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Blue Carbon in the Authie estuary: Carbon sequestration and exchanges in surface sediments in a context of dyke removal

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1. Contextual introduction

Estuaries are transition areas between terrestrial and marine domains, whose abiotic parameters such as salinity, turbidity and tidal influence vary along their length (Elliott & McLusky, 2002; Potter *et al.*, 2010). Estuaries also form an ecological unity composed of diverse habitats, including saltmarshes (Interpretation manual of EU habitats, 2013). Those habitats provide numerous ecosystem services (Millennium Ecosystem Assessment, 2005; Barbier *et al.*, 2011): serving as feeding and nesting sites for coastal birds (Hughes, 2004), being a nursery for fish species (Martinho *et al.*, 2007), purifying water (Hasani *et al.*, 2017; Hadikhani *et al.*, 2024) and participating in many biogeochemical processes (Negrin *et al.*, 2016). Especially, saltmarshes sequester carbon (Bulmer *et al.*, 2020; Mazarrasa *et al.*, 2023) (i) through autochthonous input, with the burial of biomass in sediments, after atmospheric carbon absorption during photosynthesis (McLeod *et al.*, 2011; Mason *et al.*, 2023) and (ii) through allochthonous input, with the burial of organic matter in sediments from suspended particles captured by vegetation (Mason *et al.*, 2023). However, mineralization processes, such as biomass respiration or subsurface methanogenesis, constitute carbon outputs for the ecosystem (Mason *et al.*, 2023). In this context, when carbon inputs exceed the outputs, the resulting upper sediment carbon pool is defined as “blue carbon” (Nellemann *et al.*, 2009; Lovelock & Duarte, 2019). Depending on estimations, on a global scale saltmarshes can sequester between 4.8 and 87.2 Mt of carbon within their upper sediments (McLeod *et al.*, 2011). However, a quarter of the global area of these blue carbon ecosystems, along with the associated ecosystem services, has been lost over the two past centuries (Nellemann *et al.*, 2009; McLeod *et al.*, 2011). This loss is mostly due to anthropogenic stressors such as the artificialization of coastal zones (Macreadie *et al.*, 2017; Bulmer *et al.*, 2020). For example, polders are coastal areas reclaimed from the sea by means of drainage and dike embankment. Although polders fulfilled many demographic and agricultural challenges of the past centuries, they are currently facing emerging concerns about climate change and sea level rise (Goeldner-Gianella, 2013; Macreadie *et al.*, 2017). Indeed, when high tidal coefficients and elevated river flows occur simultaneously, flooding is expected upstream these artificially altered areas. To address this issue, current local management plans consider removing or breaching protection dikes to facilitate rewilding and inundating these areas, but also enabling them to act as buffer zones again (PAPI - Authie, 2020). This approach allows both tidal and river flows to evolve more naturally, without threatening urbanised areas. However, the breaching of dikes induces geomorphological and ecological modifications to the newly rewilded zones, subsequently impacting carbon sequestration processes (Wolters *et al.*, 2005; Garbutt & Wolters, 2008; Spencer *et al.*, 2008; Burden *et al.*, 2019; Cahoon *et al.*, 2019).

The Authie estuary, located in the North of France (Fig. 1), is the subject of a planned dike removal, although the implementation timeline is yet to be determined and this process is unlikely to occur for several years. In the meantime, the fluxes and stocks of carbon throughout the ecosystem can be assessed in preparation for this transition, that can be summarised through important scientific concerns: what are the actual carbon fluxes in the various sediment facies of the Authie estuary? How is the sediment carbon pool characterized in an unaltered saltmarsh within the Authie estuary?

Here, preliminary results of lipid biomarkers from a saltmarsh sediment sample in an unaltered zone of the Authie estuary are investigated. The objectives are to (i) identify the repartition of organic carbon source type within allochthonous or autochthonous inputs and (ii) identify more precisely the sources of this organic carbon.

2. Methodology

Site location

This study was conducted in the saltmarsh of the Authie estuary (Fig. 1), in the region of Hauts-de-France (Fig. 1). Samples of subsurface sediment and two typical plants of the studied site, *Halimione portulacoides* and *Puccinellia maritima*, were collected jointly in April 2019.

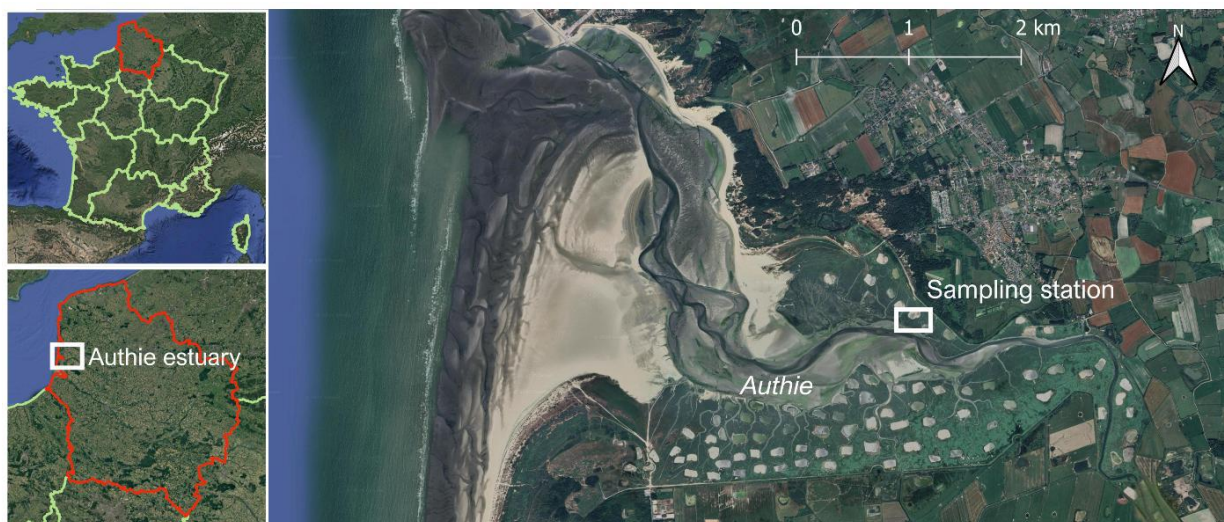


Figure 1. Location of the sampling station in the Authie estuary (region Hauts-de-France).

Sediment organic carbon: a molecular organic geochemical approach (lipid biomarkers)

A molecular biomarker is defined as “a complex organic compound having little to no changes in its chemical structure” compared to the molecules that once existed in living organisms (Derrien *et al.*, 2017). Basically, lipids are organic molecular compounds synthesised by living organisms, and are not easily degraded by microbial activity after organisms death (Carreira *et al.*, 2016). Thereby, lipid biomarker features may be used to identify organic matter sources and biogeochemical processes associated with sedimentary organic matter remineralization (Chevalier *et al.*, 2015; Derrien *et al.*, 2017). Thus, different main groups of lipids can be investigated, based on their chemical properties: *n*-alkanes (hydrocarbons), sterols, alcohols and fatty acids. Some of these compounds are associated with specific sources (Carreira *et al.*, 2016). For example, within hydrocarbon fraction, short-chain *n*-alkanes ($\leq C_{21}$) are typical of aquatic inputs (marine and freshwater phytoplankton), whereas long-chain *n*-alkanes ($\geq C_{27}$) are synthesised by terrestrial vascular plants (Chevalier *et al.*, 2015).

First, lipids are extracted from all samples using a mixture of organic solvents. Then, three fractions of lipids are analysed: hydrocarbons, alcohols/sterols and fatty acids (FAs). For each lipid fraction, a step of separation using silica chromatographic column is carried out before the analyses on Gas Chromatography-Mass Spectrometry (GC-MS). Results from the two plant samples are used as reference lipid signature for the sediment sample.

3. Results

In the three studied lipid fractions (*n*-alkanes, alcohols/sterols and FAs) sediment sample, short chain molecules are detected in very low abundance such as C17 *n*-alkane (Fig. 2), C14 *n*-alcohol and C13 FA. Conversely, long chain molecules such as C27 and C29 *n*-alkanes (Fig. 2; Table 1), C28 *n*-alcohol and C28 FA (Table 1), are detected in higher abundance. Thereby, each of the three lipid fractions indicates a low contribution of aquatic organisms and a high contribution of terrestrial higher plants in the sedimentary organic carbon pool of the Authie saltmarsh.

Note that a large number of bacterial-specific FAs, such as *iso*-/*anteiso*-C15, unsaturated C16:1, C17:1 and C18:1 FAs, are detected in high concentrations, suggesting significant bacterial activity linked to the remineralization of organic matter in the saltmarsh sediments.

Interestingly, some of the studied lipids present in sediments are detected only within one of the two studied plants (*H. portulacoides* and *P. maritima*). The stigmastan-3,5-dien, specific of *H. portulacoides*, is more abundant (1.08 µg.g⁻¹ dw) in sediments than the C33 *n*-alkane (0.56 µg.g⁻¹ dw), specific of *P. maritima* (Fig.2; Table 1). The situation is similar for the alcohol/sterol results: two typical alcohols from *H. portulacoides* (C22 and C24 *n*-alcohols), are detected in higher concentrations (2.20 µg.g⁻¹ dw and 2.69 µg.g⁻¹ dw, respectively) than the Campestanol, a typical stanol from *P. maritima* (1.77 µg.g⁻¹ dw) (Table 1). This suggests the relative predominance of *H. portulacoides* in sedimentary organic carbon pool, compared to *P. maritima*.

Furthermore, other lipids are produced in different quantities by both plants. For example, the C27 *n*-alkane is produced at a concentration of 19.5 µg.g⁻¹ dw in *P. maritima* and 68.7 µg.g⁻¹ dw in *H. portulacoides*. The proportion is inverted in each plant for C31 *n*-alkanes: 58.1 µg.g⁻¹ dw for *P. maritima* and 3.8 µg.g⁻¹ dw for *H. portulacoides*. With a similar approach, C28 *n*-alcohol is more abundant in *H. portulacoides* (95.4 µg.g⁻¹ dw) than in *P. maritima* (5.3 µg.g⁻¹ dw; Table 1). The case is inverted for Campesterol, with concentrations of 276.7 µg.g⁻¹ dw for *P. maritima* and 48.2 µg.g⁻¹ dw for *H. portulacoides* (Table 1). Eventually, for the FAs, the C20 FA was found in high abundance in *P. maritima* (249.4 µg.g⁻¹ dw), compared to *H. portulacoides* (154.8 µg.g⁻¹ dw). Conversely, the C28 FA is detected in high abundance in *H. portulacoides* (1730.8 µg.g⁻¹ dw) and in low abundance in *P. maritima* (203.9 µg.g⁻¹ dw).

Hence, the establishment of concentration ratios such as $\frac{C27\ n\text{-alkane}}{C31\ n\text{-alkane}}$, $\frac{C28\ n\text{-alcohol}}{\text{Campesterol}}$ and $\frac{C28\ FA}{C20\ FA}$ allows the characterization of both studied plants relative contribution in sediment organic carbon accumulation. Calculated ratios are respectfully 1.5, 6.5 and 10.9, which seems to confirm a large predominance of *H. portulacoides* in organic carbon inputs, compared to *P. maritima*, in the sediments of the Authie saltmarsh.

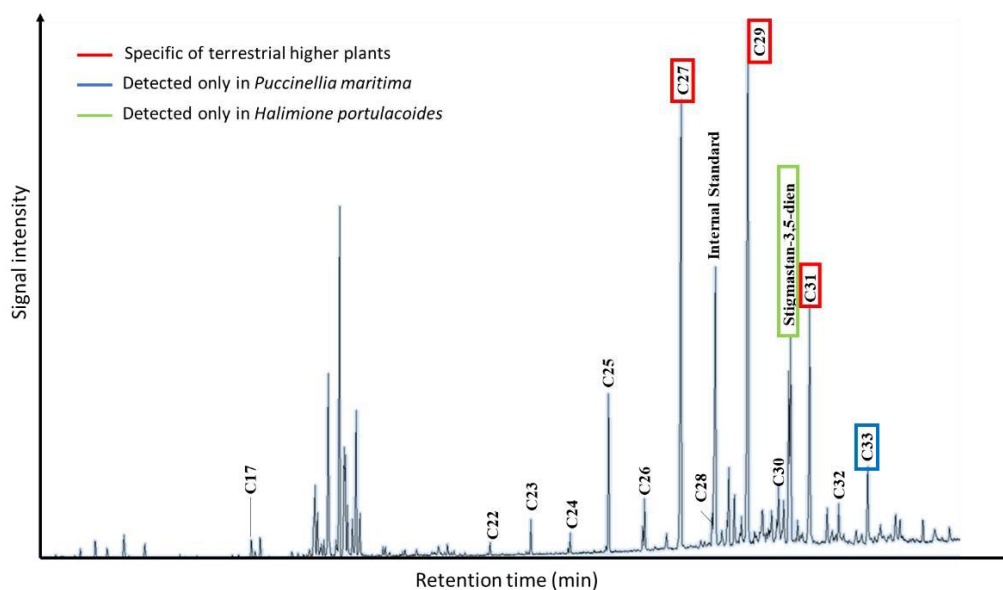


Figure 2. A GC-MS chromatogram of the hydrocarbon fraction extracted from the surface sediment sample in the saltmarsh of the Authie estuary.

	Sediment sample	<i>Puccinellia maritima</i>	<i>Halimione portulacoides</i>
<i>n</i> -alkanes	Molecular component concentration ($\mu\text{g} \cdot \text{g}^{-1} \text{dw}$)		
C27	2.318	19.5	68.701
C29	2.968	49.059	37.418
stigmastan-3,5-dien	1.076	NA	15.848
C31	1.503	58.143	3.763
C33	0.56	43.093	NA
Alcohols/sterols	Molecular component concentration ($\mu\text{g} \cdot \text{g}^{-1} \text{dw}$)		
C22-OH (I)	2.2	NA	5.77
C24-OH (I)	2.69	NA	10.01
C28-OH (I)	14.908	5.261	95.378
Campesterol	2.307	276.704	48.223
Campestanol	1.765	1.468	NA
Fatty acids (FAs)	Molecular component concentration ($\mu\text{g} \cdot \text{g}^{-1} \text{dw}$)		
C20 FA	3.542	249.38	158.411
C28 FA	35.168	203.85	1730.793

Table 1. Concentrations of specific lipid biomarkers for the sediment sample of the saltmarsh of the Authie estuary and for the terrestrial higher plants *P. maritima* and *H. portulacoides*.

4. Conclusion and perspectives

Here, we present preliminary results from the characterization of organic content in saltmarsh sediments using a lipid biomarker approach to identify major sources of the organic carbon pool in the Authie estuary. This study shows that terrestrial higher plant inputs largely exceed aquatic inputs. Moreover, it has been determined that a majority of lipids found in the sediment is associated with *Halimione portulacoides*, among saltmarsh typical species. This provides a first understanding of the carbon pool within the Authie saltmarsh sediments. As this estuary is expected to undergo dike removal in the coming years, this study serves as a prerequisite for further evaluations of the impacts of such modifications on the saltmarsh.

To complete this saltmarsh carbon budget, “instantaneous” carbon fluxes may be investigated. Its calculation requires the quantification of fluxes during emersion (gaseous flux at light and at dark) and

during immersion (dissolved fluxes always dark due to water turbidity). In order to monitor carbon fluxes (CO₂ and CH₄) during emersion, benthic chamber will be used (Voltz, 2020). For fluxes at the sediment-water interface, cores sampled at low tide will be incubated in the laboratory, with overlying water from the site (Denis & Grenz, 2003) for determination of Dissolved Inorganic Carbon (DIC) exchanges. The combination of both approaches could help accurately quantify the carbon pools and exchanges in the saltmarshes of the Authie estuary, as well as the potential changes resulting from expected estuarine management such as dike removal or breaching, followed by rewilding.

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References

- Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169-193.
- Bulmer, R. H., Stephenson, F., Jones, H. F. E., Townsend, M., Hillman, J. R., Schwendenmann, L., & Lundquist, C. J. (2020). Blue Carbon Stocks and Cross-Habitat Subsidies. *Frontiers in Marine Science*, 7. <https://doi.org/10.3389/fmars.2020.00380>
- Burden, A., Garbutt, A., & Evans, C. D. (2019). Effect of restoration on saltmarsh carbon accumulation in Eastern England. *Biology Letters*, 15(1), 20180773. <https://doi.org/10.1098/rsbl.2018.0773>
- Cahoon, D. R., Lynch, J. C., Roman, C. T., Schmit, J. P., & Skidds, D. E. (2019). Evaluating the Relationship Among Wetland Vertical Development, Elevation Capital, Sea-Level Rise, and Tidal Marsh Sustainability. *Estuaries and Coasts*, 42(1), 1-15.
- Carreira, R. S., Cordeiro, L. G. M. S., Bernardes, M. C., & Hatje, V. (2016). Distribution and characterization of organic matter using lipid biomarkers : A case study in a pristine tropical bay in NE Brazil. *Estuarine, Coastal and Shelf Science*, 168, 1-9. <https://doi.org/10.1016/j.ecss.2015.11.007>
- Chevalier, N., Savoye, N., Dubois, S., Lama, M. L., David, V., Lecroart, P., le Ménach, K., & Budzinski, H. (2015). Precise indices based on n-alkane distribution for quantifying sources of sedimentary organic matter in coastal systems. *Organic Geochemistry*, 88, 69-77. <https://doi.org/10.1016/j.orggeochem.2015.07.006>
- Denis, L., & Grenz, C. (2003). Spatial variability in oxygen and nutrient fluxes at the sediment-water interface on the continental shelf in the Gulf of Lions (NW Mediterranean). *Oceanologica Acta*, 26(4), 373-389. [https://doi.org/10.1016/S0399-1784\(03\)00017-3](https://doi.org/10.1016/S0399-1784(03)00017-3)
- Derrien, M., Yang, L., & Hur, J. (2017). Lipid biomarkers and spectroscopic indices for identifying organic matter sources in aquatic environments: A review. *Water Research*, 112, 58-71. <https://doi.org/10.1016/j.watres.2017.01.023>
- Elliott, M., & McLusky, D. S. (2002). The Need for Definitions in Understanding Estuaries. *Estuarine, Coastal and Shelf Science*, 55(6), 815-827. <https://doi.org/10.1006/ecss.2002.1031>
- Garbutt, A., & Wolters, M. (2008). The natural regeneration of salt marsh on formerly reclaimed land. *Applied Vegetation Science*, 11(3), 335-344. <https://doi.org/10.3170/2008-7-18451>

Goeldner-Gianella, L. (2013). La dépollérisation, un mouvement en plein essor en Europe.... In *Dépollériser en Europe occidentale : Pour une géographie et une gestion intégrée du littoral* (p. 21-57). Éditions de la Sorbonne.

Hadikhani, R., Karbassi, A., Tajziehchi, S., & Mehdizadeh, Y. (2024). Mechanisms and controlling factors of heavy metals removal by electroflocculation in estuarine environments. *Marine Pollution Bulletin*, 206, 116699. <https://doi.org/10.1016/j.marpolbul.2024.116699>

Hasani, S., Karbassi, A. R., & Ardesani, M. (2017). Role of Estuarine Natural Flocculation Process in Removal of Cu, Mn, Ni, Pb and Zn. *Global Journal of Environmental Science and Management*, 3, 187-196. <https://doi.org/10.22034/gjesm.2017.03.02.007>

Hughes, R. G. (2004). Climate change and loss of saltmarshes : Consequences for birds. *Ibis*, 146(s1), 21-28. <https://doi.org/10.1111/j.1474-919X.2004.00324.x>

Lovelock, C. E., & Duarte, C. M. (2019). Dimensions of Blue Carbon and emerging perspectives. *Biology Letters*, 15(3), 20180781. <https://doi.org/10.1098/rsbl.2018.0781>

Macreadie, P. I., Nielsen, D. A., Kelleway, J. J., Atwood, T. B., Seymour, J. R., Petrou, K., Connolly, R. M., Thomson, A. C., Trevathan-Tackett, S. M., & Ralph, P. J. (2017). Can we manage coastal ecosystems to sequester more blue carbon? *Frontiers in Ecology and the Environment*, 15(4), 206-213. Interpretation manual of European Union Habitats (2013). Disponible à l'adresse: [Manuel habitats UE](#)

Martinho, F., Leitão, R., Neto, J. M., Cabral, H. N., Marques, J. C., & Pardal, M. A. (2007). The use of nursery areas by juvenile fish in a temperate estuary, Portugal. *Hydrobiologia*, 587(1), 281-290. <https://doi.org/10.1007/s10750-007-0689-3>

Mason, V. G., Burden, A., Epstein, G., Jupe, L. L., Wood, K. A., & Skov, M. W. (2023). Blue carbon benefits from global saltmarsh restoration. *Global Change Biology*, 29(23), 6517-6545. <https://doi.org/10.1111/gcb.16943>

Mazarrasa, I., Neto, J. M., Bouma, T. J., Grandjean, T., Garcia-Orellana, J., Masqué, P., Recio, M., Serrano, Ó., Puente, A., & Juanes, J. A. (2023). Drivers of variability in Blue Carbon stocks and burial rates across European estuarine habitats. *Science of The Total Environment*, 886, 163957. <https://doi.org/10.1016/j.scitotenv.2023.163957>

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., & Silliman, B. R. (2011). A blueprint for blue carbon : Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO₂. *Frontiers in Ecology and the Environment*, 9(10), 552-560. <https://doi.org/10.1890/110004>

MEA - Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being : Synthesis*. Island Press. Disponible à l'adresse : <https://www.millenniumassessment.org/en/Condition.html>

Negrin, V., Botté, S., Pratolongo, P., González Trilla, G., & Marcovecchio, J. (2016). Ecological processes and biogeochemical cycling in salt marshes : Synthesis of studies in the Bahía Blanca estuary (Argentina). *Hydrobiologia*, 774(1), 217-235. <https://doi.org/10.1007/s10750-015-2582-9>

Nellemann, C., Corcoran, E., Duarte, C., Valdes, L., Young, C., Fonseca, L., & Grimsditch, G. (2009). *Blue Carbon—The Role of Healthy Oceans in Binding Carbon*.

Potter, I. C., Chuwen, B. M., Hoeksema, S. D., & Elliott, M. (2010). The concept of an estuary : A definition that incorporates systems which can become closed to the ocean and hypersaline. *Estuarine, Coastal and Shelf Science*, 87(3), 497-500. <https://doi.org/10.1016/j.ecss.2010.01.021>

PAPI - Authie : Déclarations d'intention du programme d'action de prévention des inondations Bresle Somme Authie. (2020). Les services de l'État dans la Somme. Disponible à l'adresse PAPI- Bresle - Somme - Authie

Spencer, K. L., & Harvey, G. L. (2012). Understanding system disturbance and ecosystem services in restored saltmarshes : Integrating physical and biogeochemical processes. *Estuarine, Coastal and Shelf Science*, 106, 23-32. <https://doi.org/10.1016/j.ecss.2012.04.020>

Voltz, B. (2020). Dynamique de la matière organique au sein dans les estuaires picards : Caractérisation des faciès biosédimentaires et quantification des processus de minéralisation benthique [Université du Littoral Côte d'Opale]. <https://theses.hal.science/tel-03229807>

Wolters, M., Garbutt, A., & Bakker, J. P. (2005). Salt-marsh restoration : Evaluating the success of de-embankments in north-west Europe. *Biological Conservation*, 123(2), 249-268. <https://doi.org/10.1016/j.biocon.2004.11.01>



Q&A

On complementarity between approaches: you and A.Tauran (previous presentation) used very different approaches—do you think they could complement each other?

- Absolutely. The goal is to understand the ecological transition that will occur once the dyke is removed, and ideally, anticipate its effects. Currently, baseline conditions are being characterised so that future changes can be properly assessed.

On lipid profile variations and sterol-to-acid ratios:

- These differences appear to be linked to species morphology. Root and stem tissues do not exhibit the same biochemical signatures. It likely reflects physiological traits specific to each species.

On investigating plant or sediment age:

- The primary objective is to quantify carbon pools rather than date them. However, if deeper sediment layers are analysed, dating could become relevant.

On the selection of plant species for lipid analysis:

- These two species are dominant in the ecosystem, so they were the logical starting point. The expansion of the analysis is planned to include a broader range of species in future studies.

On local community perception of the dyke removal project:

- Without speaking on their behalf, it's certainly an important question that deserves further exploration.