Can coloration of Western Alaskan lakes in satellite imagery be used to predict biological, chemical, and/or physical properties?

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Spectral lake data correlate with environmental properties; lakes of similar colorations tend to have similar properties.

Introduction

Yukon Kuskokwim Delta (YK)

- One of the largest river deltas in the world, containing over 100,000 lakes with ~63% of lakes less than 10 hectares.
- Supports the highest concentration of indigenous subsistence users and one of the most productive avian habitats in North America.
- Vulnerable to climate change e.g., sea-level rise, storm surges, permafrost degradation, and lake drainage.
- YK Delta is inaccessible to people for large-scale continuous in situ monitoring, causing patchiness in spatial and temporal data.

Lakes

- At regional and global scales, small lakes are typically overlooked due to their size, however they are vital aquatic ecosystems and play an essential role in carbon and nutrient cycling.
- Lakes are intimately connected to surrounding geology, catchment area, and vegetation which can impact water quality and coloration (Fig. 1).
- On satellite imagery, lakes in the YK Delta have a wide range of colorations ranging from brown, green, grey, white, to teal.

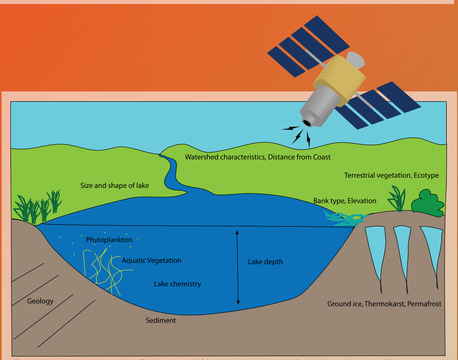

Figure 1. Diagram depicts the cross-section of a lake and potential factors that can impact water quality and the water-leaving signal. The satellite represents Sentinel-2.

Remote sensing

- Freshwater ecosystems are difficult to map spectrally because they are often smaller in size and not detected by older satellite technology.
- High concentration of components in water can affect the water-leaving signal. Such components include: Chromophoric Dissolved Organic Matter (CDOM), floating and submerged aquatic vegetation, phytoplankton, suspended particulate matter, sediments, seasonality, and lake depth (Fig. 2).
- If spectral data can be correlated with lakes biological, chemical, and physical properties; remote sensing could be used to enhance our understanding of historical, curent, and future lake satellite imagery and potential changes in the YK Delta.

Figure 2. A satellite image mosaic of the YK Delta created using bands 2,3,4, and 8 of Sentinel-2 data (Copernicus Sentinel-2 mission, ESA). The unique coloring of the water features comes from blending via "pin-lighting" the normalized wetness index (NDWI via bands 8 NIR and 3 Green) with the natural color pixels derived from bands 4,3,2 (R,G,B). This approach allowed us to enhance the natural color differences in only the wettest portions of the image mosaic. The lakes sampled are outlined in yellow.

Methodology

- In 2022, we conducted fieldwork in the YK Delta in Alaska, sampling 16 lakes based on accessibility and unique colors (Fig. 2).
- A variety of water quality parameters, nutrients, chlorophyll a (chl a) concentrations and chromophoric dissolved organic matter (CDOM) was measured at each site.
- Lake spectral values were extracted from a satellite image mosaic of the YK Delta created using bands 2,3,4, and 8 of Sentinel-2 data (Copernicus Sentinel-2 mission, ESA). The blue (B2), green (B3), red (B4), and near-infrared (B8) bands have a 10-meter resolution allowing us to capture these small lakes (Fig. 3).
- Non-Metric Multidimensional Scaling Ordinations were run with lake spectral data and environmental properties using PRIMER v7.

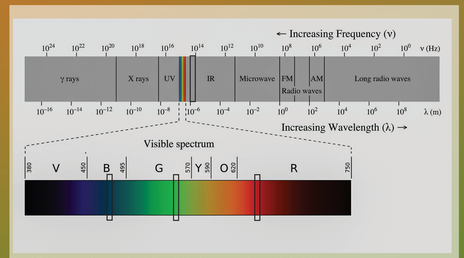

Figure 3. The electromagnetic spectrum; boxes indicate which bands were measured to create the Sentinel-2 map.

Results

- Lakes cluster by spectral data and assigned visual color; spectral band data correlate with environmental factors (Fig. 4 and Fig. 5a).
- Concentrations of CDOM align with the reflectance of Sentinel-2 Visible and Near Infrared (B8-NVIR) spectral data (Fig. 4).
- Chlorophyll a concentrations align with the Sentinel2 B2-blue and B3-green reflectance spectral data (Fig. 4).
- Concentrations of NO_3 align with Sentinel2 B4-red (Fig. 4).
- S275-295, a biomarker of terrigenous dissolved organic matter in the ocean, is negatively correlated with Sentinel-2 B8-NVIR (Fig. 4).
- 100-fold variation in lake chlorophyll A concentration, the highest in green and brown lakes and the lowest in the teal lake. (green and brown > white > gray > dark gray > teal) (Fig. 5b)
- Based on the Redfield C:N:P ratio (106:16:1) these lakes are limited by nitrate (Fig. 6a and 6b).
- The teal lake contains the lowest concentrations of nutrients, chlorophyll *a*, and DOC concentration (not shown).
- The majority of lakes are well oxygenated (not shown) and contain higher concentration of NH_4 than NO_3 (Fig. 7a).
- Almost 2-fold variation in lake pH of green lakes exhibit the highest pH (9.1-10.1), and brown lakes the lowest pH (5.4 -5.7) (Fig. 7b).

Summary and Future Work

- We confirm that spectral data from lakes in the YK Delta correlate with some of their lake's biological, chemical, and physical properties.
- Lakes of similar colors tend to have similar properties.
- Some environmental factors correlate with specific wavelengths e.g., CDOM correlates with Sentinel-2 B8-NVIR spectral data.
- This is an exploratory study; the limited sampling does not allow for extensive statistical analysis.
- We will expand the dataset using additional lake data collected by the Polaris Project team as well as supplementary map data.
- For future studies, we recommend expanding the scope of the study to a larger region and increasing sample size and distribution of lakes across the YK Delta.

Acknowledgments

Fieldwork was conducted on the traditional Yup'ik/Cup'ik lands of the Yukon Kuskokwim Delta. We thank Gerald "JJ" Frost for providing additional map data. This work was supported by an National Science Foundation grant to the Polaris Project (Award number 1915307).

NMDS of Lakes in Western Alaska

Spectral and environmental data

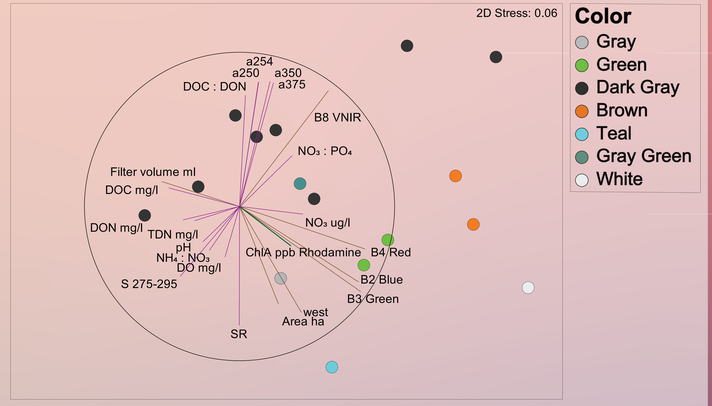

Figure 4. Non-metric multidimensional scaling (NMDS) and the ordinations below use Bray-Curtis similarity matrix. This NMDS shows the clustering of lakes based on spectral data and the correlation with physical (brown), chemical (purple), and biological (green) properties (Pearson correlation > 0.3).

NMDS of Lakes in Western Alaska

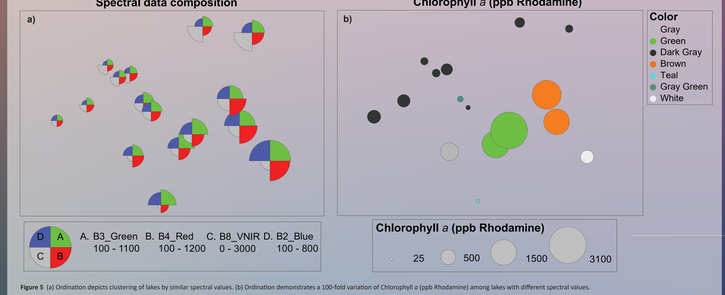

Figure 5 (a) Ordination depicts clustering of lakes by similar spectral values. (b) Ordination demonstrates a 100-fold variation of Chlorophyll *a* (ppb Rhodamine) among lakes with different spectral values.

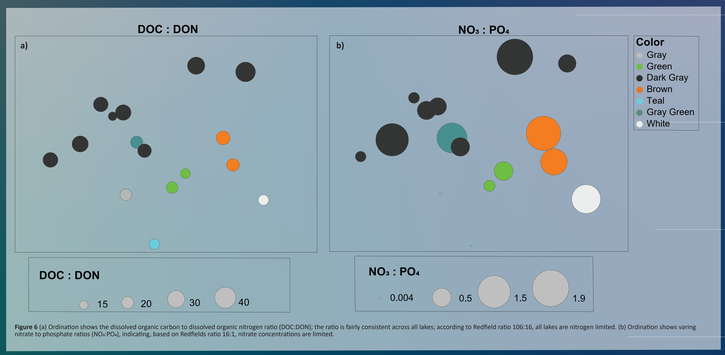

Figure 6 (a) Ordination shows the dissolved organic carbon to dissolved organic nitrogen ratio (DOC:DON); the ratio is fairly consistent across all lakes; according to Redfield ratio 106:16, all lakes are nitrogen limited. (b) Ordination shows varing nitrate to phosphate ratios (NO_3:PO_4), indicating, based on Redfields ratio 16:1, nitrate concentrations are limited.

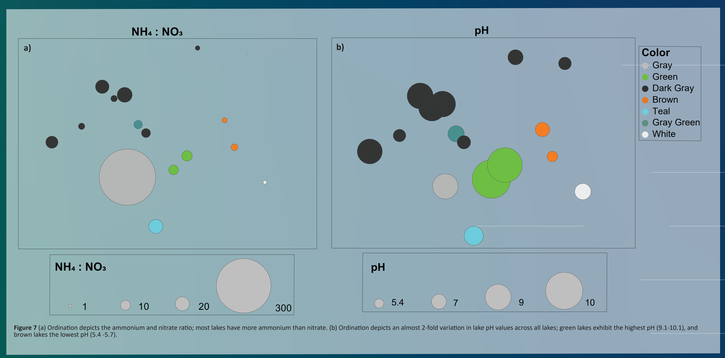

Figure 7 (a) Ordination depicts the ammonium and nitrate ratio; most lakes have more ammonium than nitrate. (b) Ordination depicts an almost 2-fold variation in lake pH values across all lakes; green lakes exhibit the highest pH (9.1-10.1), and brown lakes the lowest pH (5.4 -5.7).