SLiME – Structured Learning in Microbial Ecology Model

MTV Kickoff Meeting

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Introduction and Motivation

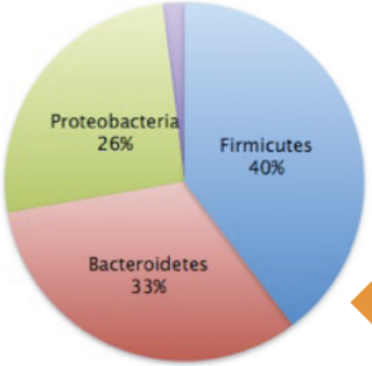
- It is difficult to detect prior exposure to radionuclides or other contaminants in common physical environments since the signals typically fade quite rapidly. We have recently shown that microbial community structure maintains a “memory” of radionuclide and contaminant exposure even when these contaminants are no longer detectable by any other physical/chemical means. However, it is not understood how long the microbial community structure can act as a biosensor
- We propose to measure how long a microbial community structure and/or specific bacteria can reflect environmental exposure to radionuclides and/or other geochemical parameters related to radionuclide contamination, e.g. nitrate, aluminum, etc. Any part of the nuclear fuel cycle that would release contaminants to the environment but especially waste shipping, waste storage, mining and milling, conversion, u metal production, shipping, processing and non-nuclear components.

- Operated from 1951 to 1983
- 400 ft x 400 ft x 17 ft deep
- Over 2.5 million gallons waste/year
- Wastes contained nitrate, uranium, Tc-99, metals, VOCs, high TDS, and low pH (<2.0)
- Neutralized in 1984 capped in 1988

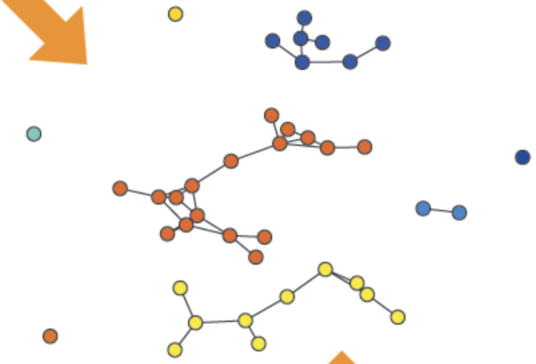
Currently a parking lot

S-3 Disposal Ponds During Denitrification

Predictive modeling of microbial ecosystems



surveys
(high-throughput 16S sequencing)



rules
(networks of co-occurence/ correlation/causality)

ODEs
(model of time evolution of ecosystem)

$$\dot{N}_i = N_i f_i\left(\vec{N}; E(t)\right) = r_i(E(t))N_i\left(1 - \frac{\sum_j a_{ij}(E(t))N_j}{K_j(E(t))}\right)$$

species-species interactions

intrinsic growth rate

environmental factors

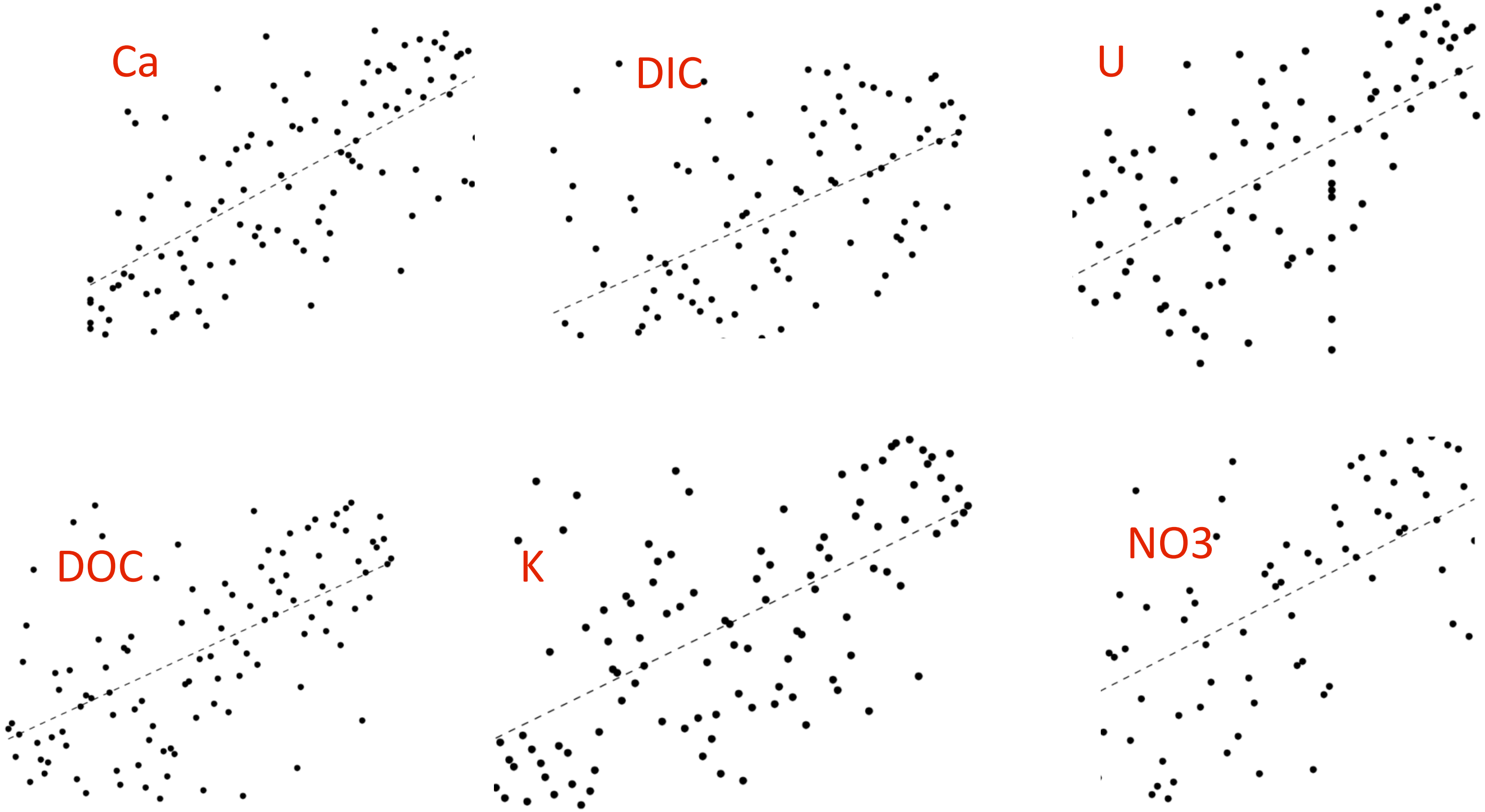
carrying capacity

abundance of species *i*

PDEs
(time & space)

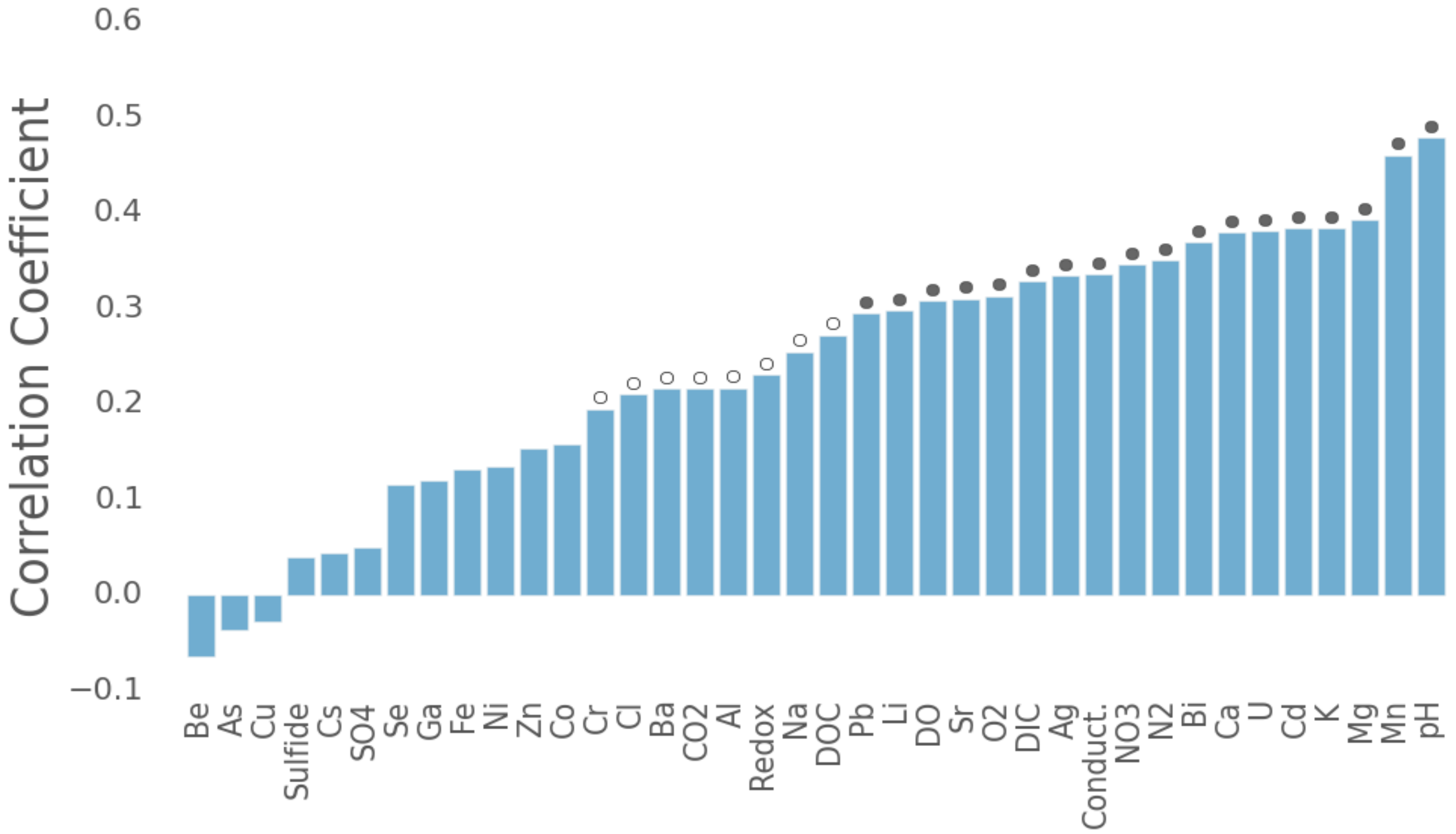
$$\dot{N}_i(x,t) = N_i f_i\left(\vec{N}; E(x,t)\right) + \nabla\left[D_i(x,t)\nabla N_i\right]$$

OTUs carry info about many parameters



Bacterial DNA can be used to quantitatively predict many geochemical features. Besides classification, we can use 16S sequence data to predict quantitative values for a variety of geochemical measurements at each well. Correlation coefficient (Kendall's tau) between true and predicted values. 18 of these correlations are highly significant ($p < 0.0001$, indicated by *), 8 are significant ($p < 0.01$, indicated by o) and 12 of these correlations are not significant

(Smith Rocha et al, 2015)



Recent Papers that build off of the SliME model

1. Dai WF, Zhang JJ, Tu QC, Deng Y, Qiu QF, Xiong JB. 2017. Bacterioplankton assembly and interspecies interaction indicating increasing coastal eutrophication. Chemosphere 177:317-325.

2. Dubinsky EA, Butkus SR, Andersen GL. 2016. Microbial source tracking in impaired watersheds using PhyloChip and machine-learning classification. Water Research 105:56-64.

3. Garza DR, van Verk MC, Huynen MA, Dutilh BE. 2018. Towards predicting the environmental metabolome from metagenomics with a mechanistic model. Nature Microbiology 3:456-460.

4. Hermans SM, Buckley HL, Case BS, Curran-Cournane F, Taylor M, Lear G. 2017. Bacteria as Emerging Indicators of Soil Condition. Applied and Environmental Microbiology 83:13.

5. Ludington WB, Seher TD, Applegate O, Li XD, Kliegman JI, Langelier C, Atwill ER, Harter T, DeRisi JL. 2017. Assessing biosynthetic potential of agricultural groundwater through metagenomic sequencing: A diverse anammox community dominates nitrate-rich groundwater. Plos One 12:29.

6. Zhou JZ, Ning DL. 2017. Stochastic Community Assembly: Does It Matter in Microbial Ecology? Microbiology and Molecular Biology Reviews 81:32.

Mission Relevance

- We propose to measure how long a microbial community structure and/or specific bacteria can reflect environmental exposure to radionuclides and/or other geochemical parameters related to radionuclide contamination, e.g. nitrate, aluminum, etc. Any part of the nuclear fuel cycle that would release contaminants to the environment but especially waste shipping, waste storage, mining and milling, conversion, u metal production, shipping, processing and non-nuclear components.
- *NNSA Mission*
  - *Website:* https://www.energy.gov/nnsa/missions/nonproliferation

  Preventing nuclear weapons proliferation and reducing the threat of nuclear and radiological terrorism around the world are key U.S national security strategic objectives that require constant vigilance.

  NNSA's Office of Defense Nuclear Nonproliferation works globally to prevent state and non-state actors from developing nuclear weapons or acquiring weapons-usable nuclear or radiological materials, equipment, technology, and expertise.

Technical Work Plan

Tasks:

TASK 1. Select contaminated Area of Interest

-select contaminants and range of concentrations for focus

TASK 2. Generate Field Test Plan

-coordinate sampling plan: ensure facility/state/federal compliance, resource availability, safety, training

-detail sampling effort: number, type, volume or mass, frequency of collection, preservation, downstream analysis and assays

TASK 3. Field Sample Collection

-field sampling to collect meteorological/chemical/microbial markers to test robustness of model over time and to include environmental influences such as seasonal and meteorological events

TASK 4. Molecular Microbial Analysis

-nucleic acid extractions and processing for community structure analysis

TASK 5. In Lab Simulations and Perturbations

-above ground reactor simulations with relevant environmental perturbations

Oak Ridge National Lab, ORR and Y-12

Milestones:

YEAR 1 Select indicators of radionuclide contamination and determine biomarkers that will be optimal responders.

YEAR 2 Begin time series analysis of microbial and chemical analysis of field samples to define microbial community structure highlighting organisms of interest, this will continue in subsequent years.

YEAR 3 Develop above ground reactor and lab based simulations to test various perturbations.

YEAR 4 Based on model feedback finalize all parameters and collection of metadata, chemical and biological markers to make robust model.

YEAR 5 Test application of model to different systems: controlled and environmental.

MTV Impact

- What do you expect will be the impact of the MTV on your project development?
  - Internships, workshop participation, networking, connections
- Personnel transitions: Plans for future relationship with national labs, currently active.
- Technology transitions
  - Who is interested or using your technology? DOD, SERDP, DOE, EPA, HSD
  - Who are you collaborating with on your technology: UTK, MIT, UCB, UM

Conclusion

- Easy sampling of soil and water from groundwater, sediment and cooling towers at contaminated sites makes this type of biosensor very advantageous, since very small samples can be taken from different sites, frozen and shipped to lab for analysis. Very sensitive and requires little resources in the field.
- Biosensor potential to determine exposure to nuclear material even when no longer detectable via physical/chemical methods and indicate time frame for recency of activity.

Acknowledgements

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