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Spatial Stability of Water Quality in the Lake Okeechobee Watershed

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What is spatial stability and why should we study it?

Spatial stability: spatial patterns of water chemistry maintained over time.

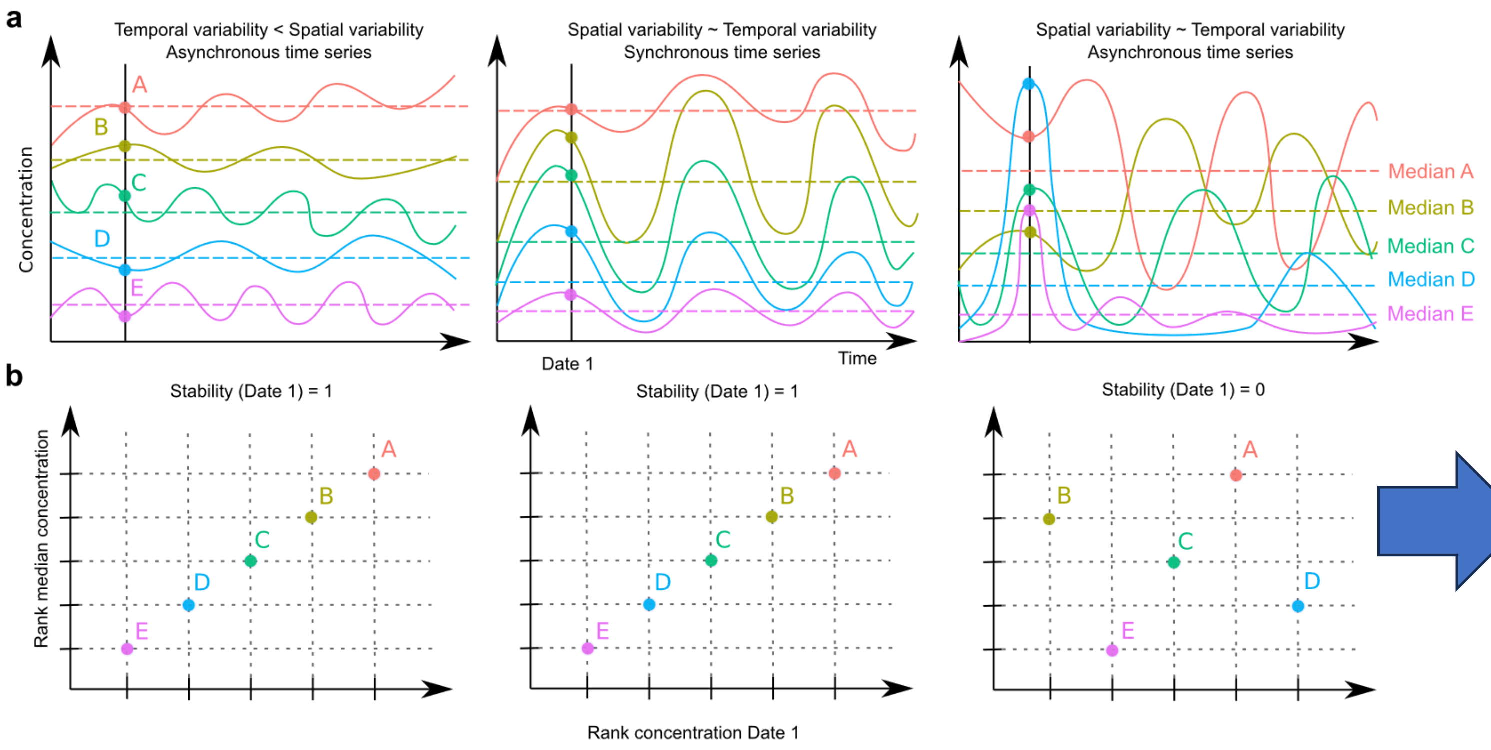

Fig.1. Conceptual diagram of how spatial stability in water chemistry could result from high spatial variability or high temporal synchrony. (a) Three concentration time series for five sites (A–E). (b) Spatial stability for the three depicted scenarios.
(Source: Dupas et al. 2019, Environmental Research Letters)

If spatial patterns are stable, infrequent samples can provide representative information about water chemistry dynamics (e.g., hotspot locations always have higher concentrations than others).

References:
Abbott et al. 2018, Ecology Letters;
Dupas et al. 2019, Environmental Research Letters;
Wheeler and Ledford 2023, Hydrological Processes

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Research question(s)

- Are the water quality patterns <u>stable</u> in the stream network of the Northern Lake Okeechobee (NLO) watershed?

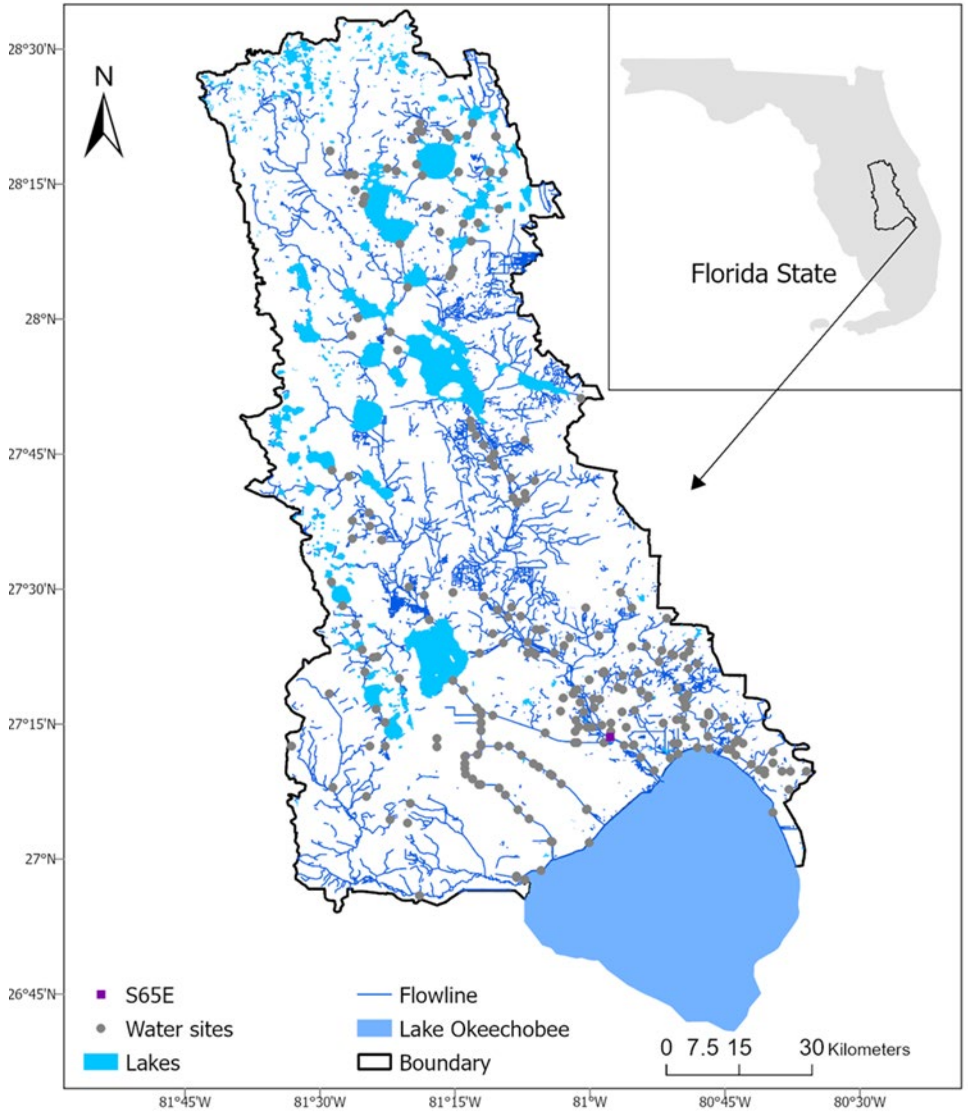

Fig. 2. Map of stream network and water quality sampling sites in the NLO watershed.

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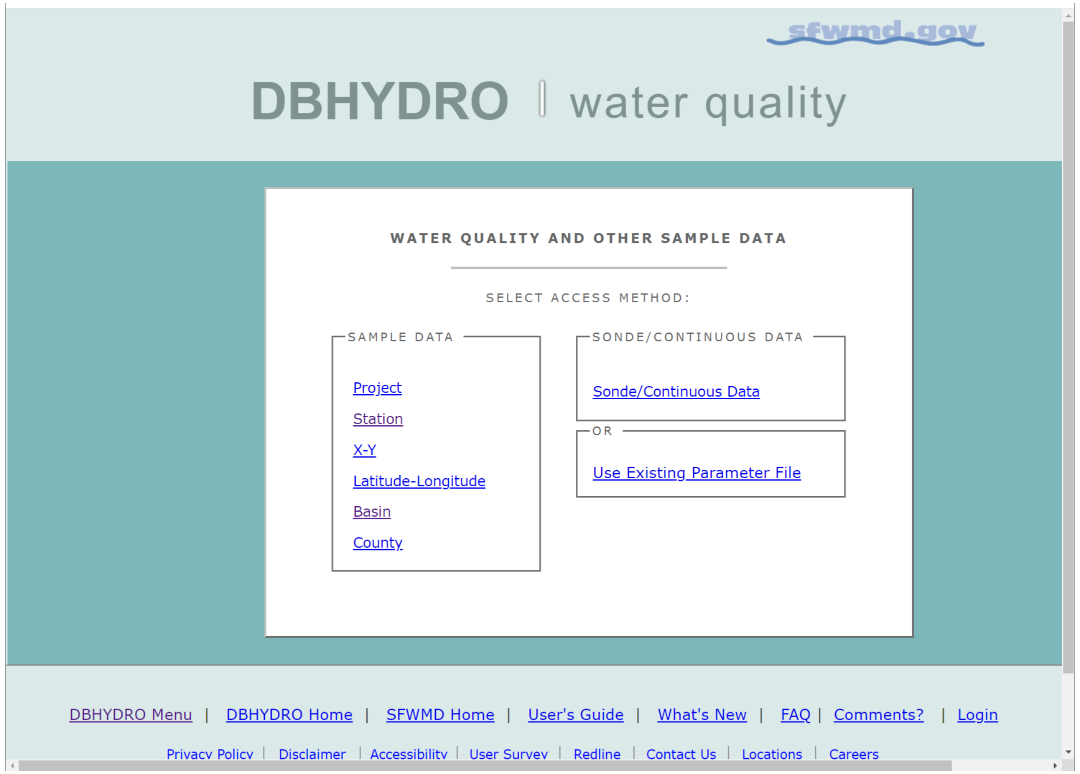
Water quality study is rooted in the Dbhydro database.

https://www.sfwmd.gov/science-data/dbhydro



- **Criteria:**
  last 2 decades (July 2003-June 2023), sampled at least 3 months, at least five sites in each month
- 253 sampling sites in the stream network

13 Water quality parameters

Group	Solute	Unit
Geogenic	Ca^{2+}	mg/L
	alkalinity	CaCO3 mg/L
	pH	
	EC	µs/cm
Biogenic	DO	mg/L
	TOC	mg/L
	DOC	mg/L
	chlorophyll-a	µg/L
Anthropogenic	NO_3^-	mg/L
	TP	mg/L
	PO_4^{3-}	mg/L
Hydrologic	TSS	mg/L
	Turbidity	NTU

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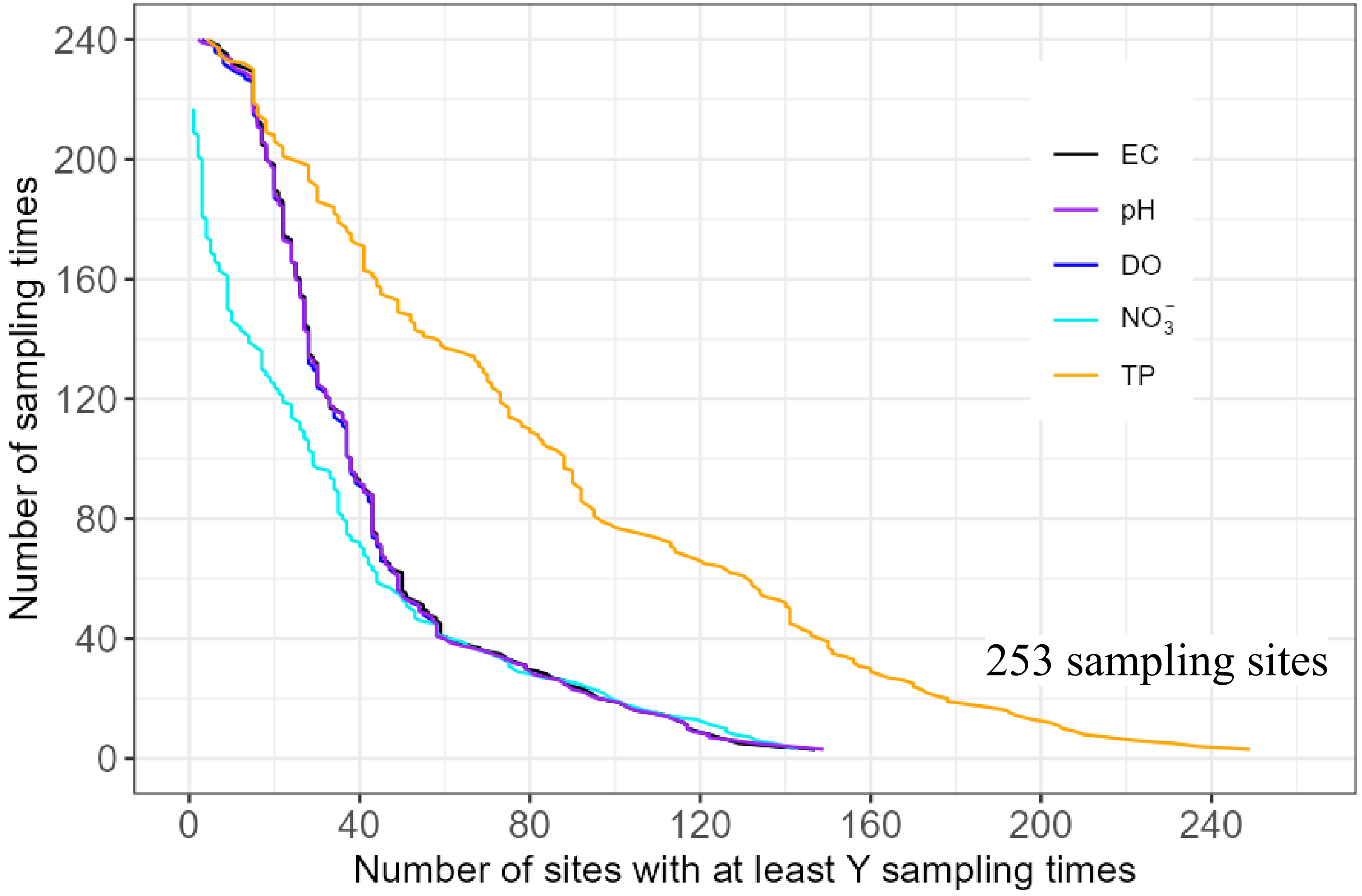
Sample locations are highly dynamic



Sampling density and frequency differed for the five water quality parameters.

Fig.3. Number of sites with at least Y sampling times of stream water quality in the NLO watershed in the 2 two decades.

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Sample locations are highly dynamic

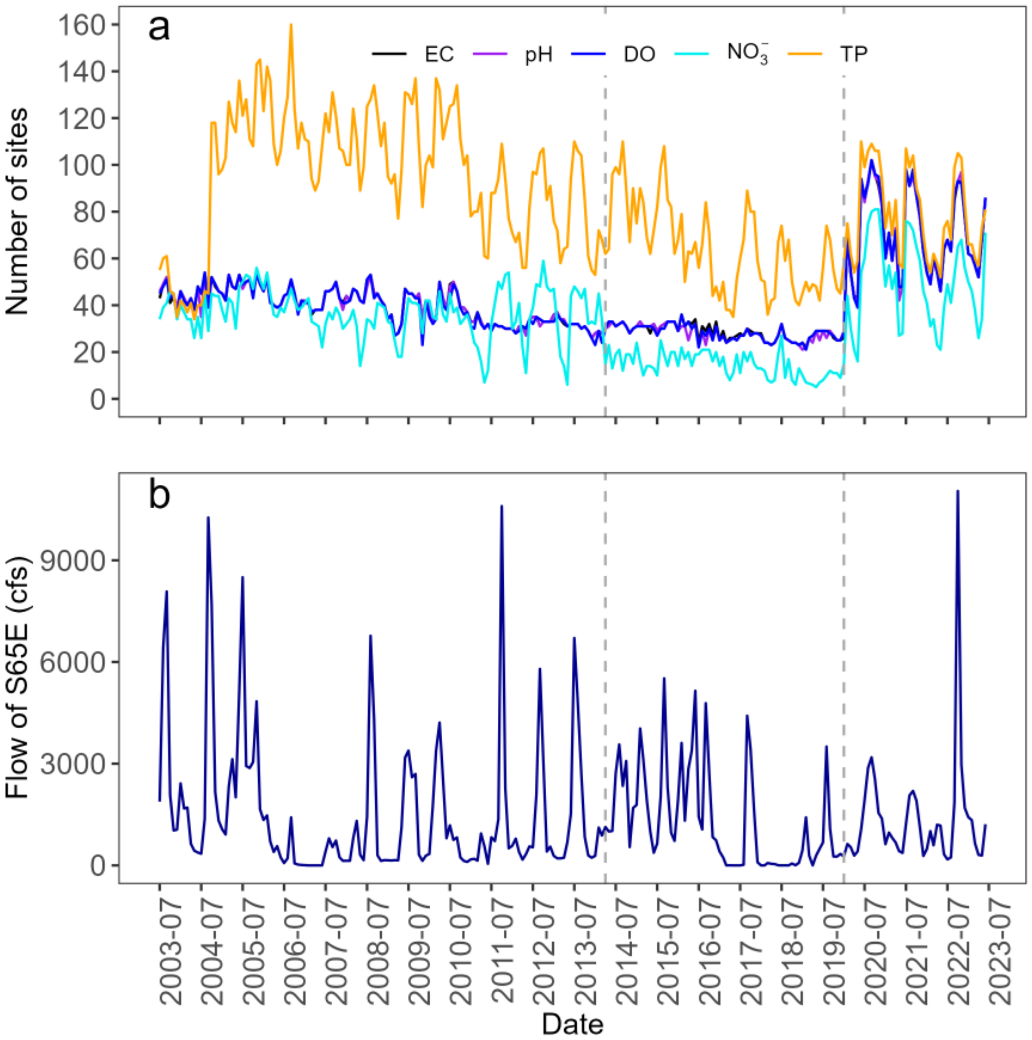

Fig.4. The stream water quality sites (a) for five water parameters (dashed lines are the dates of April 2014 and Jan 2020, respectively) and the flow of S65E gage (b) in each month.

- In each sampling month, the number of sampling sites varied considerably.
- Of 253 total sampling sites, a maximum of 160 were sampled within the same month.
- Previous stability analyses were conducted only with the same sites consistently sampled over time.

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Research question(s)

- Is it possible to accurately describe water quality patterns in the watershed with <u>infrequent</u>, spatially extensive water samplings?

Methods

- Spatial Stability (Spearman's rank correlations):

$$r_{ss} = rcorr(c_t, c_{mean})$$

c_t is the concentration of individual sites at date t and c_{mean} is the concentration across time. The threshold of r_{ss} is 0.50. r_{ss}>=0.50 means that concentrations are generally spatially stable.

- Spatial coefficient variation (CV) :

$$\text{Spatial } CV = \frac{\sigma_t}{\mu_t}$$

t is the date, σ is the standard deviation, and c is the mean concentrations at this date for all the sites.

- Temporal coefficient variation (CV) :

$$Temporal\ CV = \frac{\sigma_S}{\mu_S}$$

s is the site, σ is the standard deviation, and c is the mean concentrations at this site for all the dates.

References:

Abbott et al. 2018, Ecology Letters;
Gu et al., 2021, Water resource Research;
Shogren et al. 2022, Earth System Science Data.

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Spatial stability differs by parameters

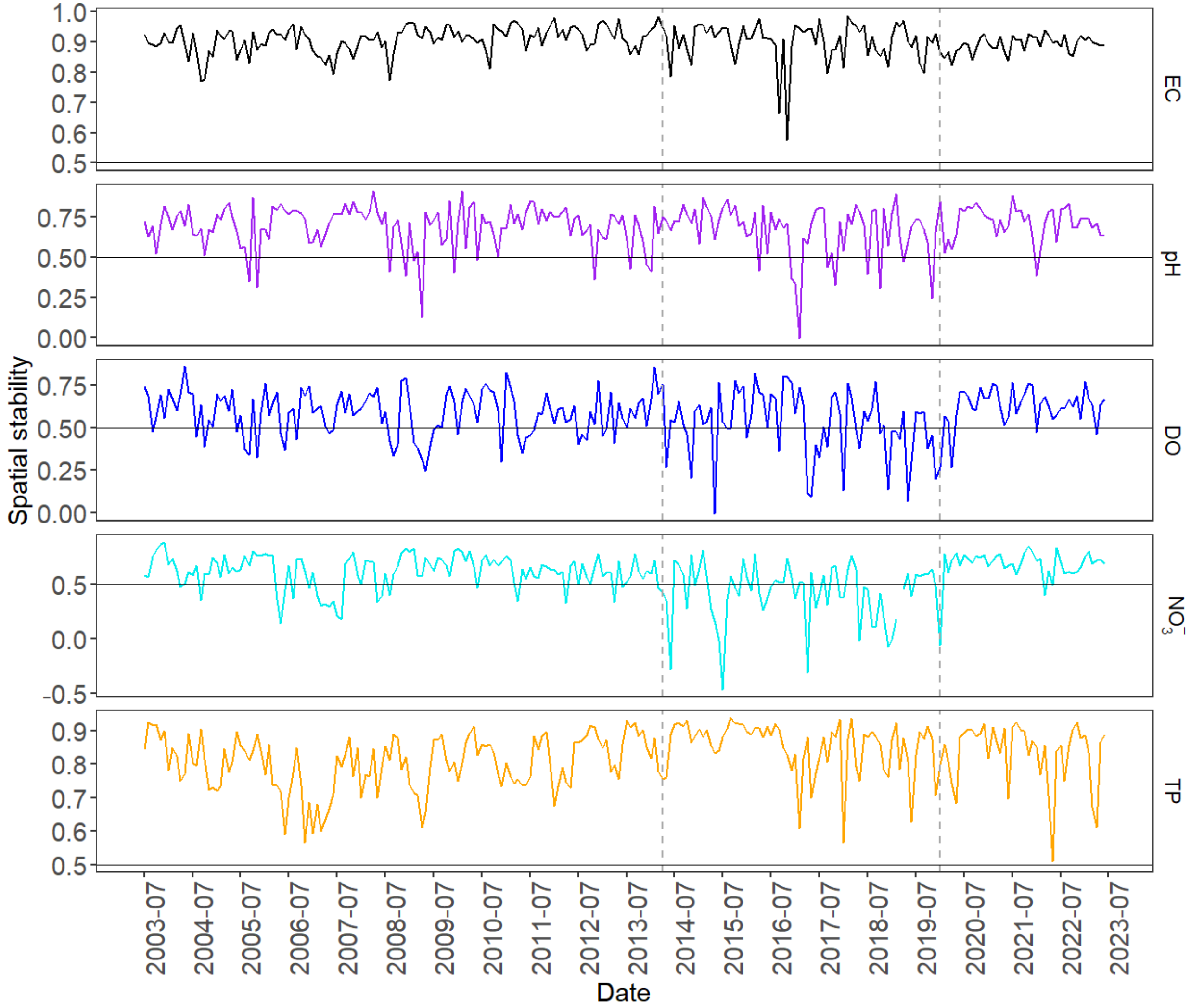

Fig.5. Spatial Stability of individual versus the mean concentration (solid lines are the threshold of r_{ss}=0.50, dashed lines are the dates of April 2014 and Jan 2020, respectively).

Spatial patterns are particularly stable for EC and TP (>0.50) .

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Spatial stability is more stable with high sampling density

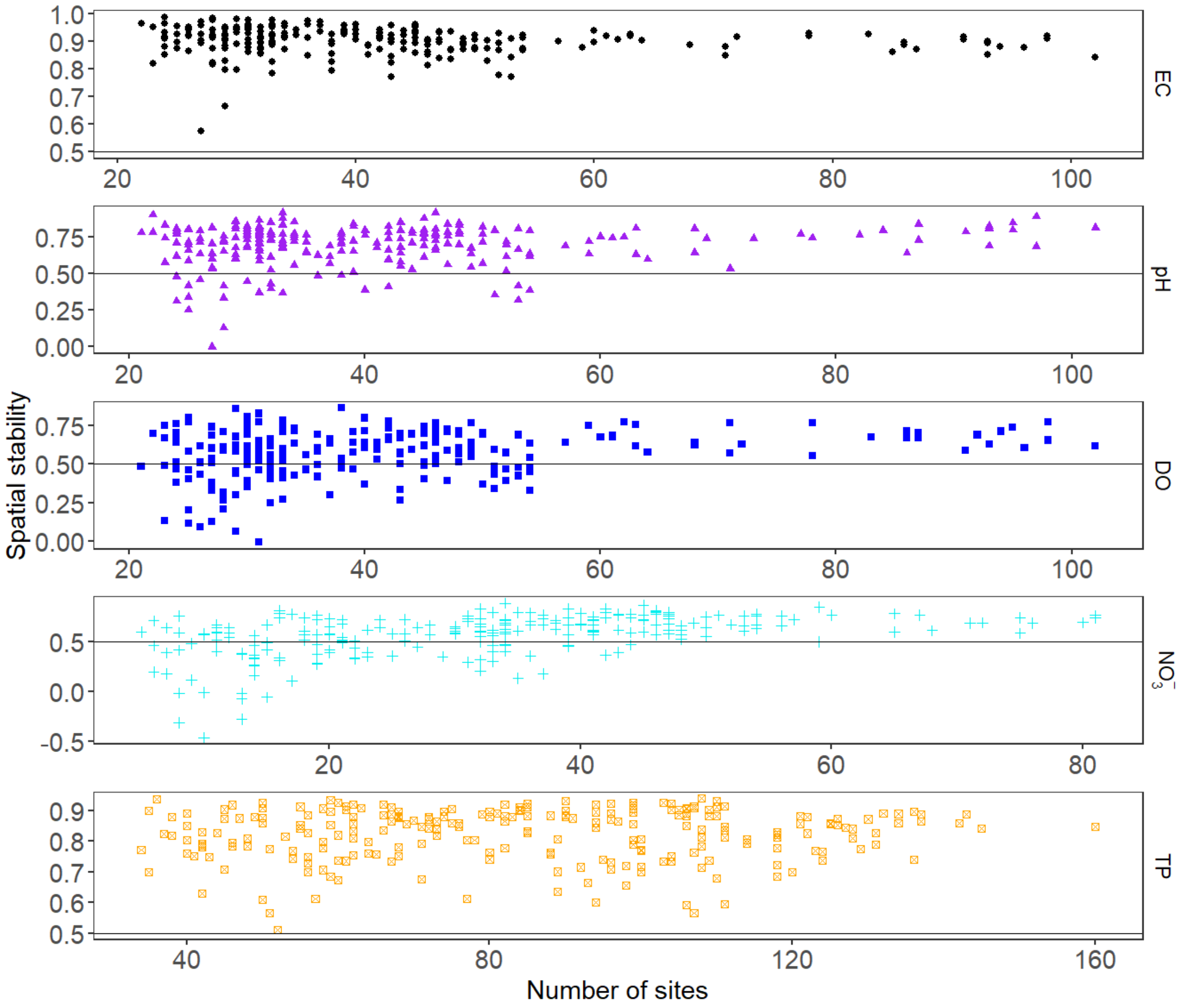

Fig.6. Comparison of spatial stability with sites, (solid lines are the threshold of r_{ss}=0.50).

Spatial stability in the NLO watershed is generally high and increases with sampling density.

Spatial stability is higher in high flow season

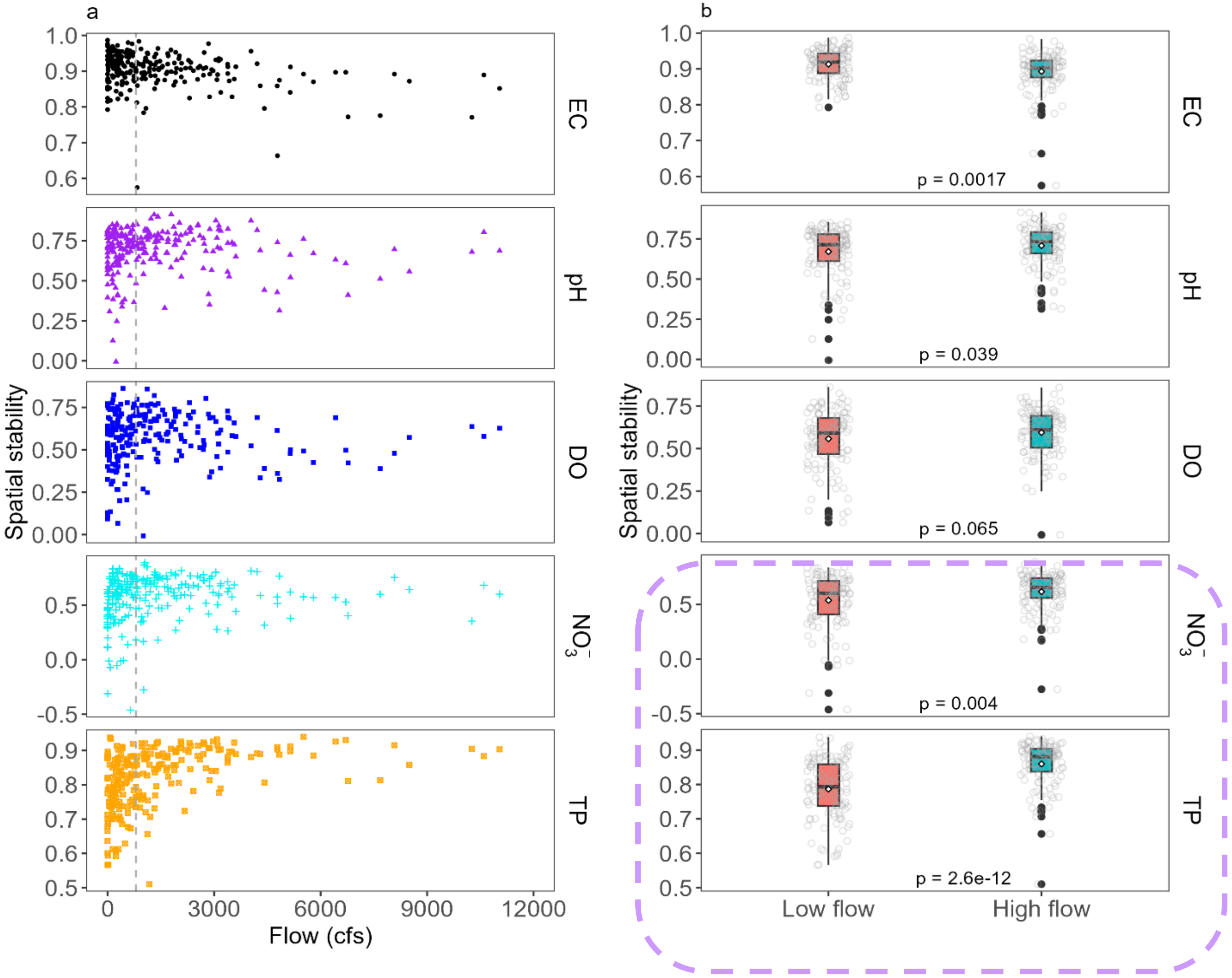

Fig. 7. Comparison of the overall spatial stability with flow conditions (a) and the spatial stability under different flow conditions (b). The dashed line is the flow under 50% exceedance probability and the white dots in the box are the mean of the spatial stability coefficient.

- Stability for TP is generally high even during low-flow season.
- But stability increases with flow, such that monitoring during these conditions provides strong representativeness of the long-term spatial structure of nutrient concentrations.

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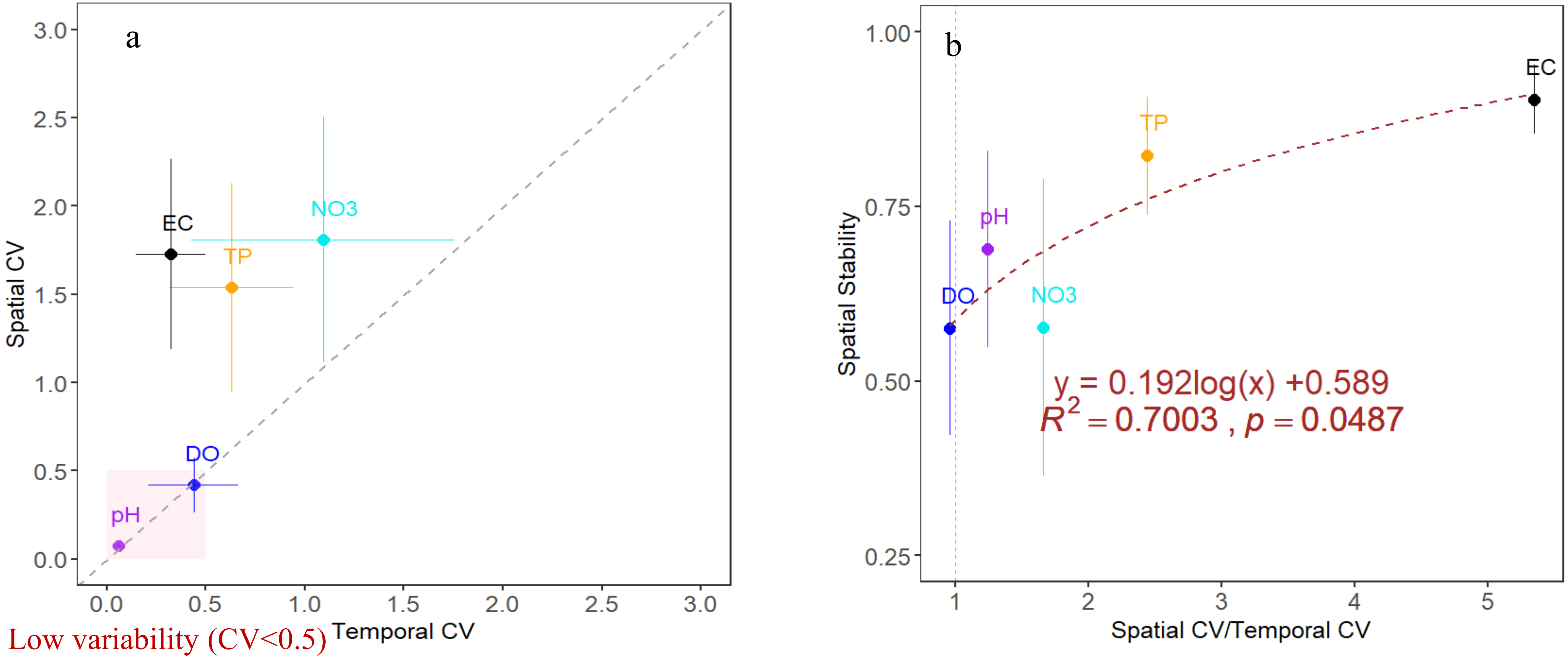
Spatial stability is attributed to higher spatial CV than temporal CV



Low variability (CV<0.5)

Fig.8. (a) Comparison of the spatial CV with mean temporal CV, (b) mean spatial stability values versus spatial CV/temporal CV. Error bas is the standard deviation.

Spatial stability results from higher spatial CV than temporal CV.

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Conclusions

Key messages of this work

- Repeated sampling of the same locations in the NLO watershed will result in similar spatial distributions of solutes, particularly for phosphorus hotspots.
- Spatial stability was strongly determined by higher spatial variation than temporal variation.
- High flow season increases the efficient identification of nutrient hotspots and restoration locations.

Implications

- High spatial stability means sample at more places, not more frequently at few locations.
- Infrequent but spatially rich sampling enables assessment of solute patterns (or nutrient fluxes and loads) at a low cost.
- Current water quality monitoring regimes can be evaluated in terms of efficiency of capturing water quality dynamics.