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LAND USE AND SILICA FLUXES THROUGH THE SCHELDT RIVER BASIN

"LUSI"

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North Sea

FINAL REPORT PHASE 1
SUMMARY

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Background

Nutrient concentrations in the North Sea and adjacent estuaries are the end-result of basin-wide input, retention, mobilization and transport of N, P and Si. Traditionally, eutrophication has been approached as a problem of increased human inputs of N and P. In contrast, dissolved Si concentrations have mostly been considered as not anthropogenically influenced. Transfer of dissolved Si (DSi) to rivers has usually been considered to result from a pure geochemical process, involving only direct chemical weathering of soil minerals. As such, the DSi emission from terrestrial systems affected by human activities into water bodies has been considered relatively constant compared to pristine natural systems. Uptake by diatoms in the river continuum was the main factor used to explain DSi profile changes through time. Current research has clearly pointed out that vegetation cover can have a strong impact on the fluxes of Si through terrestrial ecosystems. It has become clear that ecosystems can store a large amount of Si as amorphous, biogenic Si (amorphous SiO_2nH_2O, ASi), both in soil and vegetation. ASi is far more soluble than mineral Si, and terrestrial Si fluxes are thus potentially strongly controlled by biota. As a result, land use changes and concurrent changes in vegetation cover, have a strong potential impact on the fluxes of Si through river basins.

Still, the release of DSi from different terrestrial systems in river basins has never before been quantified with respect to land use changes. Current knowledge is insufficient to quantify how land use change might have influenced the transport of Si through river basins towards the coastal zone. Such information is however essential for our understanding of eutrophication problems from the upstream aquatic ecosystems way down to the North Sea. As the release of DSi counteracts eutrophication effects, quantifying the role of land use on its emission can lead to a revision of water quality objectives and maintenance objectives. In fact, the history of DSi-emission may have influenced the carrying capacity for primary production much more than is shown by current ecological models. Here lies the relevance of this study.

Objectives

This project aims to answer the question if Si fluxes through a river basin, and ultimately towards the sea, can change because of land use changes. These changes will be budgeted for the Scheldt basin, taking into account surface runoff, subsurface drainage and storage and cycling through vegetation. The results will be used to evaluate the effect of land use changes over historical times on Si fluxes. Moreover, it is the aim to formulate recommendations towards land planning with respect to the reduction of eutrophication, working from the viewpoint of Si in the nutrient ratios. As such, this study of Si can provide a mirror image for the N and P side of the eutrophication problem, and provide invaluable, new insights in our evolving concept of eutrophication

Habitat scale research towards surface erosion and subsurface transport of dissolved Si and amorphous Si and sediments (as an indicator for transport of mineral Si) will be conducted in different landscape types. On a Scheldt basin scale scale, rivers draining sub-basins, will be sampled on a regular basis for all ASi and DSi. The sampled sub-basins will represent a gradient from still largely forested to largely covered by cropland. The integration of results from both site-specific experiments and basin scale sampling will for the first time allow an estimate, based on both historical and recent land use maps, of the extent to which Si fluxes towards the coastal zone have been altered by human land use, and how this change has been triggered by changes in erosion processes, changes in vegetation type and cover, and hydrology.

Results and discussion

Our habitat and small catchment scale research shows that in agricultural catchments ASi is an important component of total Si fluxes, which is in contrast to forested catchments. Transport of ASi mostly occurs during rainfall events. Erosion induces a significant mobilization of topsoil and hence ASi from cropland ecosystems. During peak events, a clear trade-off existed between DSi and ASi concentrations, and ASi often became the dominant form of transported bio-reactive Si in croplands.

As in most of Western Europe, land use in Flanders has shifted from almost completely forest-dominated to merely 11% of forest cover over the past two millennia: only 16% of these forests are older than 250 years. Although often more severe in Flanders than many other regions, deforestation and forest fragmentation is a global problem. In general, human land use changes will result in an enhanced sensitivity of land surface to erosion, although this can strongly depend on management practices and structure of the particular watershed. Our results clearly show that land use changes, impacting on erosion, should be related to changing silica dynamics. Our plots are representative for cropland dominated watersheds as widely found in Western Europe, where deforestation and subsequent cultivation of land results in the enhanced erosion of topsoil. Recent research has emphasized the importance of these ASi rich surface soils as buffers in terrestrial Si biogeochemistry. The physical removal of ASi from surface soil layers might hence also impact buffering of DSi transport through watersheds by ecosystem soils: the effect of this remains poorly studied.

This is apparent from our Scheldt basin scale research towards silica fluxes at base-flow. Based on our results, we propose a novel conceptual model for Si fluxes with deforestation. Initial forest development is characterised by small amounts of DSi released from the soil ASi pool, compared to the amount that is annually added to the vegetation and to the soil ASi pool. Developing forests form net sinks for DSi: unfortunately, little or no research is currently addressing Si dynamics in developing forests. An equilibrium state will eventually be reached: this stage is characterised by a large, slowly growing soil ASi stock.

The forest vegetation stimulates bedrock weathering of silicates through increases in soil CO2 content, production of organic acids and stabilization of organic soil cover. Trees take up the weathered dissolved Si (DSi) and deposit it as ASi plant-bodies (phytoliths) in their biomass. The major part of the weathered DSi passes through biomass before it is eventually released to rivers. The eventual export fluxes of Si from the climax forest soils are controlled by the dissolution of soil phytoliths. With deforestation, the amount of DSi exported from the forest soils drastically increases as ASi stocks dissolve. However, DSi fluxes may be expected to gradually decrease again over time as there will be a fundamental imbalance: the production of biogenic ASi no longer balances the total amount of ASi dissolved, as harvesting of crops prevents replenishment of the soil ASi stock. Soil erosion will increase and ASi will be physically removed from the soils, especially during precipitation events. Increased TSi fluxes will only last until the soil reaches a new climax cultivation state, characterised by lower export TSi fluxes. The absence of deep-rooting vegetation and the absence of a significant soil organic layer restrain vegetation stimulated weathering mechanisms.

The timescale during which increases in TSi fluxes can be expected after forest cutting is currently not possible to estimate. The depletion of the ASi stocks in the lower soil horizons will likely be incomplete: several mechanisms inhibit ASi mobilisation in deeper soil layers, including reprecipitation in secondary mineral silicates (e.g. allophanes, immogolite, kaolinite) and incorporation of Al in phytoliths, rendering them less soluble. If forest is converted to arable land, soil erosion will also remove ASi through physical erosion, thereby further reducing the timeframe during which increased DSi export can be expected. The Scheldt watershed has been one of the most densely populated areas in Europe already since the 13th century. As early as 1250, only 10% woodland cover was left; in a pristine state the Scheldt watershed was almost fully forested (>90 %). In this conceptual model, the present Scheldt watershed therefore represents a new equilibrium state, which arises after forest soil ASi has been depleted or immobilized. Our results emphasize the necessity of increasing our understanding of land use impacts on biogeochemical Si cycling, with a millennium of soil disturbance after deforestation leading to 2-fold to even 3-fold decreases in TSi flux from a watershed where the adjacent coastal zone has experienced significant coastal eutrophication problems due to changes in Si/P and Si/N river deliveries in the three last decades. Our results emphasize that locally factors controlling terrestrial Si mobilization can be refined differently from factors important at continental and global scales, where controls mostly include lithology, precipitation and slope. We clearly show that land use should be included in watershed scale models for base-line silica mobilization. Our results shed new light on how historical cultivation has affected the terrestrial silica cycle, and indicate yet another anthropogenic reduction of silica fluxes through the aquatic continuum, adding to globally important reductions in riverine Si transport by deposition in reservoirs and in eutrophied rivers and estuarine sediments.

To refine our concept of land use changes and silica dynamics, determination of germanium/silicon ratios and the analysis of the isotopic Si composition of the river water can be used to trace the source of riverine DSi. As such, these techniques may provide additional evidence for the differences in terrestrial biological control between forested and cultivated catchments.

A new conceptual model for changes in Si cycling with long-term soil disturbance. (1) Hypothesised Si cycling in developing forest, climax forest, early deforested areas and equilibrium cultured areas, the associated soil ASi stock (2) and the resultant magnitude of TSi export (3). In (1), boxes represent stocks of Si. Arrows represent fluxes: the thickness of arrows is representative for flux size. Dashed arrows represent irrelevant fluxes. In (2), the dotted area represents the size of the soil ASi pool. In (3) the sizes of the arrows represent relative TSi fluxes. The dashed line represents the hypothesized evolution of the size of the TSi fluxes.