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Disentangling in-stream nitrate uptake pathways based on two-station high-frequency monitoring in high-order streams

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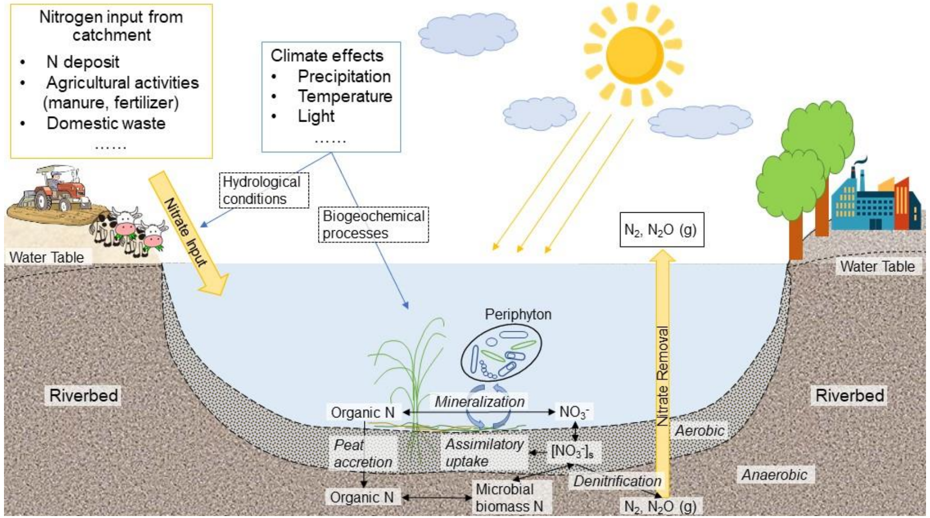
Why and What we want to do?

Motivation

- ➢ In-stream biogeochemical processes can highly influence nutrient loads transporting from land surface to the sea.
- ➢ Nitrogen is one of the most concerned nutrients when considering water quality.
- ➢ Research about N uptake in high order streams is still limited.

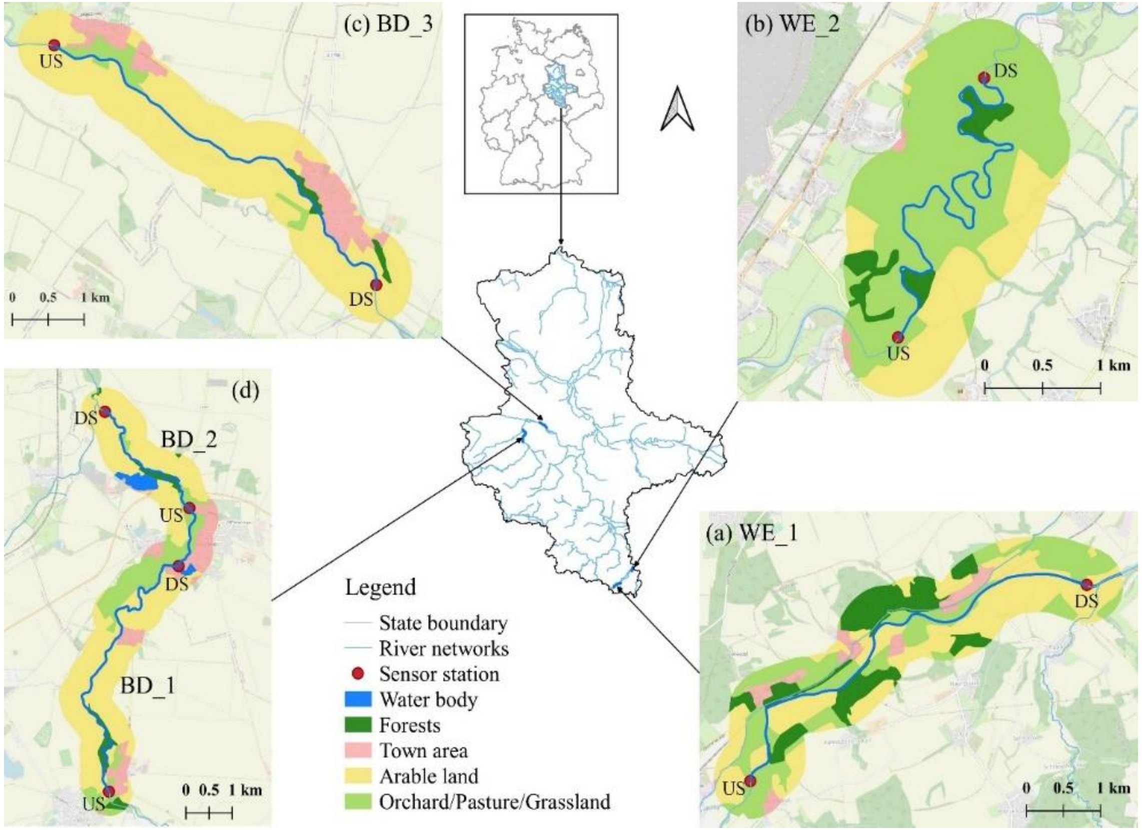


Main research questions

- How does reach-scale N uptake process change under different environment conditions and river morphology?
- How does different reach-scale N uptake pathways change?

Methods

Study reaches



- ❑ 2 rivers (the Weisse Elster (4th) and Bode (6th) river)
- ❑ 5 reaches

Methods

Study reaches

Various reach features

Reach	River	Length (m)	Width (m)	Sinuosity	Slope (‰)	River morphology status[1]& surrounding landscape[2]
WE_1	Weiße Elster	6280	23	1.20	0.5	Strongly modified and straightened; intensive arable land
WE_2	Weiße Elster	6100	23	2.65	0.89	Slightly modified and remains meandering; permanent grassland
BD_1	Middle Bode	7170	17	1.44	0.6	Slightly modified; considerable riparian forest and grassland
BD_2	Middle Bode	3360	17	1.24	0.6	Slightly to moderately modified; arable land with some forest
BD_3	Lower Bode	6150	20	1.12	0.036	Completely changed; intensive arable land

Methods

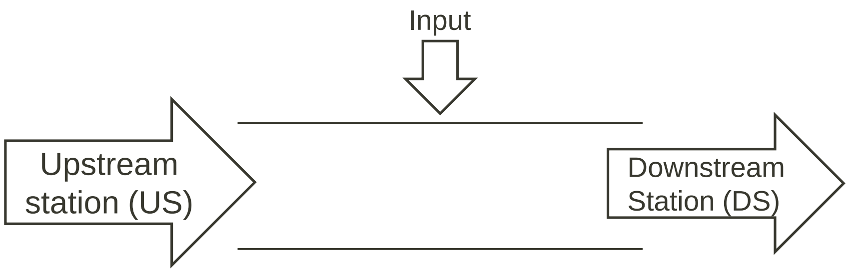
Study reaches and monitoring set-up

- ❑Multi-parameter and UV sensor at US and DS
- ❑2-3 campaigns in each reach, 11 campaigns in total
- ❑3-14 days each campaign, accompanied with water samples

Reach	Deployment periods (start date - end date)	Campaigns (seasons)
WE_1	13.-16.05.2019 18.-23.09.2019	2019-05 WE_1 (post-wet) 2019-09 WE_1 (dry)
WE_2	16.-20.05. 2019 23.-26.09.2020	2019-05 WE_2 (post-wet) 2019-09 WE_2 (dry)
BD_1	17.-20.06.2019 03.-08.10.2020	2019-06 BD_1 (post-wet) 2020-08 BD_1 (dry)
BD_2	20.-24.06.2019 12.-19.08.2020 19.07.-02.08.2021	2019-06 BD_2 (post-wet) 2020-08 BD_2 (dry) 2021-07 BD_2 (transition)
BD_3	21.-26.08.2019 27.08.-03.09.2020	2019-08 BD_3 (dry) 2020-08 BD_3 (dry)

Methods
Two-station mass balance

Conceptual model of two-station mass balance method:



Multiple parameters measuring:

- Dissolved Oxygen (DO)
- Nitrate-N concentration
- Specific conductivity
- ……

Stream metabolism

- Areal **n**et **e**cosystem **p**roduction (**NEP**)
- **E**cosystem **r**espiration (**ER**)
- **G**ross **p**rimary **p**roduction (**GPP**)

Nitrate uptake pathways

- Areal net nitrate uptake (U_{NET})
- Autotrophic assimilation (U_A)
- Heterotrophic uptake ($U_D = U_{NET} - U_A = U_{den} + U_{het}$)

Methods

Detailed equations

Stream metabolism

- Areal **n**et **e**cosystem **p**roduction (**NEP**)
- **E**cosystem **r**espiration (**ER**)
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Nitrate uptake pathways

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Stream metabolism

- $NEP_t = \frac{Q_{DSt+\tau/2}[DO]_{DSt+\tau/2} - Q_{USt-\frac{\tau}{2}}[DO]_{USt-\frac{\tau}{2}} - Q_I[DO]_I - kQ_t[DO]_{deft}}{w \times L}$
- $ER_t = NEP_{nighttime,t}$
- $GPP_t = NEP_t + ER_{mean}$

Nitrate uptake pathways

- $U_{NETt} = \frac{Q_{USt-\tau/2}[NO_3^- - N]_{USt-\tau/2} - Q_{DSt+\frac{\tau}{2}}[NO_3^- - N]_{DSt+\frac{\tau}{2}}}{w \times L}$
- $U_{At} = \frac{GPP_t}{2 \times C{:}N}$
- $U_{Dt} = U_{den} + U_{het} = U_{NETt} - U_{At}$

Results

Summary of high frequency measurements for all campaigns

Parameter	WE_1		WE_2		BD_1		BD_2			BD_3	
	2019-05	2019-09	2019-05	2019-09	2019-06	2020-08	2019-06	2020-08	2021-07	2019-08	2020-08
Q (m^3 s^{-1})	9.06±0.38	4.55±0.18	8.58±0.44	4.75±0.26	2.5±0.11	1.57±0.08	2.34±0.17	1.65±0.31	1.93±0.17	1.98±0.11	2.2±0.06
T (℃)	11.84±0.97	13.09±0.5	13.29±2.1	15.17±0.41	19.52±0.7	19.3±1.39	19.35±0.47	20.65±0.64	18.54±1.11	18.56±0.78	16.74±0.24
N (mg l^{-1})	3.84±0.05	3.85±0.13	3.62±0.11	3.51±0.05	1.76±0.03	1.23±0.05	1.65±0.05	1.22±0.08	1.73±0.09	1.23±0.06	1.01±0.06
DO (mg l^{-1})	10.86±0.54	10.33±0.3	10.84±0.82	9.99±0.73	8.68±0.45	8.59±0.37	8.77±0.35	8.16±0.37	8.82±0.41	9.32±1.18	9.45±0.54
Turb (FNU)	1.91±0.23	1.53±0.16	1.78±0.11	1.52±0.17	3.84±0.17	1.8±0.22	4.21±0.44	2.11±0.58	4.05±0.61	1.2±0.14	1.2±0.11
pH	8.13±0.08	8.44±0.05	8.26±0.1	8.65±0.06	8.25±0.07	7.97±0.04	8.23±0.05	7.88±0.05	8.01±0.05	8.15±0.11	8.03±0.06
SpCond (µS cm^{-1})	850.5±52.5	1224.4±39.0	1051.9±32.1	1337.6±16.1	727.5±6.5	733.0±23.5	822.6±21.6	789.0±48.6	768.6±32.9	1094.1±12.5	1169.9±31.6
Chl-a (µg l^{-1})	4.19±0.57	2.72±0.47	2.63±0.45	3.2±0.26	2.12±0.15	2.84±0.58	2.19±0.13	2.8±0.6	1.35±0.13	4.46±0.85	2.57±0.13
τ (h)	5	7	4.5	6	8	14	3.5	4.5	4	14	15.5
v (m s^{-1})	0.35	0.25	0.38	0.28	0.25	0.14	0.27	0.21	0.23	0.12	0.11

- Large differences between the individual campaigns

Results

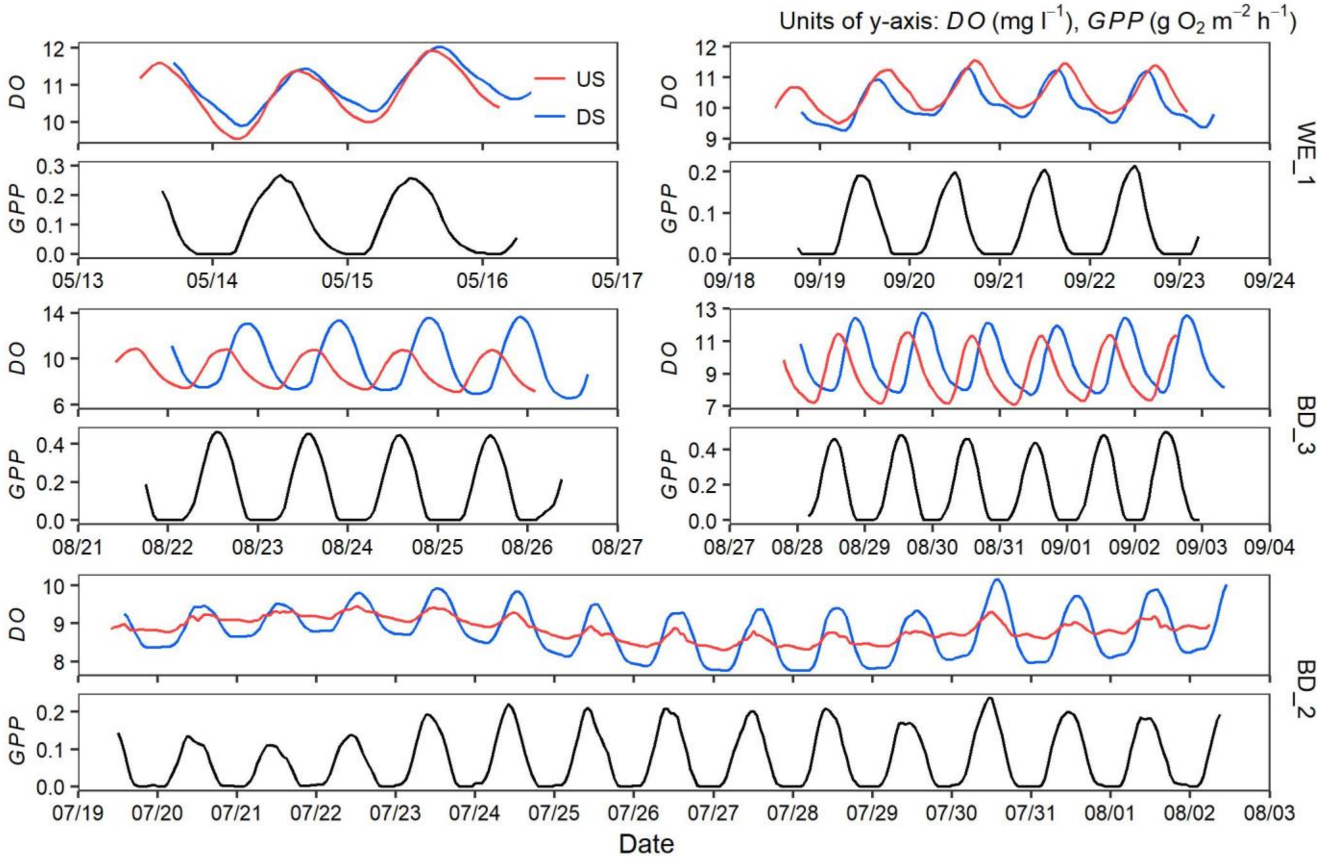
Daily results of whole-stream metabolism and in-stream N uptake processes

Process	Units	WE_1		WE_2		BD_1		BD_2			BD_3	
		2019-05	2019-09	2019-05	2019-09	2019-06	2020-08	2019-06	2020-08	2021-07	2019-08	2020-08
GPP	$g\ O_2\ m^{-2}\ d^{-1}$	2.7	1.7	2.8	2.2	0.8	0.7	1.6	1.1	1.8	4.1	4.6
ER	$g\ O_2\ m^{-2}\ d^{-1}$	-1.6	-2.5	-1.2	-3.6	-3.3	-1.6	-3.7	-2.0	-2.5	-2.3	-3.2
U_{NET}	$mg\ N\ m^{-2}\ d^{-1}$	-151.1	-30.5	319.6	33.7	-100.8	-61.2	357.8	53.6	130.9	133.7	86.8
U_A	$mg\ N\ m^{-2}\ d^{-1}$	83.9	41.1	86.4	53.0	18.6	16.4	37.1	24.7	40.9	95.2	106.1
U_D	$mg\ N\ m^{-2}\ d^{-1}$	-235.0	-71.5	233.2	-19.3	-119.4	-77.6	320.7	28.8	90.0	38.5	-19.3

Green indicates more natural morphological stream conditions
Grey indicates modified morphological stream conditions

Measuring and Calculation

DO concentration and gross primary production (GPP)

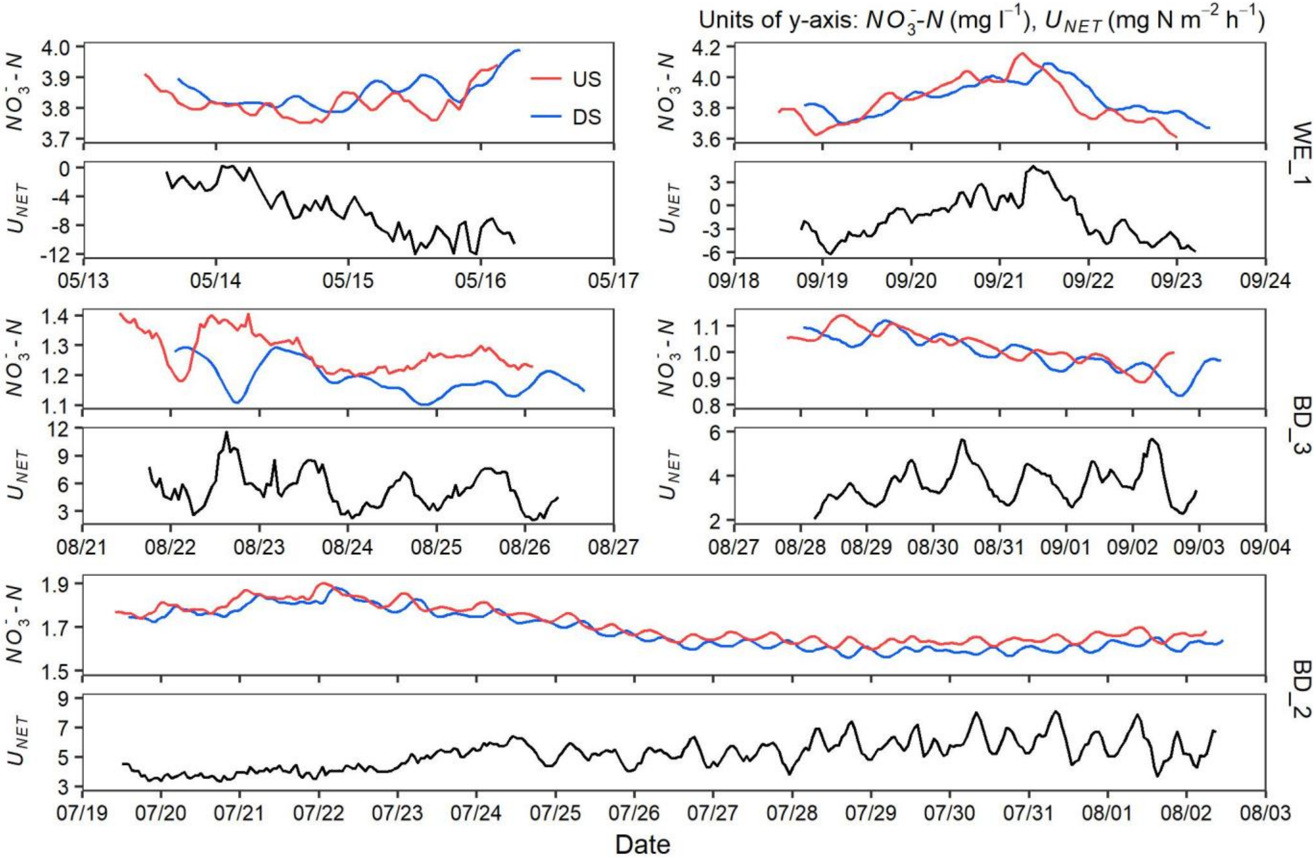


Stream metabolism

- strong diel pattern of DO
- consistent GPP diel signals with large variation between individual campaigns

Measuring and Calculation

Nitrate-N concentration and net uptake (U_{NET})

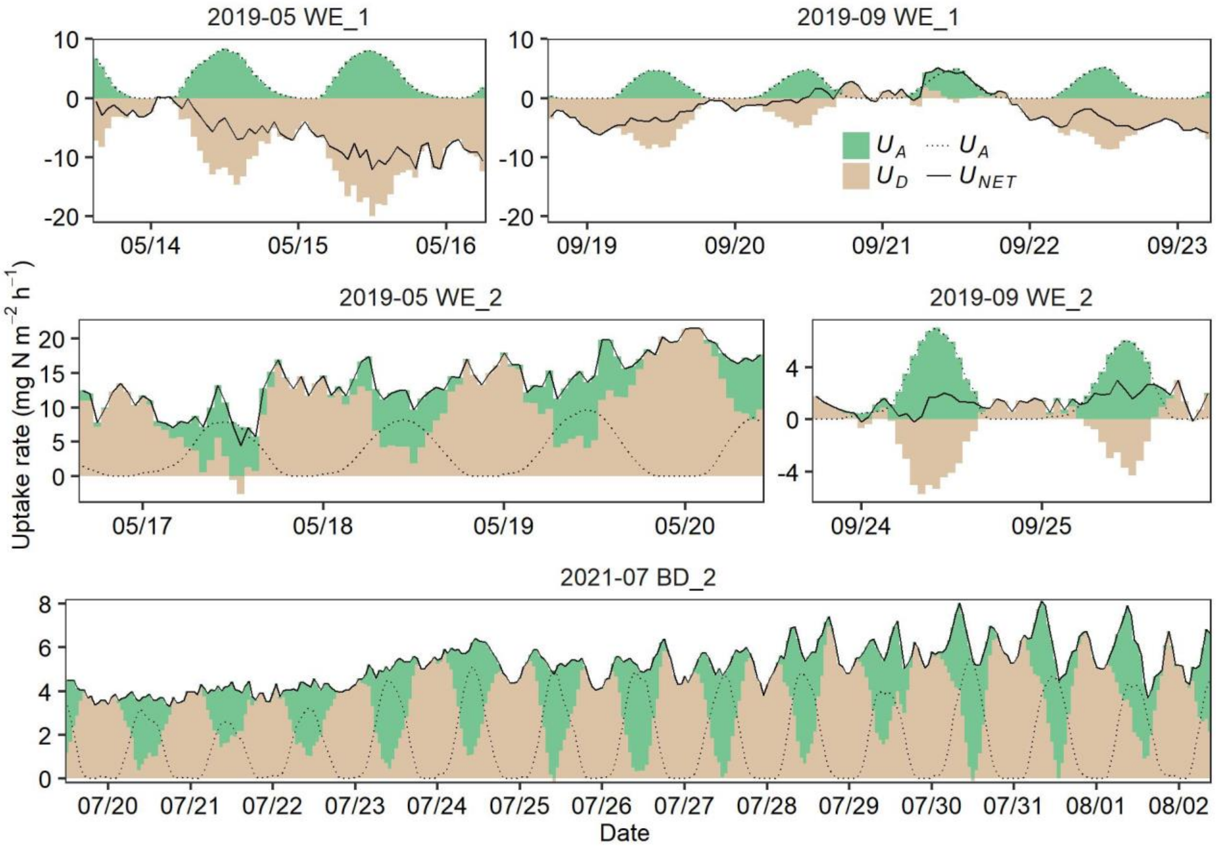


Nitrate uptake

- lack of diel pattern of NO_3^--N concentration
- U_{NET} varied strongly between reaches and between campaigns in the same reach

Results and discussion

Variations in nitrate uptake pathways



Variations of U_{NET}

- highest (post wet) → lowest (dry)
- Natural > Modified

For U_{NET} > 0

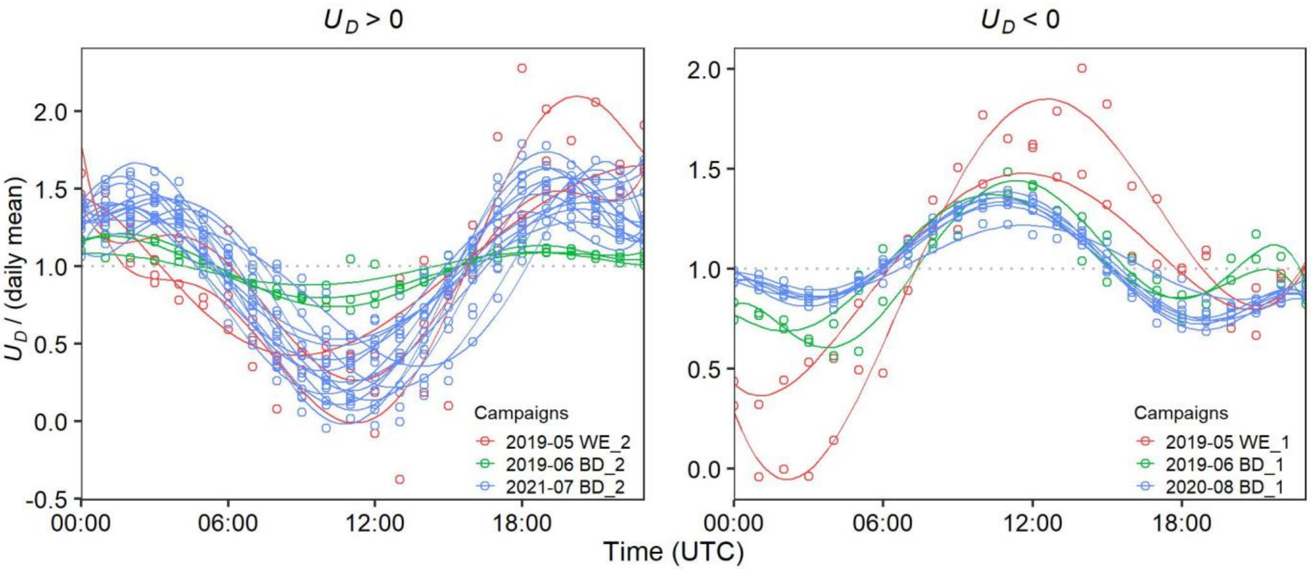
- Post-wet seasons, U_{NET} was dominated by U_D (abundant liable organic matters)
- Dry seasons, diurnal U_D shift between uptake and release

For U_{NET} < 0

- post-wet seasons > during dry seasons

Results and discussion

Diel patterns of heterotrophic uptake (U_D)



Decreasing diel pattern

Higher day-time release

The **relative magnitude** of diel variation was largely consistent **within a campaign** and similar **across reaches and seasons**.

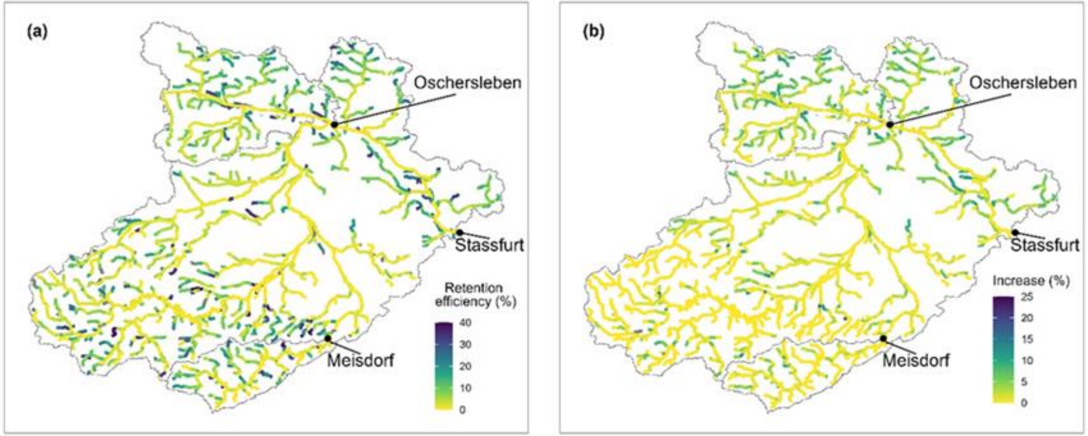
Key points

- Two-station mass balance methodology can
  - Upscale nitrate uptake measurements in heterogenous high-order streams
  - Disentangle nitrate uptake pathways in systems with unstable upstream boundary
  - Explore their temporal dynamics
- Net nitrate uptake exhibits high variations seasonally and across reach conditions, with cases of consistent net release
- Heterotrophic nitrate uptake and release were higher during post-wet seasons and exhibited various diel patterns

Zhang, X., Yang, X., Hensley, R., Lorke, A. & Rode, M. (2023). Disentangling in-stream nitrate uptake pathways based on two-station high-frequency monitoring in high-order streams. Water Resources Research, 59(3), e2022WR032329. https://doi.org/10.1016/j.jhydrol.2020.125585

Outlook

- Studies such as these can provide pathway-specific quantification of heterotrophic uptake (U_D)
- Heterotrophic uptake (U_D) measurements are still rare at larger scale
- Results can help parameterization of stream network N uptake models



Summer NO_3^- retention efficiency increases from

a) baseline to

b) stream restauration scenario