Bringing the Arctic to the High School Classroom

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Abstract

Through the PolarTREC program that pairs US educators with field researchers in polar regions, our team has been collaborating on K-12 and undergraduate curriculum development and outreach activities on Arctic amplification of climate change. We have created new lesson plans and activities focused on how organic carbon from thawing permafrost in the Arctic is turned into carbon dioxide, a greenhouse gas that amplifies climate change. This presentation will cover our collaboration to bring this knowledge and experience to high school science students through classroom activities and projects. The focus will be laboratory activities designed for the chemistry classroom: use of spectrophotometry to assess degree of photobleaching in organic samples and evaluation of data from high resolution mass spectrometry to characterize complex organic mixtures. We will also review lessons learned from our efforts to promote enthusiasm for polar science within the general public and discuss the benefits of the PolarTREC program to researchers, educators, students, and the public.

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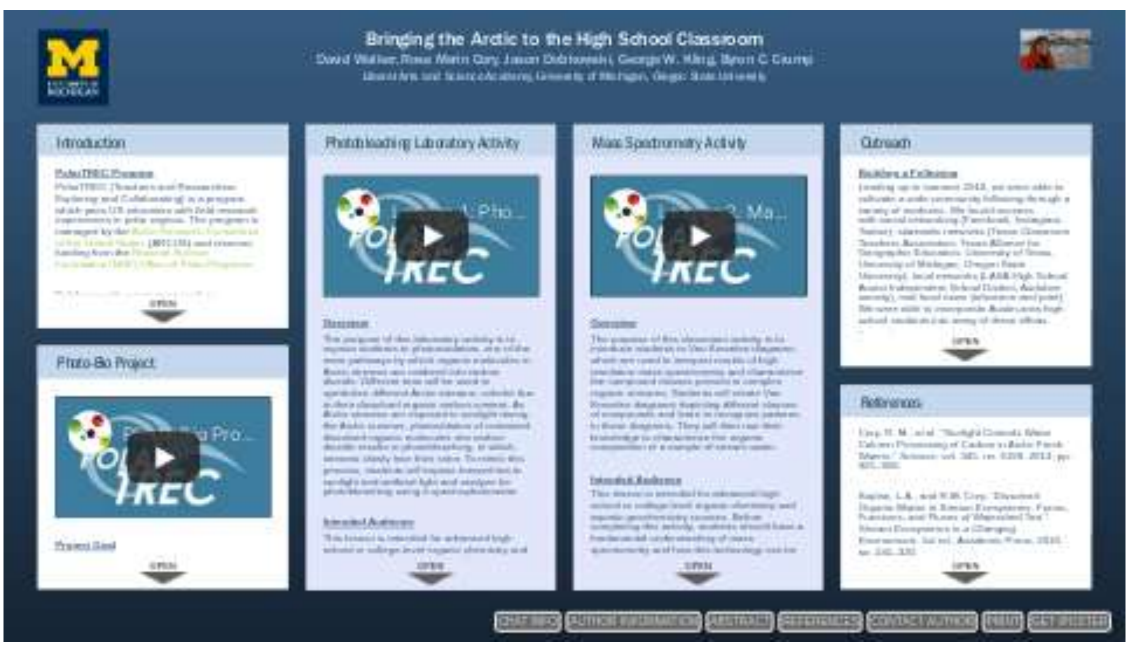


ABSTRACT

Through the PolarTREC program that pairs US educators with field researchers in polar regions, our team has been collaborating on K-12 and undergraduate curriculum development and outreach activities on Arctic amplification of climate change. We have created new lesson plans and activities focused on how organic carbon from thawing permafrost in the Arctic is turned into carbon dioxide, a greenhouse gas that amplifies climate change. This presentation covers our collaboration to bring this knowledge and experience to high school science students through classroom activities and projects. The focus is on laboratory activities designed for the chemistry classroom: use of spectrophotometry to assess degree of photobleaching in organic samples and evaluation of data from high resolution mass spectrometry to characterize complex organic mixtures. We will also review lessons learned from our efforts to promote enthusiasm for polar science within the general public and discuss the benefits of the PolarTREC program to researchers, educators, students, and the public.

INTRODUCTION

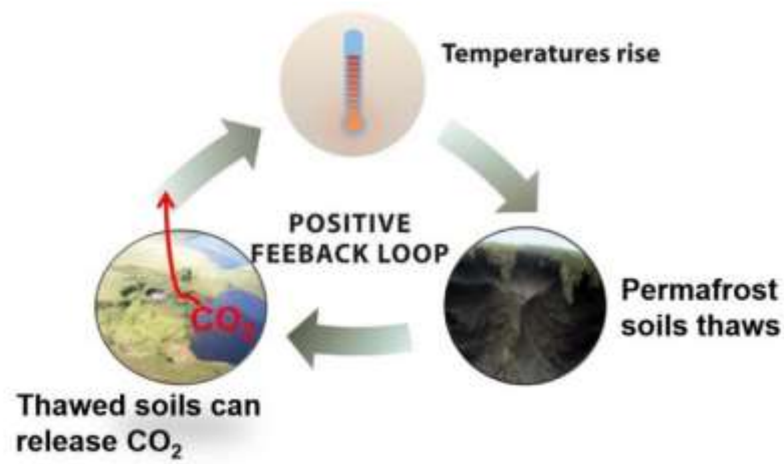
PolarTREC Program

PolarTREC (Teachers and Researchers Exploring and Collaborating) is a program which pairs US educators with field research experiences in polar regions. The program is managed by the Arctic Research Consortium of the United States (ARCUS) and receives funding from the National Science Foundation (NSF) Office of Polar Programs.

Field research experiences such as PolarTREC represent valuable professional development for science educators. Through these experiences, educators are able to: 1) increase their knowledge of polar regions and their role as a critical bellwether of climate change; 2) engage in field research, learning more about it in the process; 3) foster a long-term professional collaboration with a research team; 4) bring gained knowledge and experience back to their students through new classroom lessons, activities, and projects; 4) bring gained knowledge and experience to their broader community, to promote enthusiasm for polar science among the public.

Our Work

In Spring 2019, we worked together at Toolik Field Station in the Alaskan Arctic to investigate the role of sunlight and microbes in metabolizing the dissolved organic carbon (DOC) released from thawing permafrost. This relationship constitues a positive feedback loop, which serves to increase the speed of climate change.



Throughout this experience, we collaborated to bring current climate science and research to high school students and the general public. The culimination of this work was the creation of two activities for the high school science classroom. Here, we review these activites and lessons learned from our outreach efforts.

PHOTO-BIO PROJECT

Introduction

- [Introductory Video (Dr. Rose Cory)]

Project Goal

The goal of the photo-bio project is to investigate the role of sunlight and microbes in metabolizing the dissolved organic carbon (DOC) released from thawing permafrost in the Arctic.

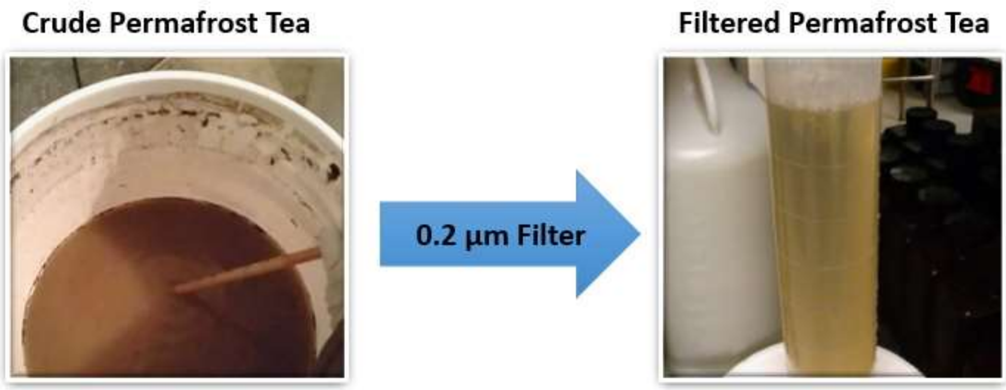
Research Questions

- How does DOC chemistry affect the metabolic processes of microbes?
- How does DOC exposure to sunlight factor into this equation?
- How does long-term microbial community adaptation affect the rate of DOC breakdown?

Summer 2019

During summer 2019, three soil pits were excavated in wet sedge tundra in the Alaskan Arctic. From each soil pit, samples were taken from two categories of soil, based on depth: surface (organic mat) layer (10-30 cm in depth, proceeds through freeze-thaw annually) and permafrost (80-120 cm in depth, frozen for at least two years).

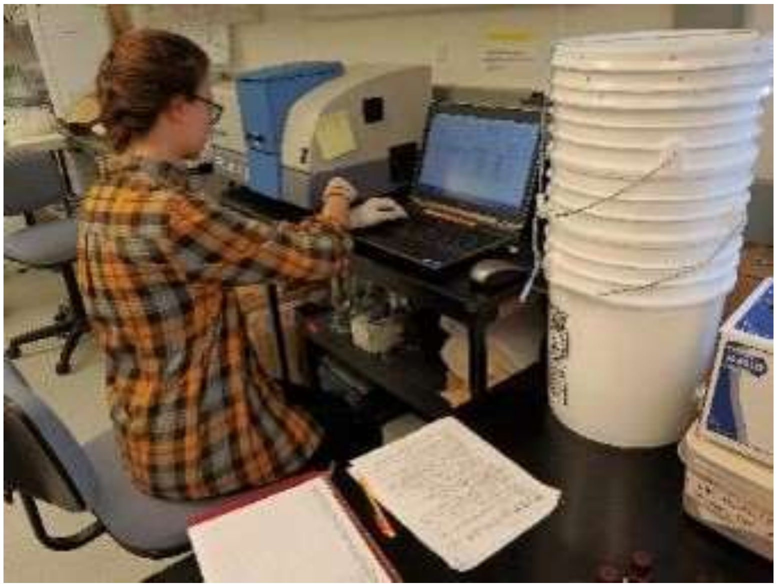
Filter-sterilized DOC was prepared from these soil samples via solid-liquid extraction (basically, preparing tea from soil) and subsequently filtered to remove all microbial content. This DOC was then reinoculated with a set amount of microbial material from the same sample site and depth and inbucated for seven days.



To address the role of sunlight in DOC breakdown, the incubation sequence was expanded to include two categories of filter-sterilized "DOC tea" – dark control (foil wrapped) and sunlight-exposed (12-18 hours).

Microbial gene abundance and expression patterns were evaluated through metagenomics and metatranscriptomics on samples taken at the beginning and end of the incubations. The goal was to elucidate and quantify the microbial enzymatic reactions used to break down DOC.

To identify the specific formulas of the compounds in the DOC that were consumed and produced during the incubations, mass spectrometry was used. In addition, spectroscopy was utilized to measure absorbance and fluorescence of the samples at different points.



To look at microbial community adaptation, data was collected on microbial abundance, CO_2production, O_2 consumption, and microbial community composition at the beginning and end of the inbucation periods for both dark and sunlight-exposed samples.

Preliminary results (Ward, et al., 2017) indicate that bacteria prefer to respire sun-brewed DOC, suggesting that sunlight and bacteria are working together synergistically in the Arctic to breakdown DOC into CO_2. This means that CO_2 will be released from thawing permafrost at a rate greater than that predicted by current climate models.

PHOTOBLEACHING LABORATORY ACTIVITY

Introduction

- **Introductory Video (David Walker)**

Formal Lesson Plan

- **Photobleaching in Arctic Streams - Spectrophotometry and Beer's Law**

Overview

The purpose of this laboratory activity is to expose students to photooxidation, one of the main pathways by which organic molecules in Arctic streams are oxidized into carbon dioxide. Different teas will be used to symbolize different Arctic streams, colorful due to their dissolved organic carbon content. As Arctic streams are exposed to sunlight during the Arctic summer, photoxidation of contained dissolved organic molecules into carbon dioxide results in photobleaching, in which streams slowly lose their color. To mimic this process, students will expose brewed tea to sunlight and artificial light and analyze for photobleaching using a spectrophotometer.

Intended Audience

This lesson is intended for advanced high school or college-level organic chemistry and aquatic geochemistry courses. Before completing this activity, students should have a foundational understanding of molecular orbital theory, organic reactions involving radicals, and spectrophotometry.

Learning Objectives

Students will able able to:

1. Use concepts of molecular orbital theory and electron delocalization to explain why organic compounds exhibit color.
2. Use a spectrophotometer to analyze the visible light absorbance of a given organic sample and determine the wavelength of maximum absorbance (λ_{max}).
3. Prepare a dilution series for an organic sample, plotting solution concentration vs. absorbance at λ_{max}.
4. Use a spectrophotometer to detect photobleaching in an organic sample.
5. Use Beer's law to quantify degree of photobleaching in an organic sample.
6. Explain the relevance of the photoxidation and photobleaching of tea to the photooxidation and photobleaching of dissolved organic carbon in Arctic streams.
7. Explain the relevance of photoxidation and photobleaching to the permafrost positive feedback loop and climate change in the Arctic.

Prepared Background Resources

- All About Permafrost
- The Permafrost Postive Feedback Loop
- Dissolved Organic Carbon
- Resonance Energy and Color
- Arctic Oxidation Culprits
- Sunlight Controls Fate of Arctic DOC
- Carbon in the Arctic (Video Presentation)
- Permafrost First-Hand
- Brewing Permafrost Tea
- Photoexposure of Permafrost Tea

Example Components

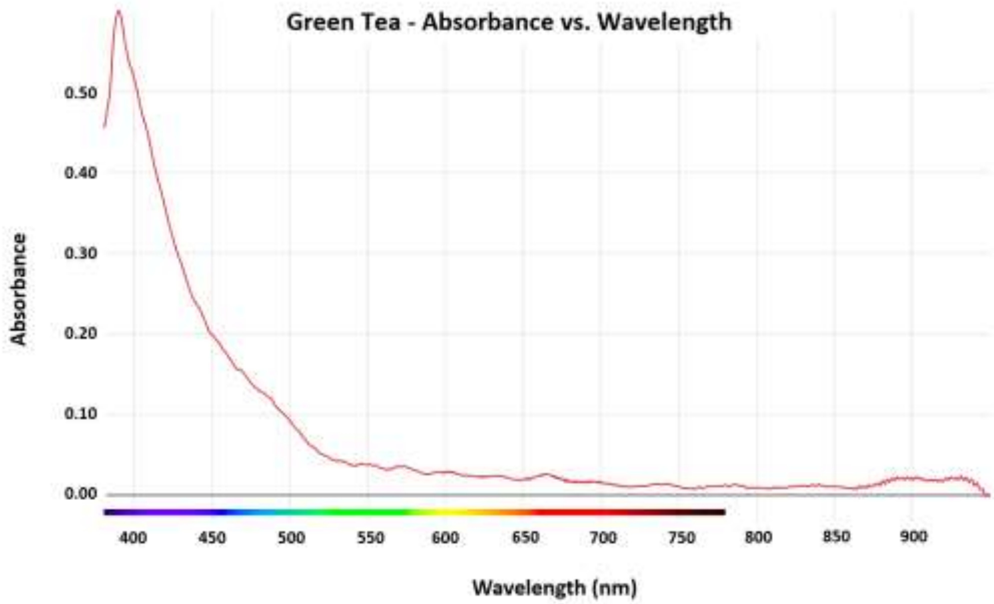
We created this timelapse to illustrate to students the importance of sunlight to aquatic geochemistry during summer in the Arctic. The video was taken overnight at Toolik Field Station (8:31 PM to 7:53 AM) in June 2019.

- Midnight Sun in the Arctic

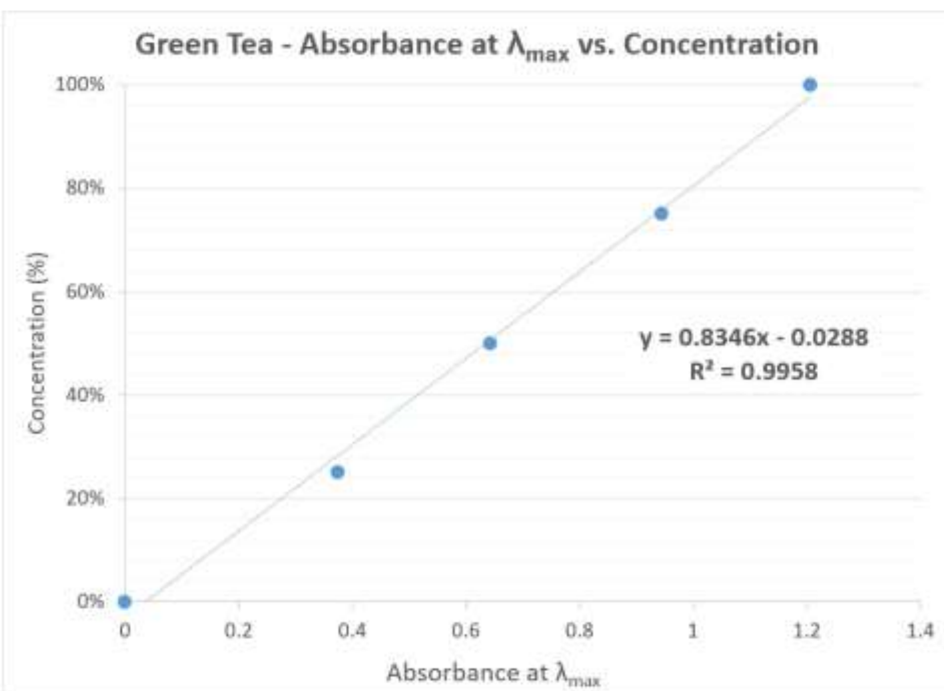
We created the below timelapse to illustrate photobleaching to students. The video documents an 8.6 day (207 hour) exposure of coke to ultraviolet and visible light under a grow bulb. As the coke is exposed to light, the contained dye is slowly photoxidized, resulting in loss of color (photobleaching).

- Photobleaching Timelapse

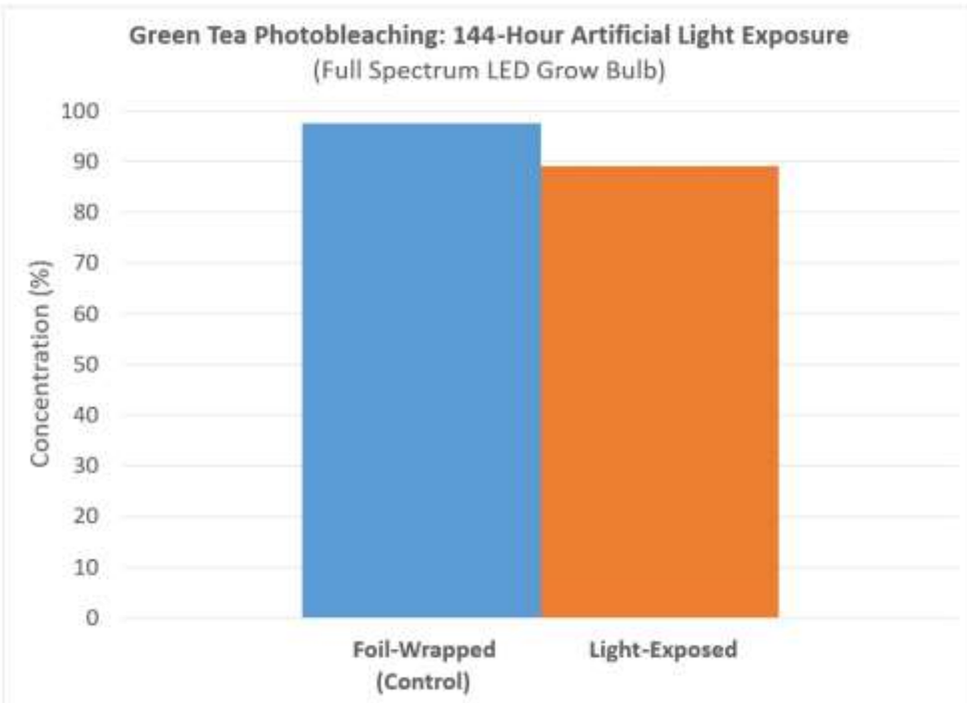
Absorbance vs. wavelength graph for a green tea sample. Data was collected using a Vernier Go Direct® SpectroVis® Plus Spectrophotometer.



Aborbance at λ_{max} vs. concentration curve for green tea, illustrating Beer's law.



Photobleaching is clearly observable in a green tea sample after 144-hours of artificial light exposure. The graph below illustrates concentrations of foil-wrapped (control) vs. light-exposed samples following 144-hour exposure.



Example Assessment Questions

- Why do the compounds in tea (and Arctic streams) exhibit color? In your answer, you will need to reference resonance, molecular orbitals, and the HOMO-LUMO gap.
- How does your prepared standard curve comparing concentration and absorbance illustrate Beer's Law?
- Explain the relevance of the photoxidation and photobleaching of tea to the photoxidation and photobleaching of dissolved organic carbon in Arctic streams.
- Explain the relevance of photoxidation and photobleaching to the permafrost positive feedback loop and climate change in the Arctic.

MASS SPECTROMETRY ACTIVITY

Introduction

- **Introductory Video (David Walker)**

Formal Lesson Plan

- **Characterization of Complex Organic Mixtures**

Overview

The purpose of this classroom activity is to introduce students to Van Krevelen diagrams, which are used to interpret results of high resolution mass spectrometry and characterize the compound classes present in complex organic mixtures. Students will create Van Krevelen diagrams depicting different classes of compounds and learn to recognize patterns in these diagrams. They will then use their knowledge to characterize the organic composition of a sample of stream water.

Intended Audience

This lesson is intended for advanced high school or college-level organic chemistry and aquatic geochemistry courses. Before completing this activity, students should have a fundamental understanding of mass spectrometry and how this technology can be used to determine the molecular formulas of simple organic unknowns. Students should also be able to identify a compound as aromatic or aliphatic, based on its structure.

Learning Objectives

Students will able able to:

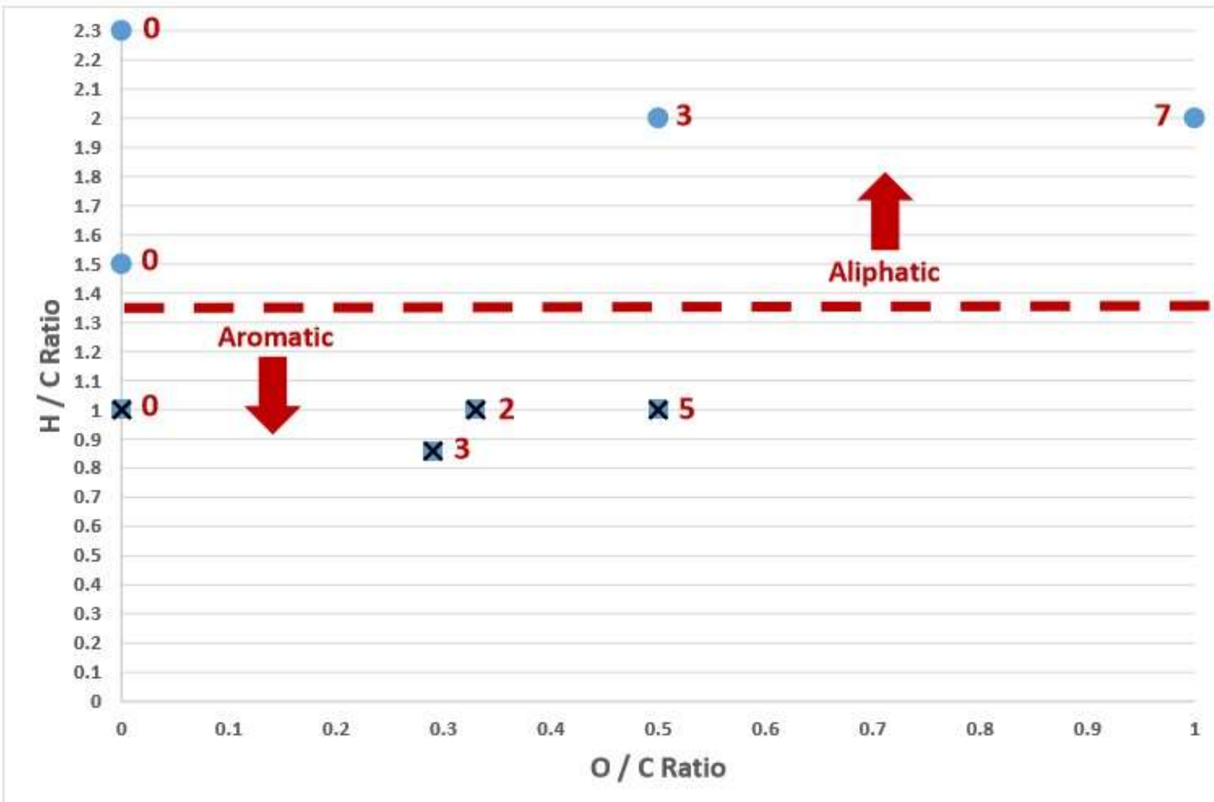
1. Prepare a Van Krevelen diagram for a series of compounds.
2. Draw conclusions regarding the general location of aromatic vs. aliphatic compounds on a Van Krevelen diagram.
3. Draw conclusions regarding compound oxidation and location on a Van Krevelen diagram.
4. Define general compound classes present in complex organic mixtures found in nature.
5. Diagram general compound class regions on a Van Krevelen diagram.
6. Distinguish between compound classes based on their aromaticity and oxidation.
7. Draw conclusions regarding the aromatic vs. aliphatic organic content in a water sample.
8. Draw conclusions regarding the organic compound classes present in water sample.

Prepared Background Resources

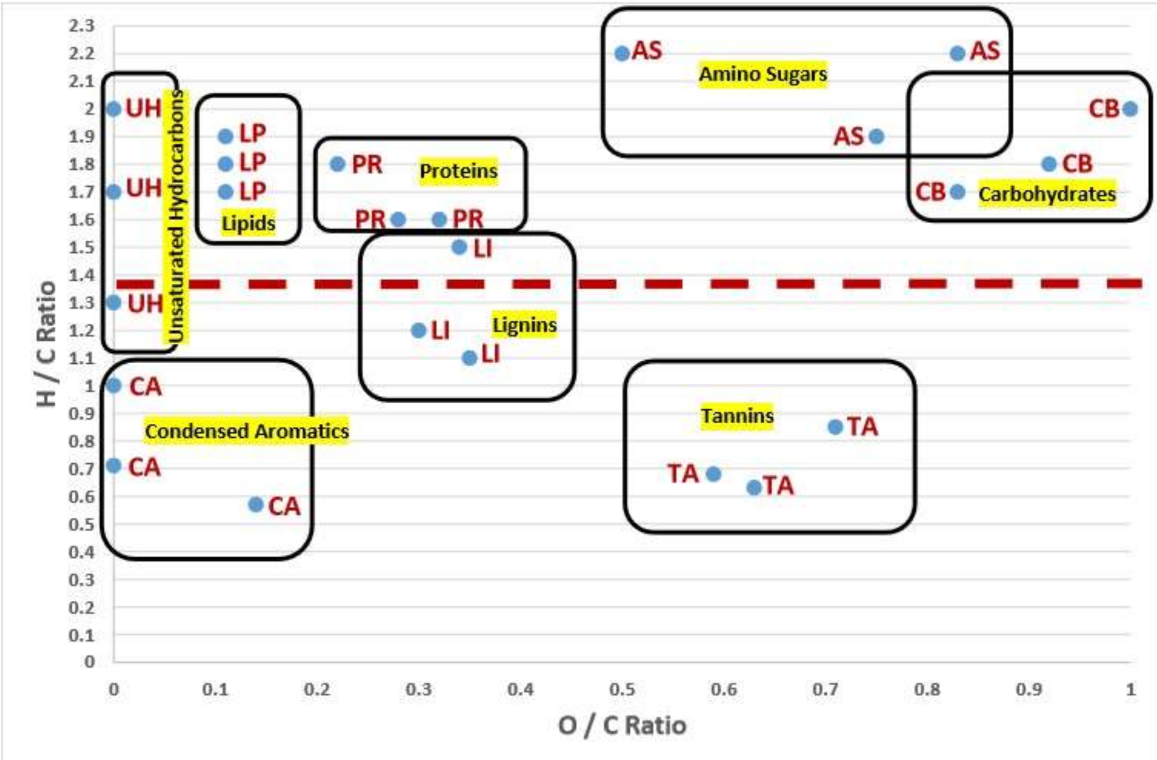
- [Characterization of Complex Organic Mixtures via Mass Spectrometry]
- [Photodegradation of Permafrost DOC Yield Bacterial Fuel]

Example Components

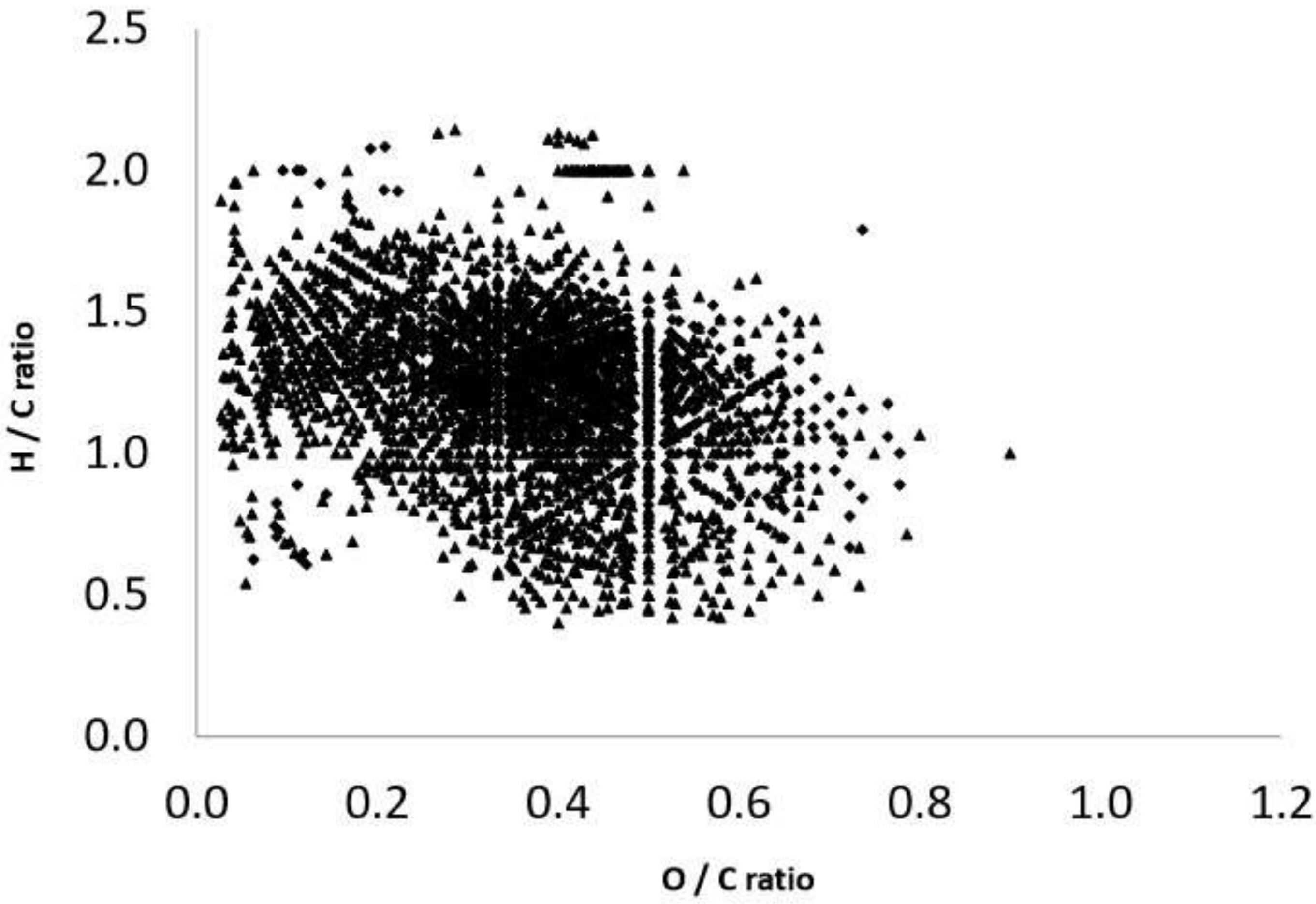
Sample work plotting H/C vs. O/C ratio (Van Krevelen diagram) for simple organic compounds.



Sample work plotting H/C vs. O/C ratio (Van Krevelen diagram) for complex organic compounds .



High resolution mass spectrometry of a stream water sample from the Alaskan Arctic. Students use knowledge gained through the activity to evaluate this sample.



Example Assessment Questions

- What conclusions can you draw regarding the aromatic vs. aliphatic organic content in this water sample?
- What compound class is most prevalent in this water sample? Given the nature of this compound class (chemical structure, role in nature), attempt to explain why.
- Which compound classes are least prevalent in this water sample? Given the nature of these compound classes (chemical structure, role in nature), attempt to explain why.

OUTREACH

Building a Following

Leading up to summer 2019, we were able to cultivate a wide community following through a variety of mediums. We found success with social networking (Facebook, Instagram, Twitter), statewide networks (Texas Classroom Teachers Association, Texas Alliance for Geographic Education, University of Texas, University of Michigan, Oregon State University), local networks (LASA High School, Austin Independent School District, Audubon society), and local news (television and print). We were able to incorporate Austin-area high school students into many of these efforts.

Examples:

- **Print News Story from Austin Monitor News**
- **Television News Story from Spectrum News Austin**
- **Television News Story from KVUE News Austin**

From the Arctic

While at Toolik Field Station, we engaged in student and community outreach through social networking, regular journal postings (through PolarTREC), audio recordings, live video broadcasts and Q&As, and live formal presentations.

Examples:

- **PolarTREC Journal**
- **Research Presentation Livestream**
- **Photos and Other Media**
- **Example Video 1**
- **Example Video 2**
- **Example Video 3**

Subsequent Outreach

Since summer 2019, we have continued outreach in polar science through school and community presentations, as well as radio, television, and print news.

Examples:

- **Video and Radio News Story from KUT Austin (NPR)**
- **Print News Story in The Classroom Teacher Magazine (Texas Classroom Teachers Association)**
- **STEM Experience Report**

Summary

Below is a summary of different major avenues of outreach and their respective impacts.

Outreach Activity	Audience Type	Estimated Reach
PolarTREC Journals	Students, Parents, Family, General Public	7000+
PolarConnect Presentation	Students, Parents, Family, General Public	44
Instagram Posts	Students, Parents, General Public	641
Austin Monitor News Story	General Public	5000+
Spectrum News Story	General Public	100,000+
KVUE News Story	General Public	200,000+
Travis Audubon News	Local Audubon Club	1,244
Digg News Video	General Public	2,561
Austin ISD News	School District Students, Parents, and Staff	200,000+
KUT/NPR Story	General Public	300,000+
ATPE News Story	Association of Texas Professional Educators (ATPE) Members	100,000+
LASA High School Professional Development Presentation	LASA High School Teachers	20
Geobiology Class	Students	60
Organic Chemistry Class	Students	60

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