Potential Environmental Drivers of Algal Blooms & Utility of LANDSAT characterization of the James River

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Introduction

Research Question

- What environmental factors are driving algal bloom?
- What is the efficacy of LANDSAT 8 data in characterizing blooms?

Background

- Nutrient pollution (primarily from runoff and sewage effluent) often results in seasonal eutrophication, phytoplankton blooms and hypoxia in parts of the Chesapeake, especially during the summer months[1,2].
- Consequences of blooms includes[3]:
  - Depletion of dissolved oxygen → fish kills
  - Toxin release from HABs → results in wildlife mortality
    → cause adverse health effects to local communities
  - Clogging water treatment plants

Figure 1. Algal blooms in the James River near the Monitor Merrimac Bridge in August 2013. (Wolfgang Vogelbein/VIMS)

Figure 2. Extreme case of algal blooms leading to fish kills due to hypoxic conditions. (J.B. Forbes)

Methods

Study Site

A section of the James River at 5 stations from January 2013 to December 2022

Figure 3. Image taken from Google Maps plotting the 5 stations along the James River.

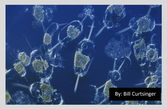
About the Data

Chesapeake Bay Program
Science. Restoration. Partnership.

- Monthly monitoring has occurred since the mid-1980s on water quality & phytoplankton
- Collected by Maryland Department of Natural Resources, Morgan State University, Old Dominion & the Virginia Department of Environmental Quality (VDEQ)
- Variable of Interest: Chl-a, Nutrients, Turbidity & Water Temperature

- Launch on February 11, 2013 (still operational)
- Bands of interest: Coastal aerosols, blue, green, red, near infrared
- 30-meter multispectral resolutions along a 185km swath

CONCEPT MAP

CHL-a →  → 

Proxy for: Phytoplankton — Algal bloom

Results & Models

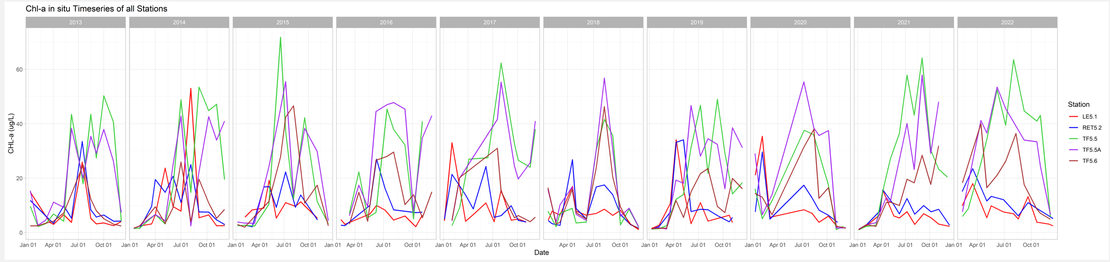


Figure 4. In situ Chl-a record as a function of time for the 5-sampling stations along the James River from January 2013 to December 2022.

Generalized Additive Model (GAM)

Major factors that influence/drive the growth of phytoplankton are carbon, nitrogen, phosphorus and light[4].

Chl-a ⟹ NH_4^+ PO_4^3 + **Turbidity** + **Water Temp.**

NITROGEN: Ammonium
Studies found that ammonium appears to be the primary inorganic nitrogen form that goes into synthetic reactions and is the most energetically favorable source of inorganic nitrogen because of its reduced state[4].

PHOSPHORUS: Phosphate
Phytoplankton uses both phosphate and dissolved organic phosphorus, particularly at high substrate concentrations[5].

TURBIDITY: May be a sign of greater sediments/detritus → Leading to enhance nutrients in the river for phytoplankton growth to an extent

WATER TEMPERATURE: Can affect the metabolism and hence the biological activity of organisms. Blooms around the Chesapeake Bay were found to be between 18.0-26.1 ºC [6].

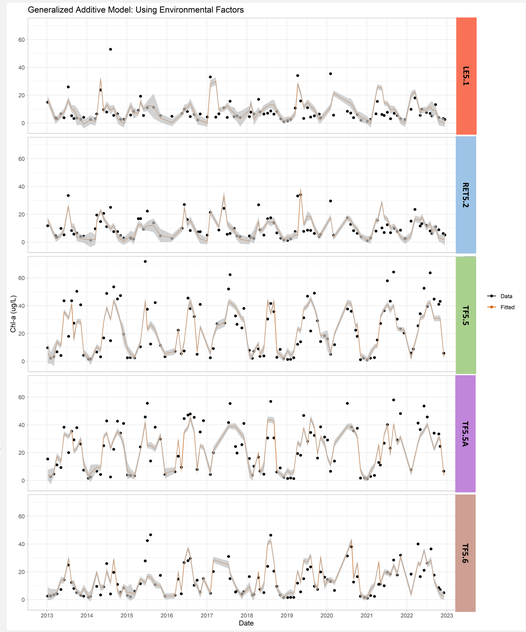
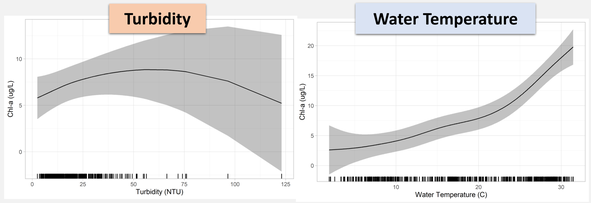


Figure 5. GAM fitted line plotted over time from 2013 to 2022 across 5 stations. Confidence band signifies 95% with in-situ Chl-a measurements data plotted as points.

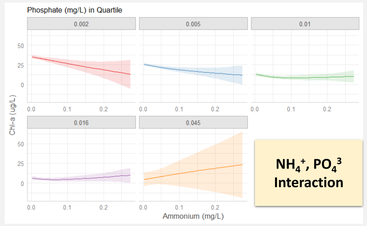
The model explains 71.7% of the deviance. (r^{-2} = 0.709, RMSE= 7.83, MAE = 5.43).

Marginal Mean Effects



- Appears that increasing turbidity is associated with decrease in Chl-a
- Speculation: Highly turbid environments limit space for phytoplankton growth
- Phytoplankton driving turbidity → Shading light from more growth

- Appears that increasing water temperature is associated with increasing Chl-a
- Speculation: Higher temperature → More sunlight → enhance photosynthesis reactions

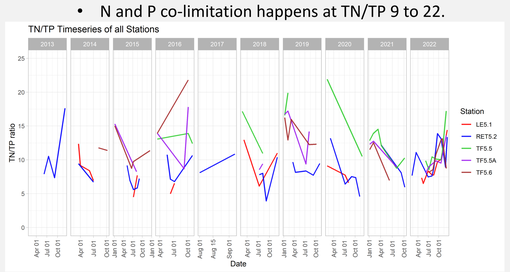


NH_4^+, PO_4^3 Interaction

Increasing ammonium while holding phosphate constant:
- At 0,25,50%: Shows phosphorus is limiting
- At 75,100%: Shows nitrogen is limiting

Figure 6. Marginal predictions for each of the environmental variables; shaded areas represent the 95% confidence intervals.

Guildford and Hecky[7]: Suggested for lakes and oceans
- N limitation occurred at TN/TP < 9
- N and P co-limitation happens at TN/TP 9 to 22.



The James River is mostly a nitrogen limiting OR nitrogen and phosphorus co-limiting system

Data Analysis: Conducted using RStudio Jupyter

Discussion

- The blooms observed on the James may be driven by ammonium and phosphate availability, and water temperature.
- On average, the head of the James experience higher volume of phytoplankton blooms than compared to the mouth of the river
- It appears that algal bloom trends was not affected by the pandemic in 2020 (consistent with both GAM & CHL Models)

Variables excluded from analysis due to data availability:
- Light & Carbon: Necessary for photosynthesis
- Silica: Needed for growth of diatoms
- Salinity: Determines whether freshwater or marine species of planktons are found along the James

Importance

- Help identify algal blooms in other regions (using environmental drivers and spectral data)
- Provide a stepping-stone for monitoring programs on HABS

Chlorophyll Model

(Developed by Isha Chinniah) → **Using LANDSAT to characterize blooms**

A. PRE Pandemic

B. During Pandemic

C. POST Pandemic

Figure 7. Using chlorophyll model developed using principal component analysis by Isha (colleague), chl-a was derived using scores calculated based on LANDSAT bands (coastal, red, green, blue, near infrared). Map depicted shows model prediction spatially along the entire James River (A) on July 27, 2019, (B) on July 13, 2020, and (C) on August 4, 2022.

References

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