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A reply to the comment by Karlsson et al.

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In their comment "On the role of sedimentological processes controlling phosphorus burial in the coastal zone of the Baltic Sea," Karlsson et al. raise important aspects about the factors and uncertainties in estimating P burial in coastal sediments. Their main concerns are about (1) the estimate of the areal extent of depositional areas, (2) the rate of the P burial, and (3) the origin of P being buried.

We acknowledge that a better constraint on the actual depositional bottom area and especially the net sediment accumulation rate would improve our estimate of retention. Determining the proportion of the accumulation area is not straightforward, and in the literature, a range of values has been used. In an earlier study, Karlsson et al. (2014) use a value of 0.43 for the east coast of Sweden, taken from a report by Jonsson et al. (2003). This value is not very far from our estimate of 0.55. In the report by Jonsson et al. (2003), a considerable range of values for accumulation areas in Swedish coastal areas (n = 43) was provided, with a minimum value of 0.15 and a maximum value of 0.79. The above-mentioned 0.43 is the average of this range, with a standard deviation of 0.13. This implies that the value of 0.55 for the proportion of accumulation area used in Asmala et al. (2017) falls within the range of the average value given by Jonsson et al. (2003).

Karlsson et al. argue in the comment that P budgets from the Baltic Sea do not generally take into account the erosion from old clays, which is also the case in Asmala et al. (2017). The hypothesis of glacial clays contributing to P loadings by becoming more exposed by land uplift is to some extent speculative, as there is little evidence of this mechanism contributing to P loading in the Baltic Sea. Studies suggesting a clay contribution base this hypothesis on measurements of the P-content of clays and mass balance calculations, but no direct evidence of clay-based P loadings have been provided (Jonsson et al. 2003; Bryhn and Håkanson 2011). Since the contribution of erosion of old clays to P budgets is poorly constrained and highly uncertain, its inclusion in an empirical study such as that of Asmala et al. (2017) would likely not improve the accuracy of the P burial estimates.

In the comment, Karlsson et al. made their own estimate of the total P accumulation in the archipelago zone of the Baltic Proper, which they argue is approximately three times lower than our estimate (Asmala et al. 2017). They write that they used "empirical data from Baltic Proper coastal areas on the distribution of accumulation areas based on detailed hydro acoustic surveys in combination with sediment sampling." However, no details are presented in their comment to compare with our estimates or to verify the assumptions made. Furthermore, in their comment, Karlsson et al. compare our estimate for coastal P retention (Asmala et al. 2017) to a later study from Walve et al. (2018), who estimate a P burial for the Stockholm Archipelago that is only 8% of the inputs. However, the model of Walve et al. (2018) was constructed only for the inner archipelago, not the entire archipelago area, implying that the estimates cannot be directly compared.

Finally, Almroth-Rosell et al. (2016) estimated a P retention of 65% in the Stockholm Archipelago and recently, Edman et al. (2018) estimated a P retention for the Swedish coastal zone of 70%. In both of these model studies, mass balances of inputs and exports of P from the coastal zone were used to calculate P retention. The sediment area and sedimentation rate, which are referred to as sources of high uncertainty and/or overestimation by Karlsson et al. in their comment, were not used by either Almroth-Rosell et al. (2016) or Edman et al. (2018). These independent studies confirm the high P retention in the Swedish coastal zone presented by Asmala et al. (2017) and how Karlsson et al. in their comment reconcile these estimates is unclear.

We agree with Karlsson et al. that there are large uncertainties regarding P burial in the coastal environment. These uncertainties are not limited to P burial, but to coastal processes in this highly heterogeneous environment in general. There are three major knowledge gaps that should be addressed in future studies in coastal Baltic Sea. First, a greater spatial coverage of process studies in this very complicated

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system is needed. At the moment, process studies are mostly focused on a handful of coastal sites across the coastal Baltic Sea (Asmala et al. 2017, fig. 2). Second, a better understanding of the role of glacial clays and their contribution to estimates of permanent P burial is needed. Third, we need better constraints on the spatial variability of depositional areas (and as a result the local sediment focusing) across the coastal Baltic Sea.

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Conflict of Interest

None declared.

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