plot yields river values that are too high, due to processes in the estuary and not on the shelf (unpublished results). We have not observed local shelf sources for phosphate in our phosphate data from longitudinal transects from zero salinity on the Scheldt to the Belgian coastal zone ($S>32$).

691/2 A sentence has been added to this effect. And we have also included new information on the temporal and spatial chlorophyll a patterns.

691/7 The contribution of locally produced organic P (and organic C) has now been discussed in the results sections 3.1 and 3.3 and additional graphs have been included.

691/20 The decrease in PO4 is not in line with the increase in POP and DOP (both in

μM) during the blooms. The decrease in PO4 and increase in POP occur at the same time but are not of the exact same magnitude. We have amended the sentence. See our reply to one of the general comments above and Figure B below.

692/4 The NO3/PO4 ratios from the monitoring data in the Rhine and Scheldt have now been included. TN data were not available.

692/18 Yes, they might also play a role. We have added a sentence about this at the end of the paragraph.

692/20 The SPM concentration ranged from 1 to 144 mg/l at our stations. We have checked this with data from 2003 of the Wadden Sea (www.waterbase.nl) and although at some sites in the Wadden Sea the SPM concentration is higher, overall the range in SPM concentrations for the Wadden Sea stations in the database are similar to ours. Anyway, we are not interested in arguing about light limitation. We have already stated that light is not the limiting factor for primary production in our case. We have omitted the beginning of paragraph 4.3 until "(Allen, 1997)".

692/28 Colijn and Cadee (2003) are not mentioned anymore in the text. See 692/20.

693/2 Allen (1997) is not mentioned anymore in the text. See 692/20.

693 Section 4.3 has been amended. Diatoms are the most important phytoplankton species, except in March and April 2003 when Phaeocystis dominates the phytoplankton community. Thus, Si may just as well be a limiting nutrient in the months after April as P or N. The fact that P is recycled faster than Si is not contradictory to the statement that P is the first limiting nutrient. The rate-limiting step will be the liberation of PO4. When we described the approach based on the nutrient ratios, we expressed ourselves very carefully: "We have compiled a table in attempt to give an indication of what the limiting nutrient for phytoplankton growth can be (Table 2)." And "When N:P and Si:P are larger than 16, phosphate is likely to be the limiting nutrient. In the case where Si:P$<$16 and Si:N$<$1, then silicate is likely to be the limiting nutrient (for diatom

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growth).” And in the Conclusions we stated: “The elemental ratios of N, P and Si suggest that either P or Si limitation of phytoplankton growth could develop, and for the stations on the Scheldt transect first P and later Si limitation.” So we do not think that we are overestimating potential P limitation. We are only saying that when one applies this approach, one finds P to be the first limiting nutrient, often followed by Si. We will not change the order of the sections in the Discussion as we find this to be the most logical order and the other referees do not seem to have a problem with it (Referee #3 states that the manuscript is well structured).

693/13 The organisation of all the graphs and Table 1 is such that first the stations on the Nieuwpoort transect are presented, then the stations on the Oostend Transect and finally the stations on the Scheldt transect. We do not think that it would make the Table better readable if we organize on months first.

694/14 The missing reference of van Boekel and Veldhuis (1990) has been added.

694 We have added a reference to the work of Butler et al. (1979) in the DON and DOP discussions.

695/11 We have now additionally mentioned the POP-POPRS concentration in this paragraph. See also our reply to the general comments above.

P695/20-22 No, P cycling is not less intense between these two periods nor is a steady state reached. There are two periods of elevated production of DOP. The first one is associated with the enhanced primary production. After this DOP maximum, more DOP is consumed then produced, thus the concentration decreases. The phosphate part of the DOP is released and taken up, so there is no accumulation of phosphate. The second period of elevated DOP production is associated with the decay of the bloom. DOP is produced as POP is degraded. The DOP is subsequently consumed, but this time phosphate is released and is not taken up as rapidly as it is produced. The DOP concentration decreases again, while the phosphate concentration increase. Thus, the two maximal DOP concentrations mark the start of two distinct periods of intense P cycling. And there is no time gap between the two periods. We have rephrased the one before last sentence of the discussion.

Interactive comment on Biogeosciences Discussions, 1, 681, 2004.