Controls on organic matter degradability in suspended matter and sediments of the Elbe river
(EGU2020-9015)

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Prediction of organic matter degradability in river sediments (EGU2020-22064)

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Research questions

The described gradient of the organic matter degradability from upstream to downstream of the Elbe river (Zander et al. 2020) leads to the following questions:

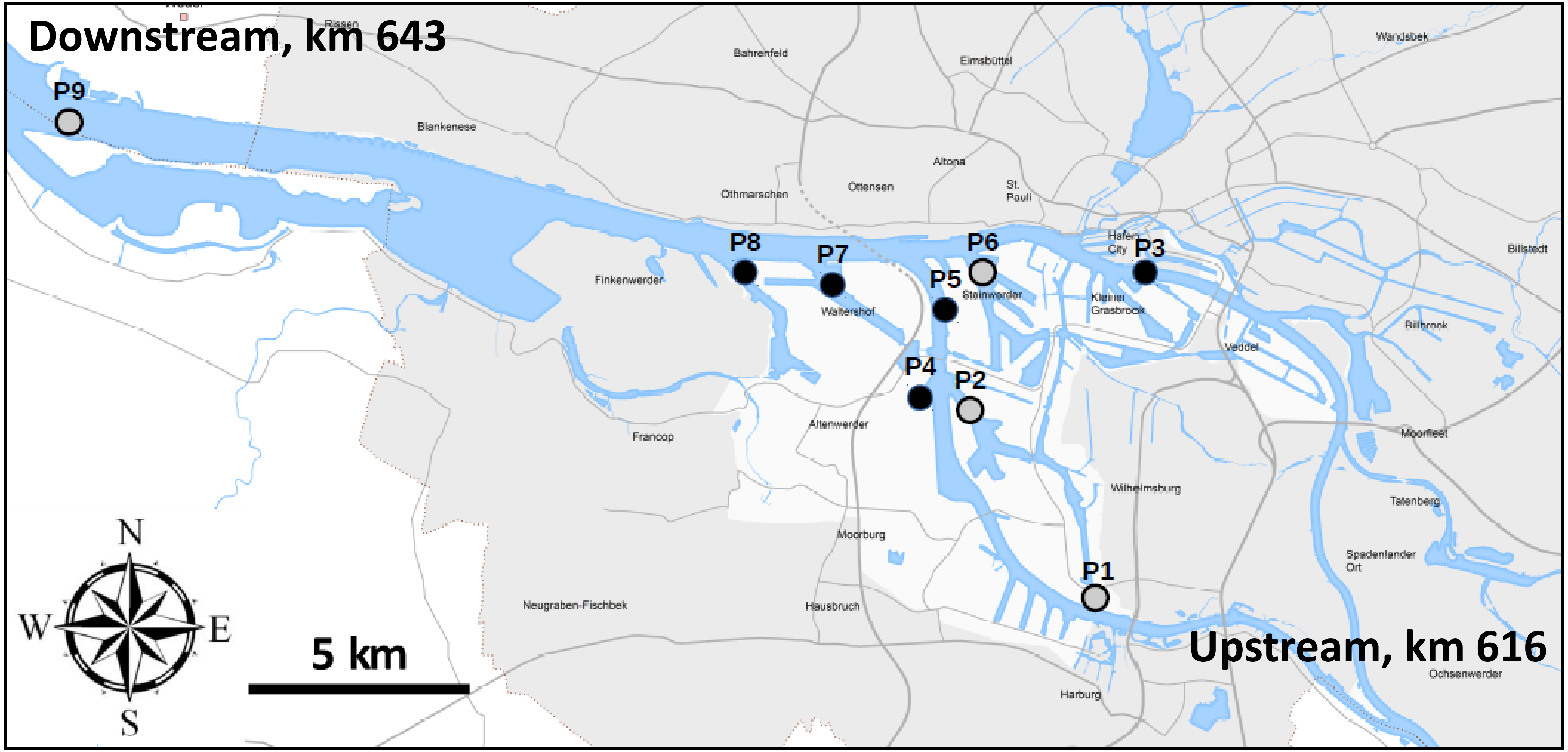
- **How does the organic matter quality vary along the upstream-downstream transect?**
- **How do the organic matter quality (origin and physicochemical properties) and sediment properties influence the organic matter degradability?**
- **Can long-term degradation of sediment organic matter be inferred from short-term measurements?**

Zander, F., Heimovaara, T., Gebert, J. (2020): Spatial variability of organic matter degradability in tidal Elbe sediments. Journal of Soils and Sediments. DOI https://doi.org/10.1007/s11368-020-02569-4.

Investigation area: Port of Hamburg, Germany

Sampling locations, P1 to P9

Grey dots: focussed locations where DOC fractionation analyses were performed



Sampling procedures

- 1 m core of the first sediment layers (7 to 17 m depth below water level)
- Stratified sampling of individual layers (see next slide)
- Sampling from March to November 1 x per month in 2018 and 2019

A detailed look reveals...

Suspended particulate matter SPM, oxidized

Fluid mud FM

Oxidized or reduced

Pre-consolidated sediment PS

Reduced

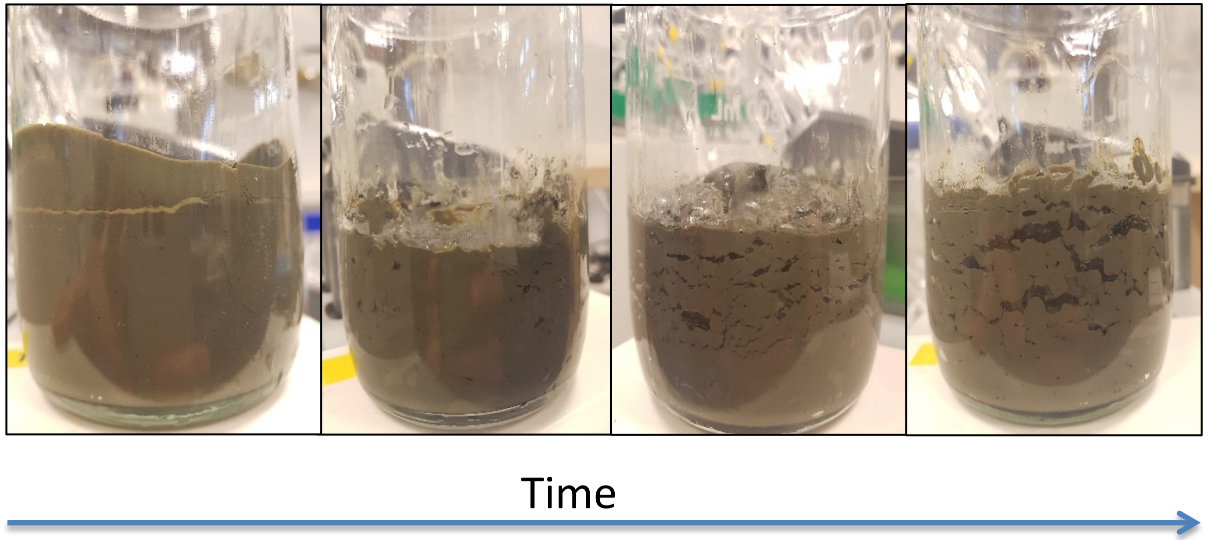
Consolidated sediment CS

Reduced

- A multi-layered system, layers differ in
  - Flow behaviour (rheology)
  - Color (redox potential)
  - Density (in-situ)
  - Water content
  - C content and C mineralisation
  - ... And many more properties
- Consolidation chrono-sequence
- > 80% fines (< 63 µm)
- FM = lutocline / “river bottom”

Methods

- **Quantification of organic matter degradation and degradability**
  - Long-term anaerobic incubations to quantify C mineralisation (> 250 d)
  - Organic matter pools (inferred from degradation rates)
- **Selected properties of Elbe river water**
  - Chlorophyll content
- **Selected sediment properties**
  - Biological parameters
    - Extrapolymeric substances (EPS)
    - Microbial biomass
  - Chemical parameters
    - DOC fractions (water and acid/base extractable)
    - Total DOC
    - Share of HoN, HA, Hi, and FA
  - Physical parameters:
    - Density fractionation



- **Correlation analyses**
  - Influence of abiotic and biotic sediment properties on organic matter degradability

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Ebullition of gas from anaerobic degradation of sediment organic matter in Port of Hamburg

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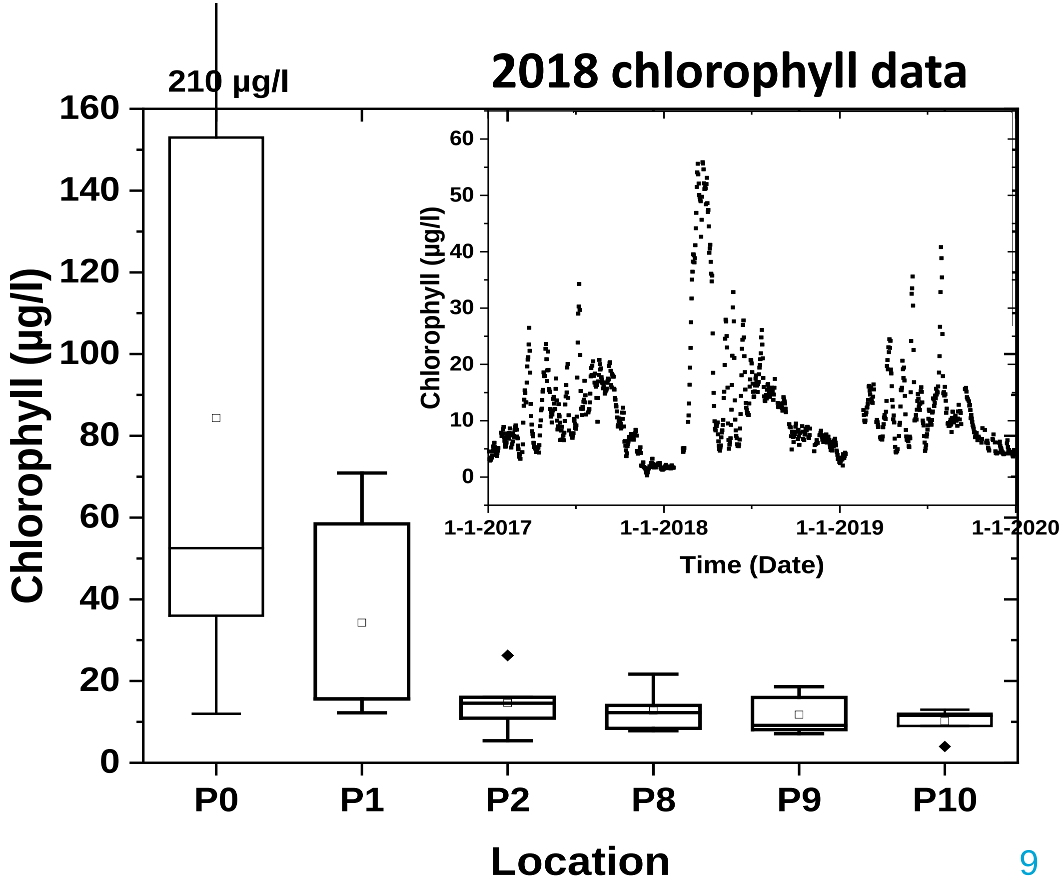
Water properties: chlorophyll concentration

- Chlorophyll gradient from upstream to downstream **(measured in situ)**
  - Small figure: multi-peak algae plume near location P8 (Hamburg Service portal, 2017-2020)
  - P0 (river-km 599) and P10 (river-km 646) are showing data from FGG server (Elbe data portal, 2020)

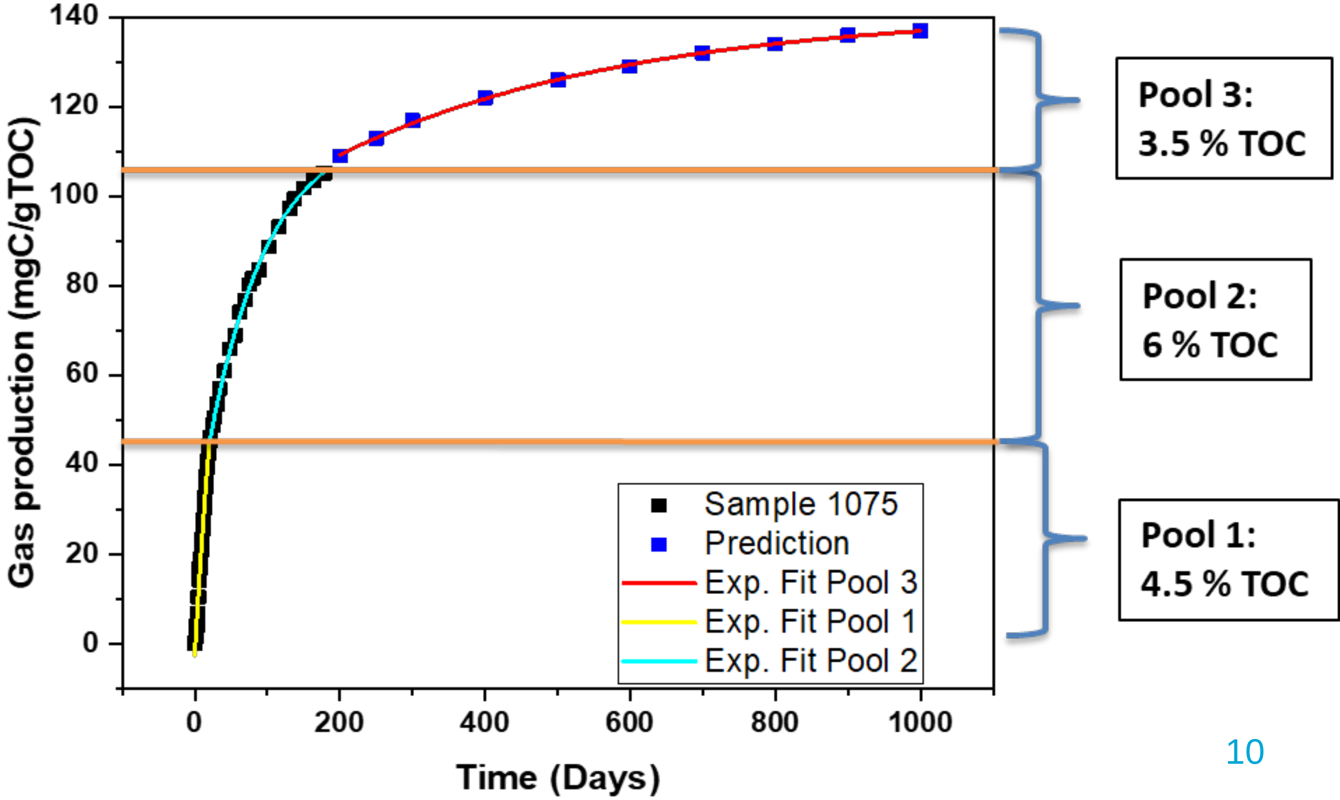
Hypothesis: Greater input of easily degradable organic matter (algae) at upstream locations (from P0)



Determination of organic matter pools

- Organic matter pools are defined by OM **degradation rate** (**k**) / half life
- Prediction of gas generation with e.g. three phase function (y = A1*exp(-x/t1) + A2*exp(-x/t2) + A3*exp(-x/t3) + y0)
- Example for a three phase function
  - Total (assumed) gas generation: **14% TOC**

Exemplary cumulative C-degradation curve

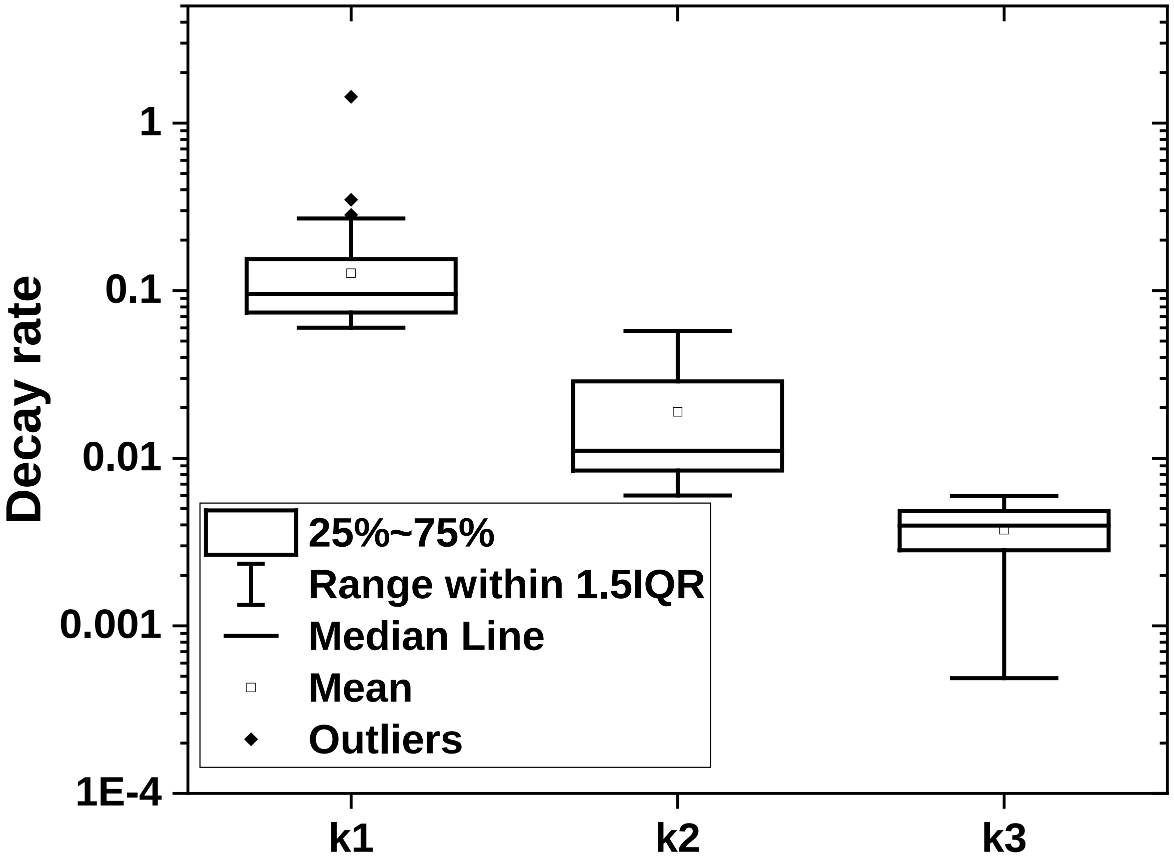


Determination of organic matter pools

The borders between organic matter pools were chosen with respect to the overall range of organic matter decay rates (0.5 to 500 days):

- Borders between pool one and pool two: half life of 5 days, corresponding **degradation rate k: 0.06**
- Between pool two and pool three: 50 days, corresponding **degradation rate k: 0.006**

- Half live of the anaerobic samples varied between 0.5 days and 500 days, corresponding **decay rates** varied between 0.6 and 0.0006
- Samples with greater decay rate than 0.06 belonged to pool 1 (k1)
- Samples with decay rate smaller than 0.006 days belonged to pool 3 (k3)



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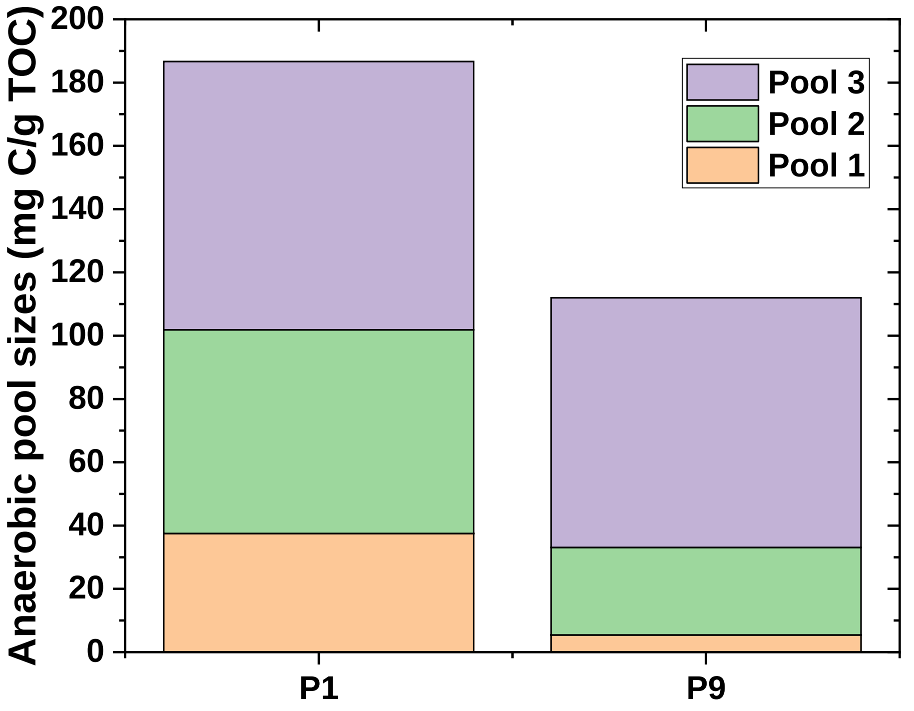
Organic matter pools upstream vs. downstream

- Anaerobic organic matter pools from June campaign 2018
- **Upstream**: more degradable OM and bigger pool 1 (fast degradable OM)
- **Downstream**: mostly pool 3 (slow degradable OM)
- N > 20

Hypothesis: easily degradable OM at upstream is degraded on its way downstream, this can show an age gradient and/or a source gradient. FM and PS only show pool 3 material – easily degradable material has been degraded.



Upstream, km 616

Downstream, km 643

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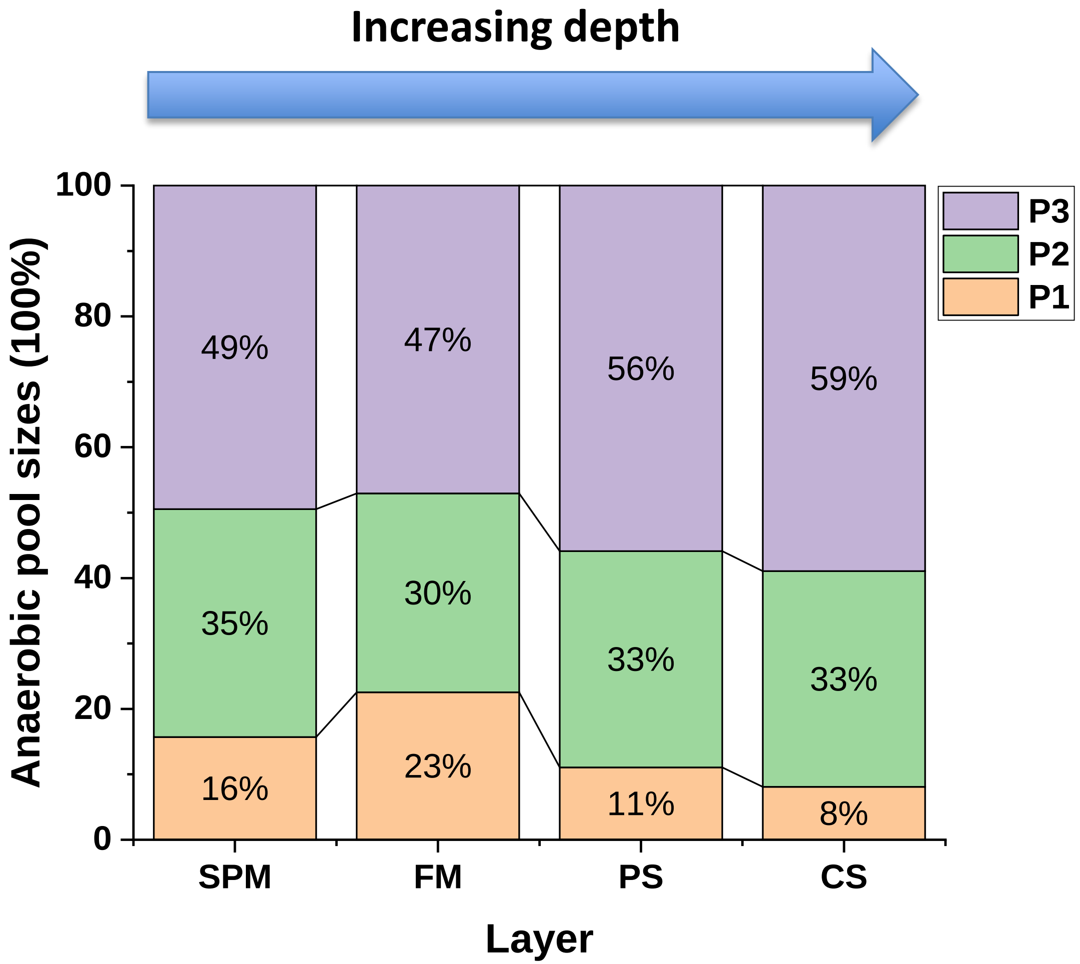
Anaerobic pool sizes with depth

- Pool 1 is dominant at FM layers, pool 3 at CS layers.
- Pool 2 is about one third of the total pool size
- For each layer, around one half of have of the pool size is made out of pool 3
- n > 50



Chemical organic matter fractionation

Methods

- Acid/base extraction
- Water/$CaCl_2$ extraction
- Total DOC is separated into several fractions (e.g. humic acids, fulvic acids, hydrophilic fraction, etc.)

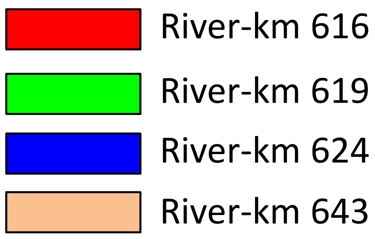
- Here: focus on the **hydrophilic** DOC fraction (**Hi**)

For methods also see: Van Zomeren and Comans (2007), DOI https://doi.org/10.1021/es0709223

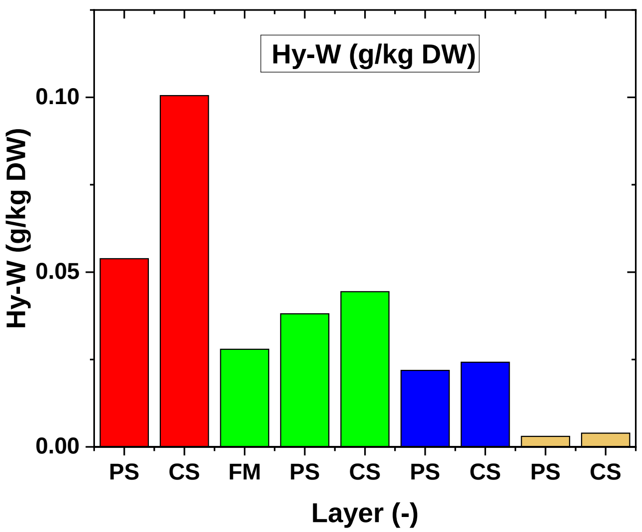
Hydrophilic (Hi) DOC fraction (per DW / per TOC)

- Decreasing gradient from upstream to downstream
- High Hi concentrations at areas with high OM degradation (high input of fresh OM)
- High ratio between acid-base(AB)- and water-extraction at downstream due to low water extractable Hi
- Acid/base extraction is not/barely available for microbial organic matter degradation

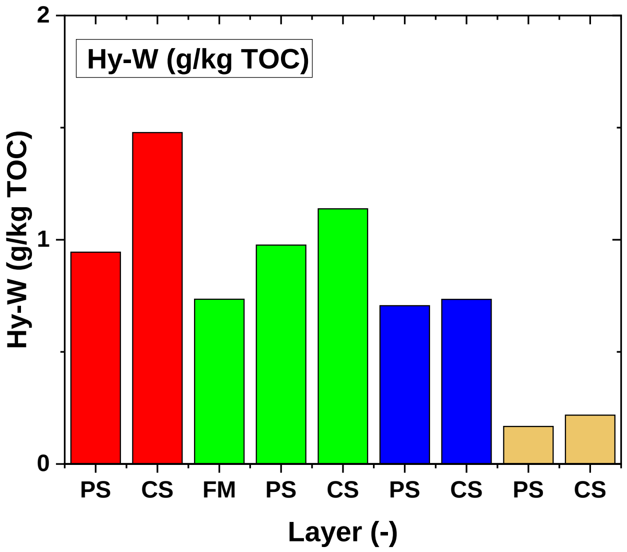
Hypothesis: Hi is mostly responsible for the fast OM degradation and therefore an indicator for high OM quality at upstream locations



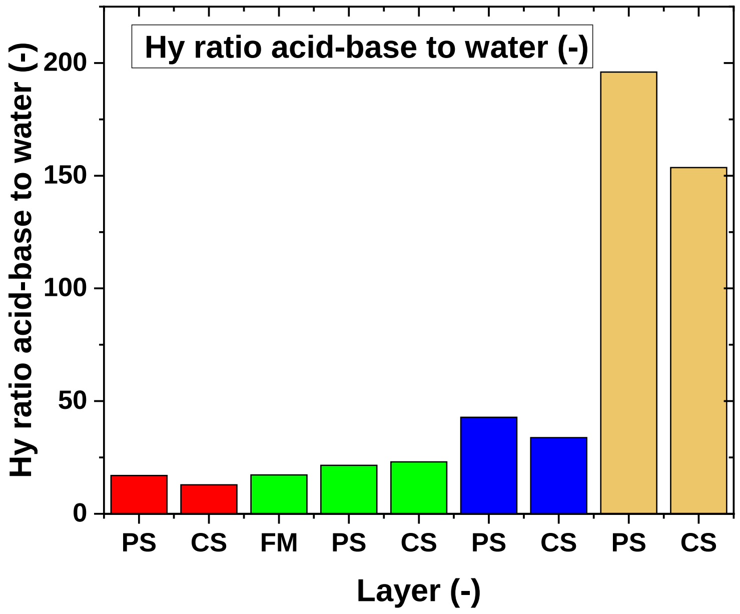
water extract per DW



water extract per TOC



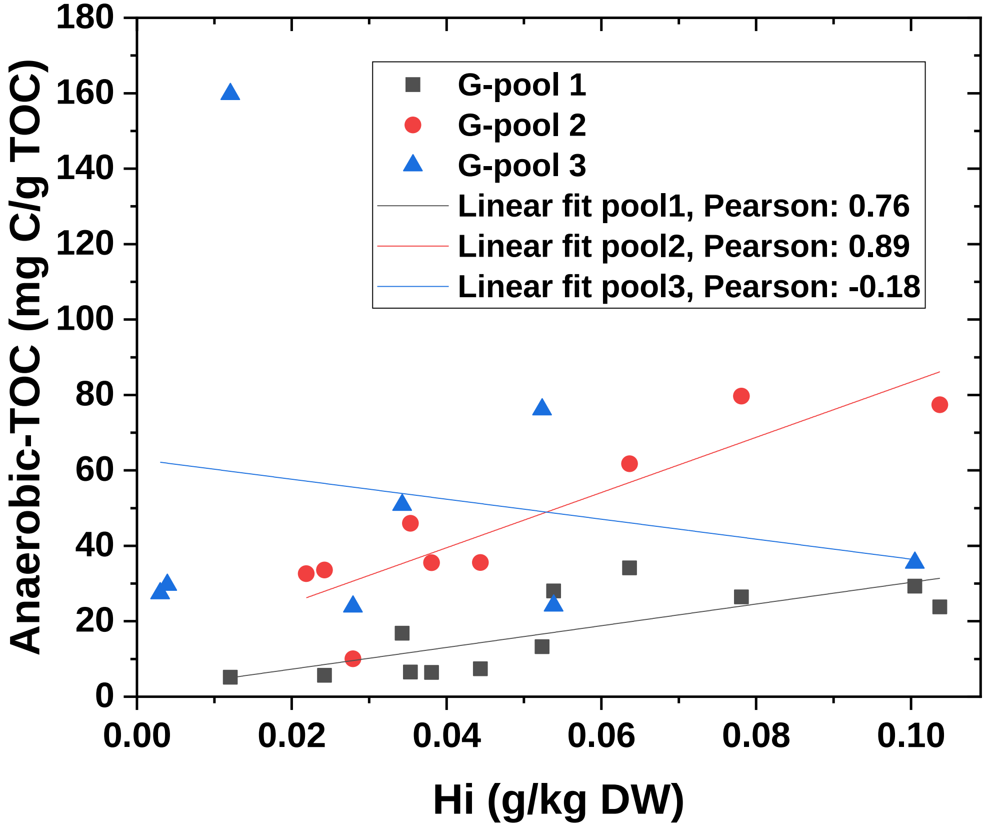
Ratio AB-water



Hi fraction vs. anaerobic OM-pools, PS layers, 2018

- Fast and moderate degradable organic matter pools (pool 1 and pool 2) are correlating well with hydrophilic DOC fraction
- Slow degradable pool 3 is not correlating with Hi fraction

Hypothesis: pool 3 is not influenced by the Hi fraction. Pool 1 and pool 2 are driven by easily degradable OM, e.g. Hi fraction



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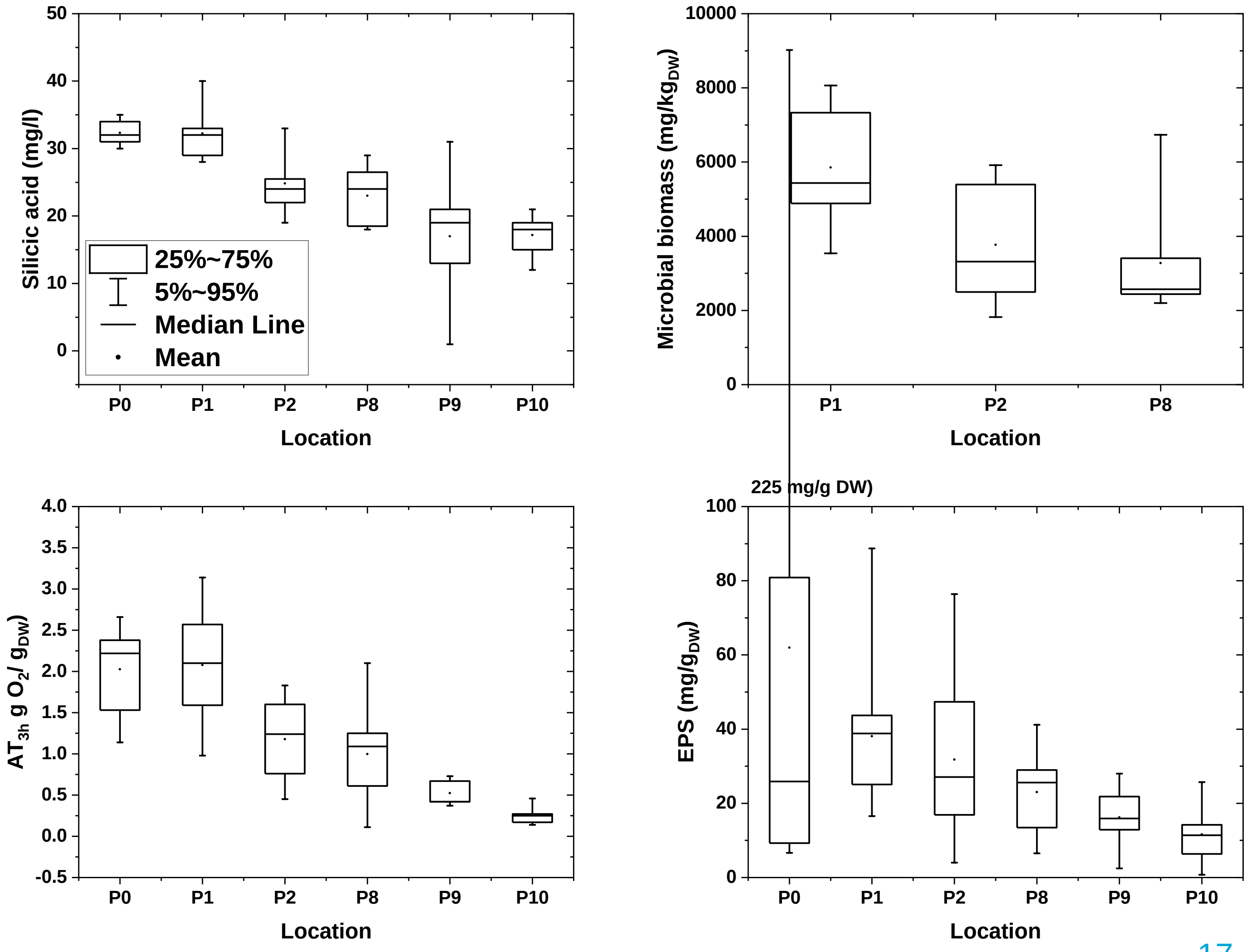
Silicic acid, biomass, respiration activity (AT3h), EPS, PS layers, 2018+2019

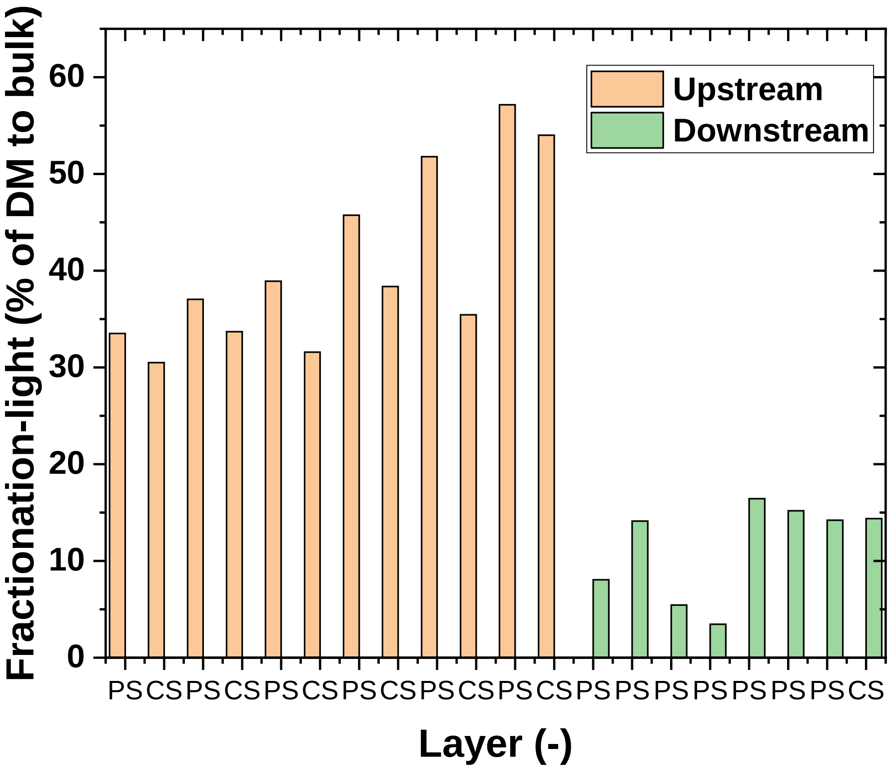
- Downstream: lowest total amount of biomass, anaerobic OM degradation after 100 days (G100) silicic acid and oxygen consumption after three hours (AT3h, lab value)
- Sample n between six and 18

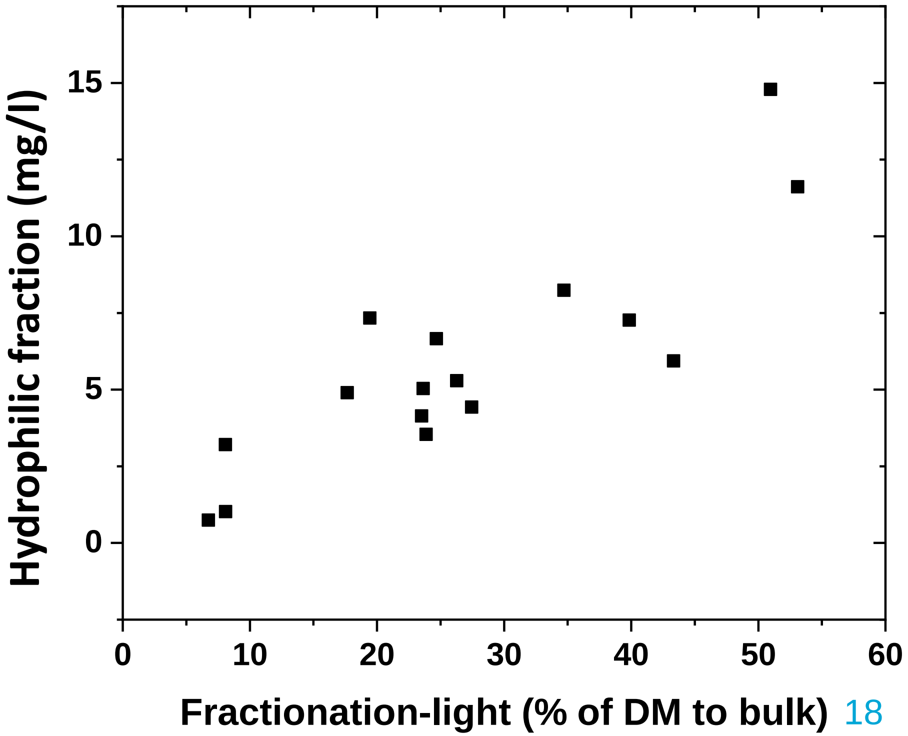
Hypothesis: upstream is found more silicic acid, produced by algae, and more EPS, due to microbial activity, both resulting in a higher oxygen consumption, higher organic matter degradation and bigger pool 1 (not shown)



Density fractionation: light organic matter fraction, 2019

- Upstream sediments contain higher concentrations of easily degradable organic matter per dry weight (**left graph**)
  - Association of OM with mineral phase at downstream locations
- Correlation hydrophilic DOC fraction with light density fraction (**right graph**)





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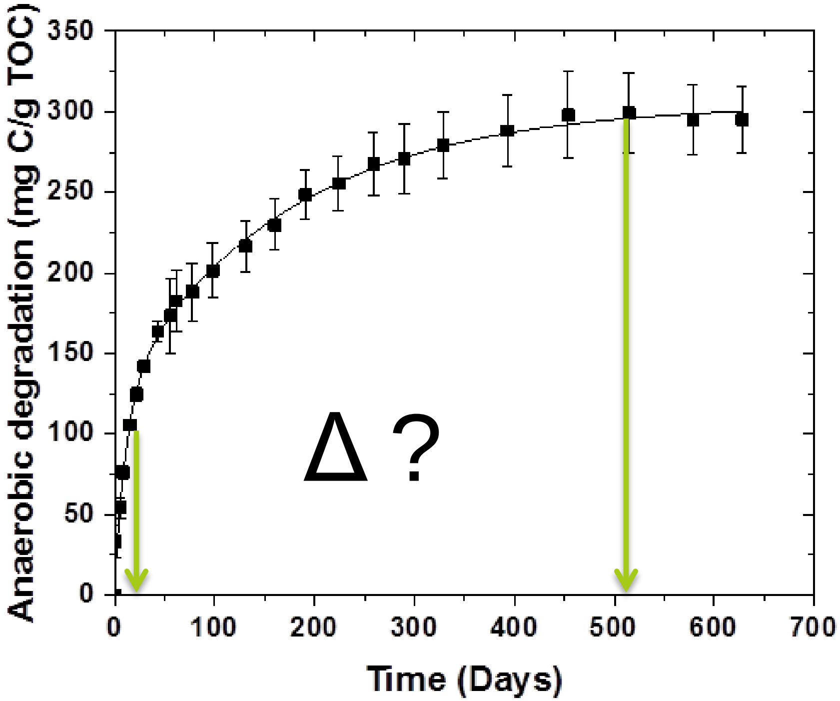

Research questions:

- Can long-term degradation of sediment organic matter (SOM) be predicted from short-term degradation experiments?
- Is the relationship between short-term and long-term carbon mineralisation similar for different sites in Port of Hamburg and at any one site, for different layers?

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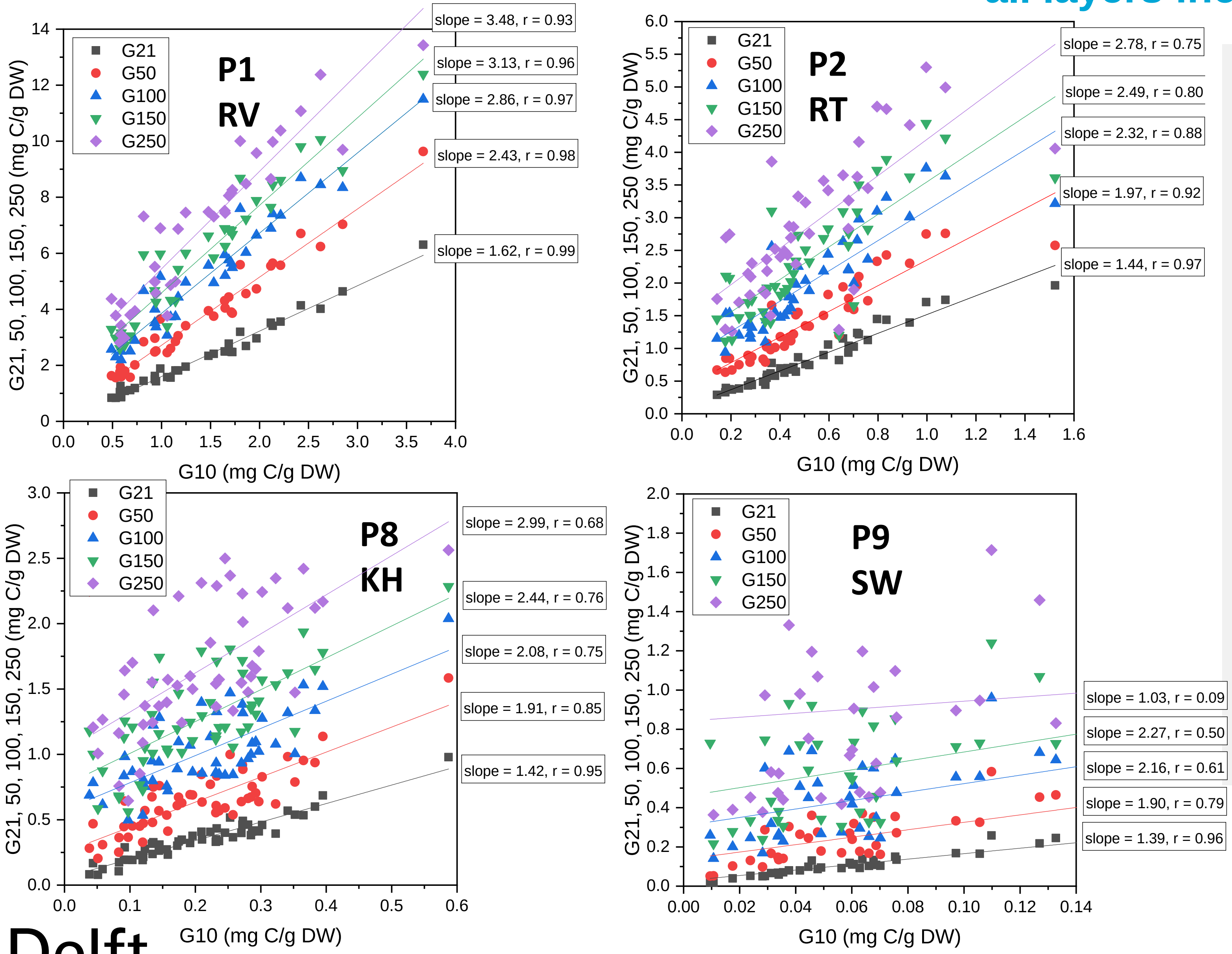
Relationship between short-term and long-term anaerobic C release by site, all layers included (SPM, FM, PS, CS)

Up-stream

Down-stream



- Upstream locations show higher anaerobic C mineralisation than downstream sites (compare Zander et al., 2020)
- Upstream locations show much higher correlation coefficients between short-term and long-term cumulative C-mineralisation
- At the most downstream point P9, which is also hydrodynamically most dynamic, inferring C mineralisation beyond 21 days from short-term measurements bears large uncertainty
- Slopes differ per site, higher slopes upstream, lower slopes downstream

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x-axis: cumulative anaerobic C release after 10 days of incubation (G10), **y-axis:** cumulative C release after 21, 50, 100, 150 and 250 days

Relationship between short-term and long-term anaerobic C release by layer, all four sites included (P1, P2, P8, P9)

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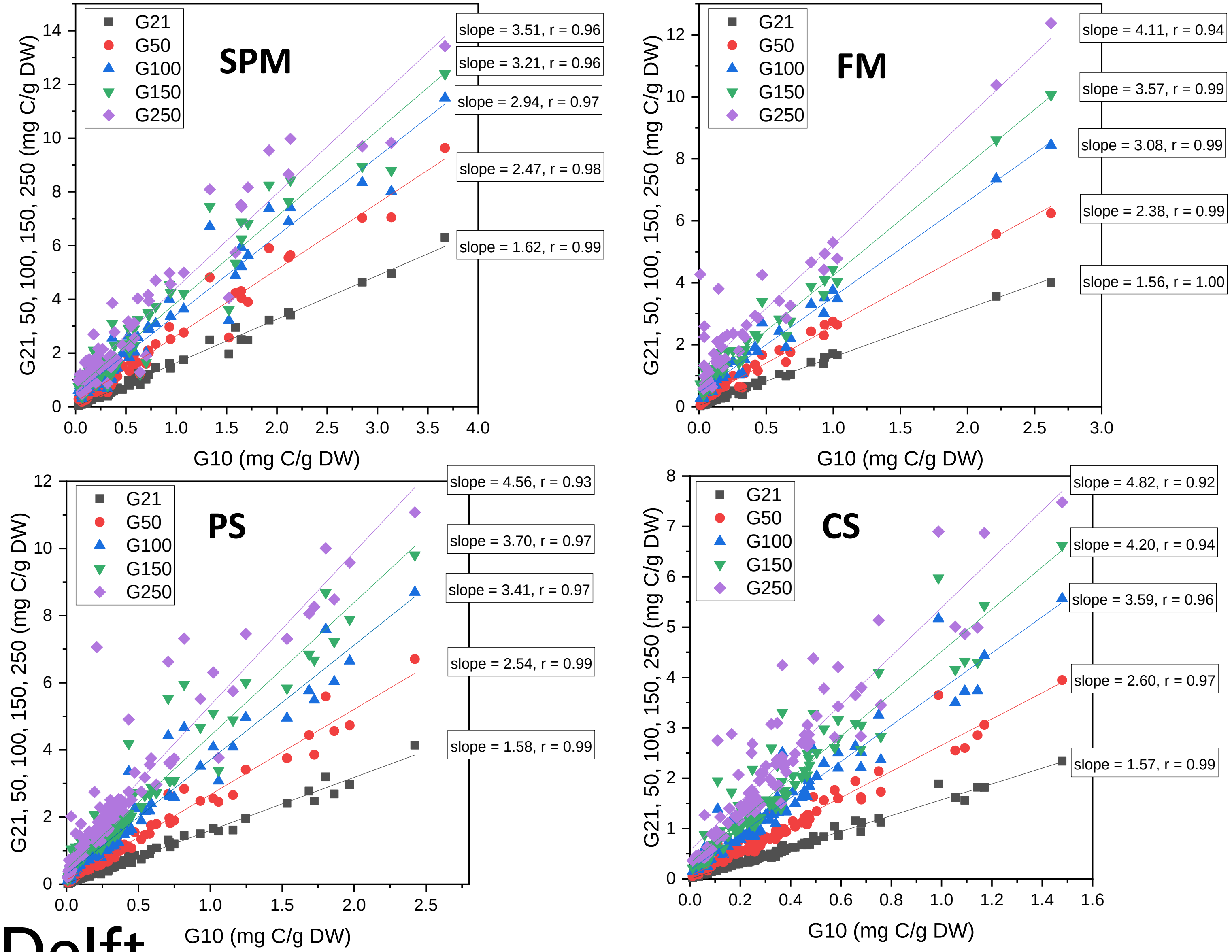
Top two layers

Bottom two layers



- Top layers show higher cumulative C mineralisation than deeper layers (compare Zander et al., 2020)
- High quality of correlation when sample pool is separated by layer rather than by site (previous slide)
- Larger variability in bottom layers PS and CS

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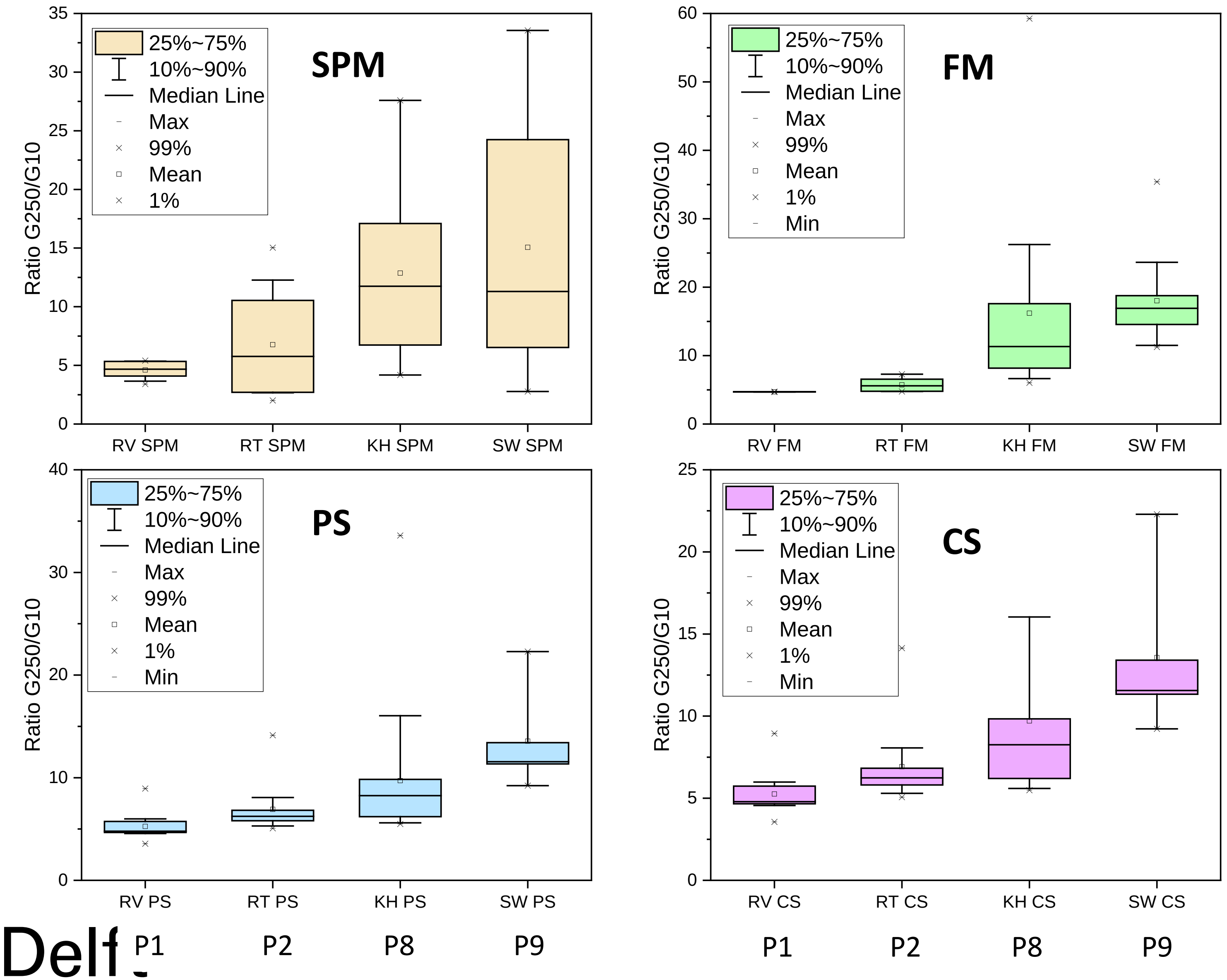
x-axis: cumulative anaerobic C release after 10 days of incubation (G10), **y-axis:** cumulative C release after 21, 50, 100, 150 and 250 days

Ratio of G250 to G10 along transect and by layer



- Factor between long-term and short-term C mineralisation is most uniform across all layers at upstream sites
- Higher variability of factor at downstream sites
- Difference between long-term and short-term anaerobic C mineralisation increases from upstream to downstream

Conclusions

- Organic matter with high degradability (e.g. algae) derived from upstream resulting in high chlorophyll, silicic acid, biomass and EPS concentration as well as oxygen consumption.

- The hydrophilic DOC fraction (Hi) correlates well with fast organic matter degradation (e.g. light density fraction) and is therefore an indicator for high organic matter lability at upstream locations.

- Slowly degradable pool 3 material is found more often at downstream locations, easily accessible organic matter at upstream is degraded on its way downstream (age/source gradient).

- The pool determination is a suitable tool to separate between fast, intermediate and slow degradable organic matter.

Conclusions

- Different sites along the transect P1 → P9 and the different layers are characterised by different quality of SOM, reflected by different specific relationships between long-term and short-term C mineralisation
- Predictability of anaerobic C mineralisation increases when sediments are separated by layer rather than by site, indicating that specific SOM quality is associated with individual layers
- Higher uniformity of SOM mineralisation upstream may be due to single-source input (from upstream), whereas downstream locations receive OM from both upstream (river catchment) and downstream directions (North Sea) which is assumed to differ in composition/quality and degree of association with the mineral phase

Thank you for your attention !

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