Vertical habitat gradients: Comparing seasonal dynamics of chlorophyll *a* fluorescence in lakes driven by dissolved organic carbon concentration

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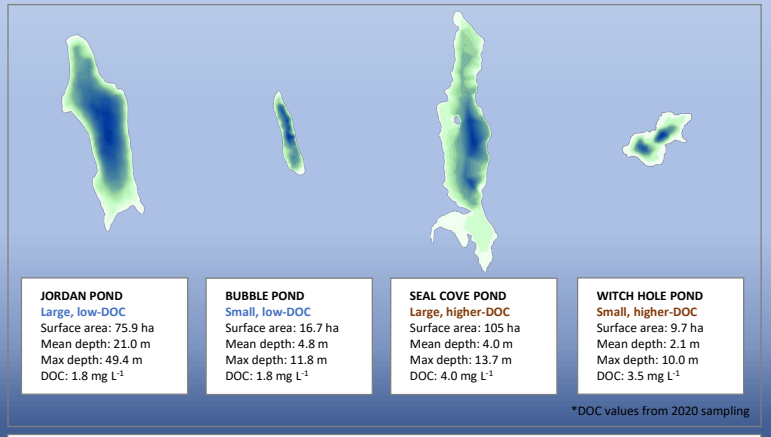
INTRODUCTION

Lakes of the northeastern United States underwent several decades of increases in dissolved organic carbon (DOC) concentration (Monteith et al. 2007). High-DOC lakes (> 5 mg L^{-1}) are often brown in color, resulting in decreased water clarity, higher light attenuation, and warmer surface waters. In the past decade, DOC trends in lakes of Acadia National Park (ANP) have diverged, with some lakes decreasing in DOC concentration while others remain increasing (Fig. 1). To understand the ecological consequences of changing DOC concentration, we compared the seasonal changes of vertical chlorophyll *a* profiles in low-DOC lakes to that of higher-DOC lakes. We predicted that the low-DOC lakes would undergo less seasonal change compared to the higher-DOC lakes, from under-ice through the open water season. Low-DOC lakes are clearer, allowing for deeper light penetration, and thus more vertical heterogeneity of habitat availability for phytoplankton.

METHODS



JORDAN POND
Large, low-DOC
Surface area: 75.9 ha
Mean depth: 21.0 m
Max depth: 49.4 m
DOC: 1.8 mg L^{-1}

BUBBLE POND
Small, low-DOC
Surface area: 16.7 ha
Mean depth: 4.8 m
Max depth: 11.8 m
DOC: 1.8 mg L^{-1}

SEAL COVE POND
Large, higher-DOC
Surface area: 105 ha
Mean depth: 4.0 m
Max depth: 13.7 m
DOC: 4.0 mg L^{-1}

WITCH HOLE POND
Small, higher-DOC
Surface area: 9.7 ha
Mean depth: 2.1 m
Max depth: 10.0 m
DOC: 3.5 mg L^{-1}

*DOC values from 2020 sampling

Four lakes in Acadia National Park were sampled through the ice in February 2020, and bi-weekly from May until November 2020. Vertical profiles of chlorophyll *a* fluorescence, a proxy for relative algal biomass, were measured. Water samples were collected at three depths and filtered for extracted chlorophyll *a* biomass. Secchi depth was recorded by lowering a Secchi disk into the water until no longer visible.

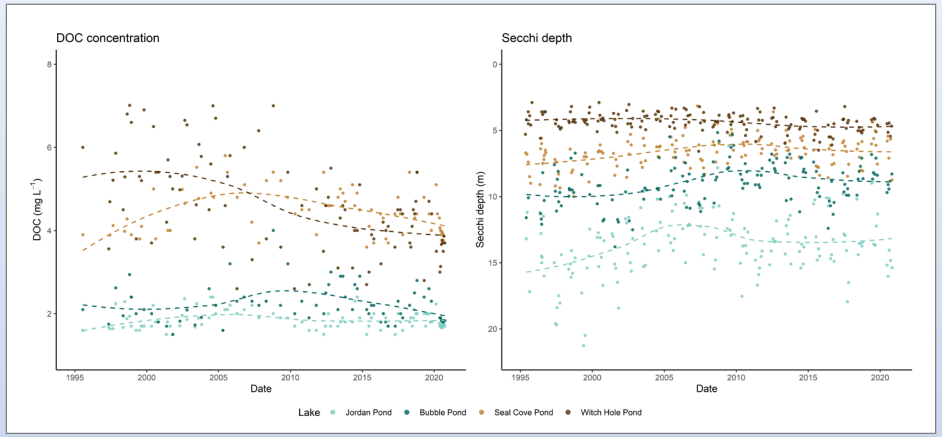


Figure 1. Long-term trends of DOC concentration and Secchi depth for each study lake. 1995-2019 data from Acadia National Park Service. 2020 data from bi-weekly sampling.

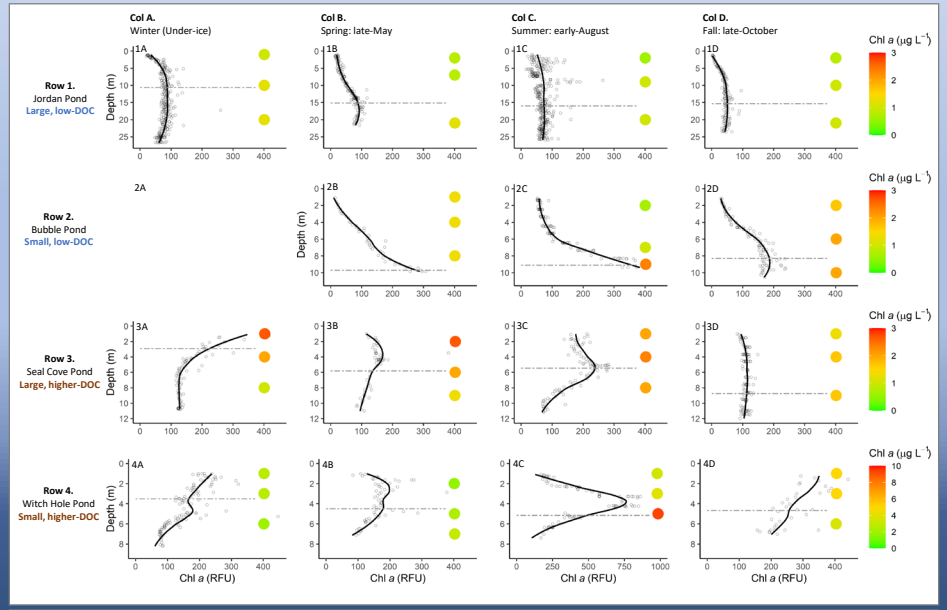


Figure 2. Vertical profiles of chlorophyll *a* fluorescence (RFU) for each lake (rows) from a sampling event in each season (columns), with extracted chlorophyll *a* biomass (µg L^{-1}) for top, middle, and bottom depths on right-hand side of each plot. Dashed horizontal lines indicate Secchi depth from nearest date (data provided by Acadia NPS). Rows 1 and 2 are low-DOC lakes (~2 mg L^{-1}) and rows 3 and 4 are higher-DOC lakes (~4 mg L^{-1}). Note that the color scale for extracted chlorophyll *a* is the same for the top three lakes but is different for Witch Hole Pond. Also note that the scale for chlorophyll *a* RFU is the same for all plots except for plot 4C. Data unavailable for 2A.

RESULTS

- Lower seasonal change of chlorophyll *a* fluorescence profiles in low-DOC lakes than in higher-DOC lakes.
- Greater vertical heterogeneity and less seasonal change of extracted chlorophyll *a* biomass in low-DOC lakes than higher-DOC lakes.
- More variable formations of a deep chlorophyll maxima (DCM) in higher-DOC lakes.
- Secchi depth was often lower than the DCM in these instances.

DISCUSSION

1. Large degree of difference at low DOC concentrations

There were pronounced differences in the seasonal changes of vertical chlorophyll *a* profiles between low- and higher-DOC lakes despite the DOC concentrations of each study lake being less than what is considered moderate (5 mg L^{-1}). This finding indicates that ecological conditions can vary substantially between lakes that differ only slightly at relatively low-DOC concentrations.

2. Lower vertical heterogeneity in higher-DOC lakes

Higher-DOC lakes had more variable vertical habitat gradients, resulting in more seasonal shifts in the depth of the DCM. DCMs in stratified lakes contribute to a large portion of total ecosystem productivity, and their spatial and temporal characteristics can indicate changes in key environmental drivers such as DOC concentration (Lofton et al., 2020).

3. DOC effects outweigh lake bathymetry effects

Both the deep and shallow low-DOC lakes showed less seasonal change than both higher-DOC lakes. While there was no higher-DOC lake as deep as Jordan Pond in this study, the overlapping bathymetry characteristics of the other three lakes reveal that the effects of DOC concentration were more impactful than the effects of bathymetry.

ACKNOWLEDGEMENTS
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REFERENCES
Monteith DT et al. (2007) Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature*, 450: 537-540.
Lofton ME et al, (2020) Relative importance of top-down vs. bottom-up control of lake phytoplankton vertical distributions varies among fluorescence-based spectral groups. *Limnology & Oceanography*, 65:10, 2485-2501.