Understanding Alternative Stable States and Regime Shifts Between Macrophyte and Cyanobacteria Dominance

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INTRODUCTION

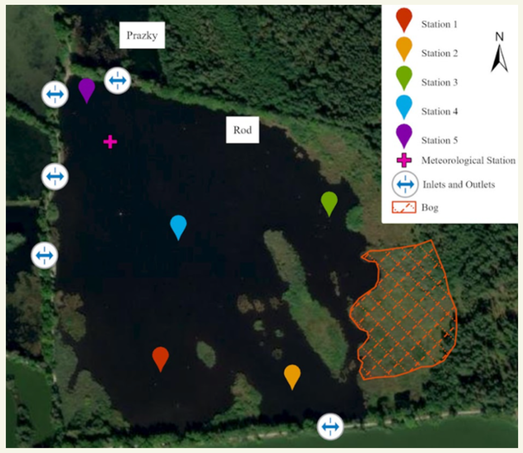
- First law of geography: "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970)
- Multiple possible stable states
  - to shift out of a stable state, it must be disrupted to the extent of reaching a tipping point
  - assumes homogeneity
  - shift may be abrupt, but not instantaneous
- Bog, inlet, and obstructions create a heterogeneous environment

Understanding the change in Rybník Rod may provide insight useful for managing it and surrounding lakes

METHODS AND DATASETS

- **Time series (June 4–July 23)**
  - daily data from 5 stations
  - algae torch (measures cyanobacteria, total chlorophyll, and turbidity)
  - YSI portable sensor (temperature, dissolved oxygen in percent and mg/L, specific conductivity, and pH)
  - phytoplankton samples (preserved using Iodine), zooplankton samples (preserved with ethanol)
  - secchi disk (light depth penetration)
- **Meteorological station (June 8–July 23)**
  - collected data on 10 minute intervals 24/7
- **Manual mapping (June 24–July 23)**
  - mapped roughly 200 locations weekly (5)
  - percent ground cover by macrophytes and primary species
  - chlorophyll and cyanobacteria

SITE DESCRIPTION: RYBNÍK ROD



Map of the site including surrounding lakes, measurement stations, inlets and outlets, meteorological station, and an estimate of the bog

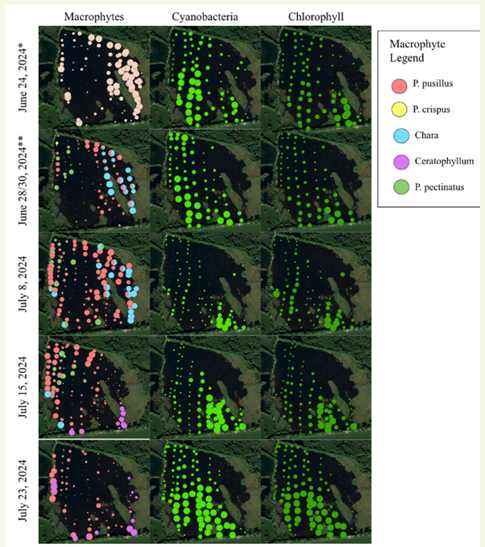
- Most Bohemian fish ponds were constructed in the 1500s
- Rod has mean depth of 0.6m
  - within a cascade of fishery ponds (Naděje), made of 14 lakes which primarily produce carp
- Trebon Fishpond district is designated as a UNESCO Man and Biosphere Reserve (Baxa et al., 2021)
  - bog has greater protections (red shading)
- Rybník Rod is the only lake managed for clear state
  - contains Pike and Zander

CONCLUSIONS

- **Macrophytes and cyanobacteria are in direct competition**
- **Spatial interactions**
  - Stations 1,4, and 5 are most similar in internal structure, are driven by primary productivity, and behave similarly
  - Station 3 is driven by the bog and Station 2 is driven by the inlet from Naděje
- **Heterogeneity in the form of patches creates resistance to smaller disturbances and external pressures (Janssen et al., 2014)**
  - a large disruption is required to fully shift states
  - when the lake shifts, it will happen patch by patch starting with the least stable
- **High precipitation and wind may flush water from the bog into the rest of the lake and damange existing macrophytes**
  - regular input from Naděje would contribute cyanobacteria giving them an advantage following a disturbance

This illustrates how heterogeneity and external pressures contribute to the resilience or transformation of aquatic systems. The patches' unique reactions highlight the importance of considering spatial variation and site-specific influences when assessing the stability and health of lake ecosystems.

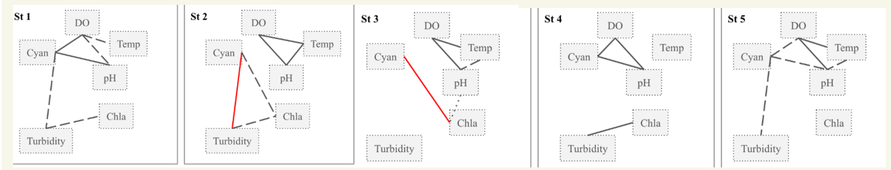
RESULTS: MACROPHYTE DISTRIBUTION

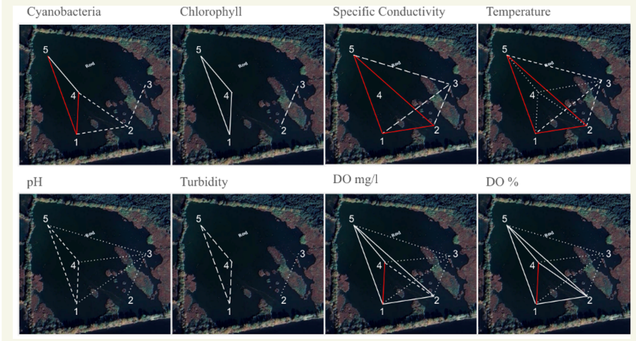


- Cyanobacteria and macrophytes are inversely present
- **Change in regime between June 30 and July 8**
  - likely large disturbance
  - reduced macrophyte population, added to cyanobacteria population, or increased the amount of nutrients past the critical point for a clear state
- **Change in the south between July 8 and July 15**
  - pressure not applied equally to the entire lake
  - greatest initial impact on bay near station 3
- Event which benefited the cyanobacteria or harmed the macrophytes to the point of a potential regime switch likely occurred
  - shoreline often had more macrophytes, possibly due to protection from wind
  - inlet adds cyanobacteria

Spatial distribution and concentration of macrophytes by percent cover and species, cyanobacteria, and total chlorophyll from June 24 to July 23, 2024

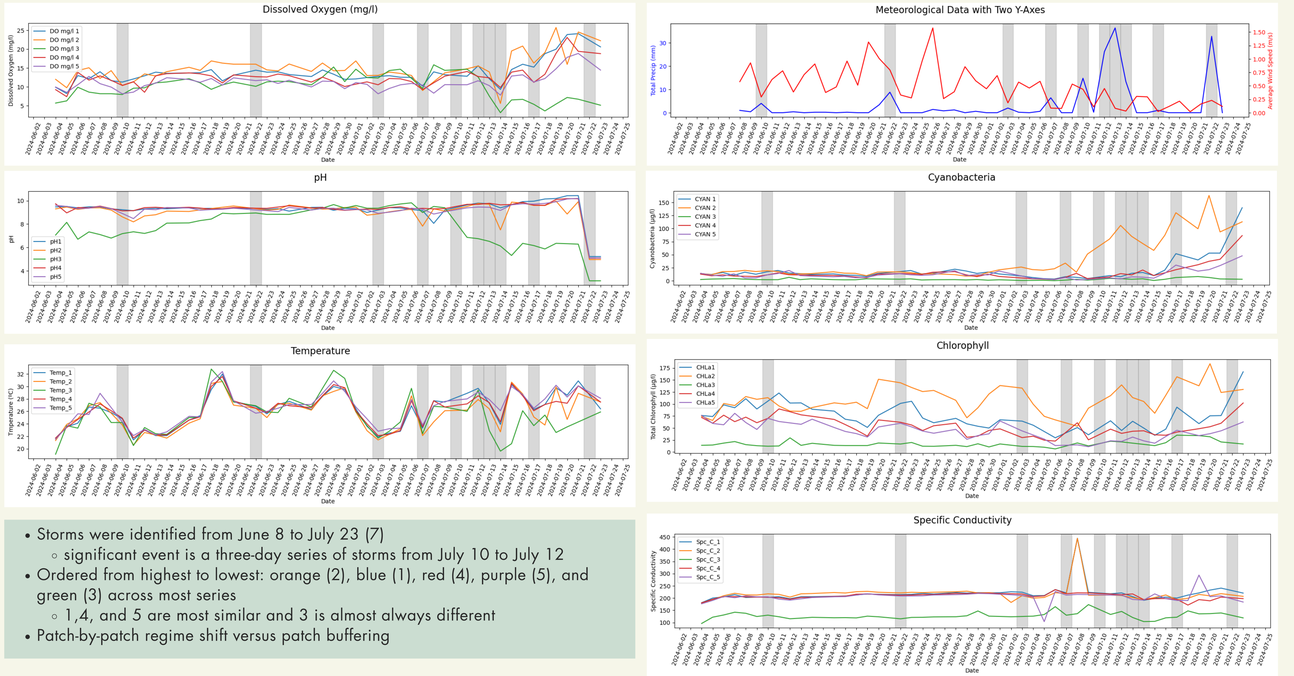
RESULTS: SPATIAL AND INTERNAL STRUCTURE





- **Stations 1/4/5**
  - Related to each other, few physical barriers between
  - Dissolved oxygen (DO) and pH correlation suggests high photosynthesis
  - connection to cyanobacteria suggests it makes up the majority of chlorophyll
- **Station 2**
  - Some relation to each of the other stations
  - DO, temperature, and pH related
  - cyanobacteria, total chlorophyll, and turbidity related
  - both suggest influence by inlet from Naděje
- **Station 3**
  - dissimilar to all other stations
  - DO and pH related to temperature suggests influence from the bog
  - Cyanobacteria makes most of the chlorophyll

RESULTS: TEMPORAL PATTERNS AND TIME SERIES ANALYSIS



- Storms were identified from June 8 to July 23 (7)
  - significant event is a three-day series of storms from July 10 to July 12
- Ordered from highest to lowest: orange (2), blue (1), red (4), purple (5), and green (3) across most series
  - 1,4, and 5 are most similar and 3 is almost always different
- Patch-by-patch regime shift versus patch buffering

Time series plots of daily measurements across five stations of chlorophyll, cyanobacteria, dissolved oxygen, turbidity, and pH. Each color represents a different station. The grey bars represent peaks in precipitation.

Schematic of correlation coefficients from pairwise correlations of each metric between every station and within each station. A solid red line represents r>0.90, a solid white line represents 0.89>r>0.80, a dashed white line represents 0.79>r>0.75, and a white dotted line represents any negative r-value.

REFERENCES

Baxa, M., Musil, M., Kummel, M., Hanzlík, P., Tesařová, B., & Pechar, L. (2021). Dissolved oxygen deficits in a shallow eutrophic aquatic ecosystem (fishpond) – Sediment oxygen demand and water column respiration alternately drive the oxygen regime. Science of the Total Environment, 766. https://doi.org/10.1016/j.scitotenv.2020.142647

Janssen, A. B. G., Teurlincx, S., An, S., Janse, J. H., Paerl, H. W., & Mooij, W. M. (2014). Alternative stable states in large shallow lakes? Journal of Great Lakes Research, 40(4), 813–826. https://doi.org/10.1016/J.JGLR.2014.09.019

Tobler, W. R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. 46, 234–240.

ACKNOWLEGEMENTS

Thank you to the staff of ENKI and Professor Miroslav Kummel for making this research project possible. Additional thanks to the Colorado College Environmental Science Department for their support and to Lucy Hylton and Emily Marple for their field collaboration