Effects of natural processes and human activity on North Sea sediment biogeochemistry

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In sediments of shelf seas, organic material of marine or terrestrial origin is recycled to free nutrients, available to processes in the water column (= mineralization). Thus, these sediments provide valuable ecosystem services in terms of nutrient cycling, eutrophication buffering and climate regulation. The intense human activities in these regions, bring sediments in an altered state, changing their nutrient recycling and storage capacity.

Sediment biogeochemistry is controlled by environmental conditions, such as the sediment type and hydrodynamics that determine deposition and retention of organic material. Likewise, benthic fauna play a pivotal role in the regulation of mineralization processes through various activities. The balance of these drivers, as well as the spatial variation they exhibit remain difficult to understand, and this hampers our capability to anticipate or predict the effects of anthropogenic activities on the workings of sediments.

This PhD thesis aimed to characterize sediment biogeochemistry in the North Sea, a heavily impacted shelf sea. Two studies, performed in a coastal area (the Belgian Part) and offshore (the Central and Northern North Sea) looked at the current biogeochemical functioning in relation to biology and environmental drivers. Models were developed based on these data and used to describe the effects of two anthropogenic activities on mineralization of organic matter (OM) in sediments: bottom trawling and offshore windfarm construction. Finally we tested in how far biological information can be used to derive biogeochemical characteristics, using a crucial faunal activity, bio-irrigation.

Fundamental work was discussed in Chapters 2 and 3. In Chapter 2, sediment characteristics and the benthic species community were determined in the Belgian Part of the North Sea (BPNS), along with the characterization of mineralization processes. Using variance partitioning, we found that anoxic mineralization processes were predominantly related to physical environmental parameters, whereas oxic mineralization processes were more strongly linked to the faunal component. Based on these data, we constructed linear models relating mineralization process rates to biotic and/or abiotic variables. Such models can increase our capacity to estimate how mineralization processes will change as a result of alterations to the biotic or abiotic environment.

An investigation of the greater North Sea was performed on a 670 km long transect spanning from Terschelling, 100 km from the coast, to the Fladen Grounds in the Northern North Sea (Chapter 3). Mineralization process rates were derived from on on-board core incubations and solute profiles through early diagenetic modelling. In contrast to the work performed in Chapter 2, mineralization processes correlated less to sediment characteristics, but were more related to water depth and bottom water concentrations of certain nutrients (NO_3^-). An offshore gradient of increased removal of nitrogen and decreased removal of phosphorus by the sediments was found.

The effects of specific anthropogenic impacts (bottom trawl fisheries, offshore windfarm development) were investigated in Chapters 4 and 5 using dynamic models of sediment diagenesis. In Chapter 4, bottom trawling impacts were implemented in the dynamic model as a combined erosion and mixing event. This affected the upper few centimeters of the sediment matrix, and also reduced faunal activity.

By evaluating the effects of continuous trawling events on mineralization pathways over a period of 15 years, our main results were that sediments became depleted in organic carbon and nutrients, regardless of the trawling frequency they were subjected to (1 – 5 trawls y-1). By simultaneously reducing the amount of bioturbating fauna, these effects were exacerbated. This has negative consequences for the buffering and eutrophication countering functions that sediments provide.

The effects of offshore windfarms (OWFs) on benthic processes (Chapter 5) were assessed by coupling our diagenetic model with an extended hydrodynamic model (in cooperation with Liege University). The redistribution of OM to sediments as a result of current and future OWF developments was calculated using a 3D hydrodynamic model of the Southern Bight of the North Sea. By coupling this output to a model of early diagenesis, changes to sedimentary carbon and nutrient cycling were assessed. This showed that sediments in OWFs can become sites of enhanced OM mineralization, where more carbon is stored in sediments as a result of an increased importance of anoxic mineralization processes. When integrated over the full area of the BPNS, alterations to C and N cycling were small, but of sufficient magnitude to be relevant in national greenhouse gas budgeting.

In Chapter 6 we describe a novel technique to quantify bioirrigation rates, the exchange of solutes between the sediment and the water column through organismal activities. Measurements from core incubations were combined with a mechanistic model of solute exchange. This improved on current measurements, by separating the bioirrigation process in an exchange rate, and a depth over which this exchange occurs. This technique was applied on field measurements collected in several sites in the Oosterscheldt estuary over the course of a year. We found similar pumping rates in subtidal and intertidal habitats, but shallower irrigation in the subtidal, linked to differences in species composition between both.

In the discussion (Chapter 7), we highlight that drivers of sediment biogeochemistry may vary strongly. Sometimes this relates to causes that are not currently observable, e.g. the historic context (e.g. biogeography, chronic bottom trawling) and connectivity of different habitats. We also point to ways in which more biology can be included in models of sediment biogeochemistry. Our novel measurement technique for bioirrigation is a first step, that may allow us to link species traits with faunal activity and biogeochemical consequences. Lastly, there remain understudied regions in the North Sea in which economic developments are being planned. In light of likely impacts, these are locations where the functioning of sediments needs to be described in order to anticipate future changes to the North Sea ecosystem.