Technology Limit of Enhanced Biological Phosphorus Removal Process for Achieving Extremely Low Effluent Phosphorus Levels

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Background

Increasingly Stringent Regulations for Controlling P Discharge

- **Non-point sources are difficult to control**
- **Strict EPA regulations for point sources**

Treatment Levels of different TMDL

Treatment Level 3:
0.01 mg/L TP

Treatment Level 2:
0.1 mg/L TP

Treatment Level 1:
1 mg/L TP

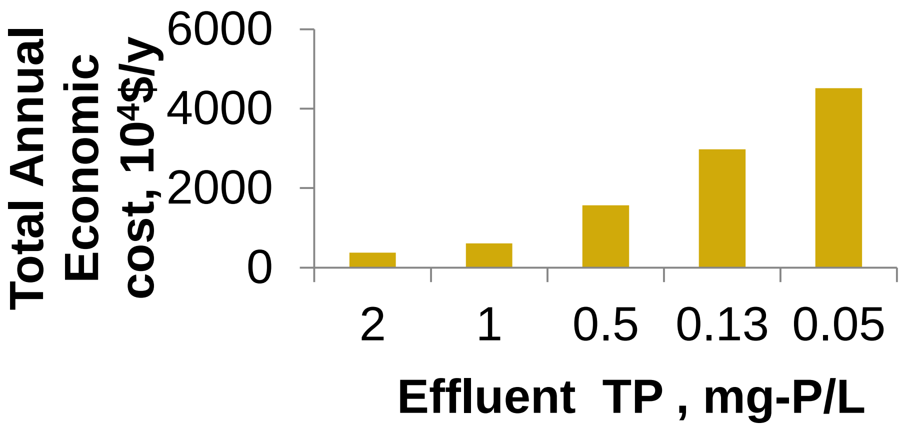
Clark et. al. ,WERF, 2010.

- Depending on the receiving water body
  - For sensitive areas (e.g. Spokane River basin): <0.05 mg P/L
  - More and more plants are facing 0.1 to 0.3 mg P/L effluent limit
  - Challenging to meet- LOT (limit of technology)

Challenges for Current P Removal Technologies

P Removal Technology

- **Chemical Precipitation/Adsorption (Aluminum and Iron Salts)**
- **Enhanced Biological Phosphorus Removal (EBPR)**



Jiang et al. 2005

- Effluent P as low as 0.05 to 0.005 mg-P/L with the chemical P removal technology is **not feasible or economical** (Neethling, Bakke et al. 2005; Gu, Pedros et al. 2007; Rahman, Eckelman et al. 2016).

Challenges for Current P Removal Technologies

P Removal Technology

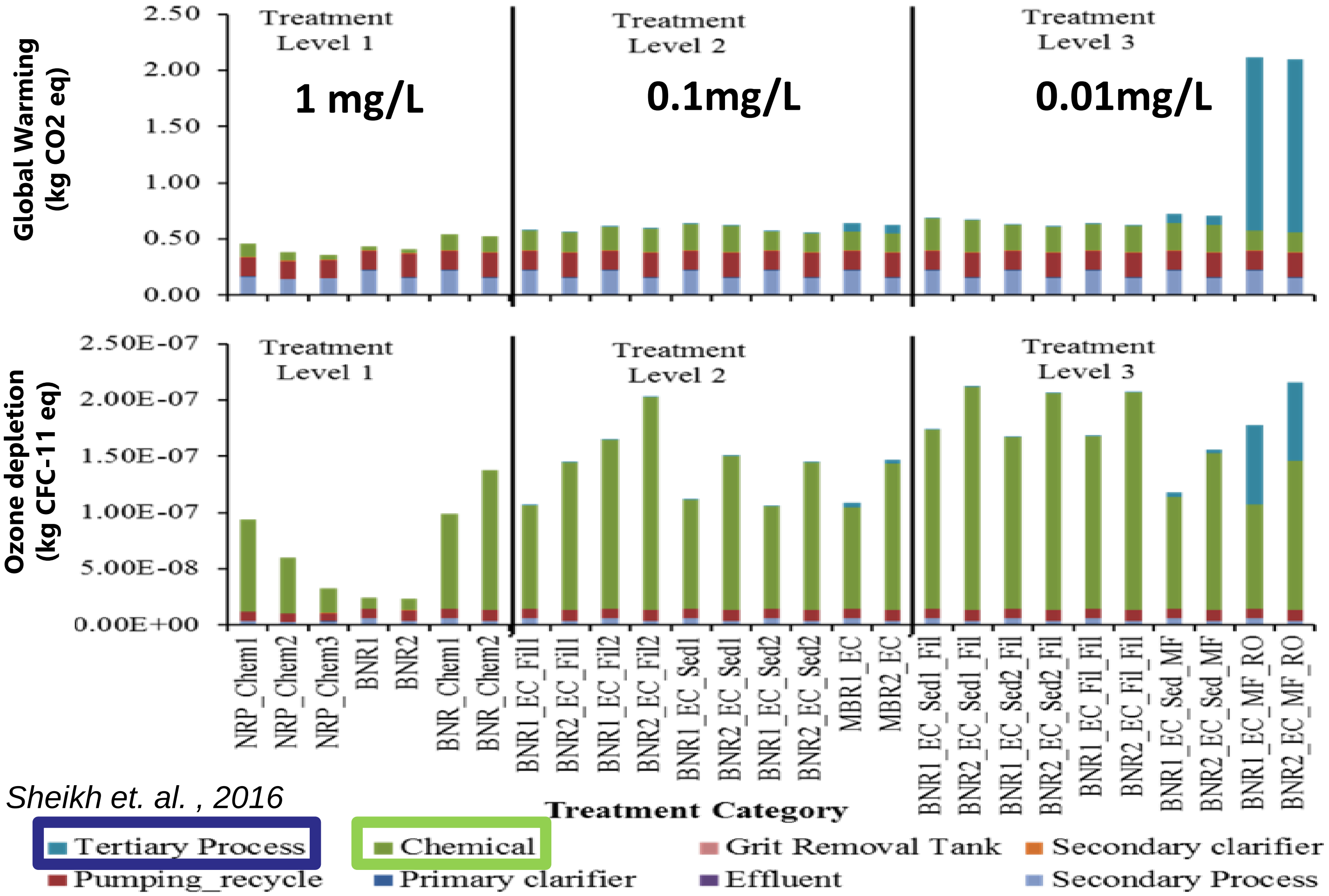
- **Chemical Precipitation/Adsorption (Aluminum and Iron Salts)**
- **Enhanced Biological Phosphorus Removal (EBPR)**

Tertiary Process

- Filtration
- Membrane Separation
- Ionic Exchange
- Reverse Osmosis
- Enhanced Sedimentation

- " Chemical precipitation, EBPR, and tertiary process needed for achieving effluent TP< 0.1 mg P/L " *Clark et al. WERF, 2010*
- " Single/multi-staged tertiary processes needed for extremely low target levels (i.e. 0.01 to 0.06 mg/L total P)." *Gu et al. ,WERF, 2014*

High Environmental/Health Impacts for Achieving Extremely Low P Level



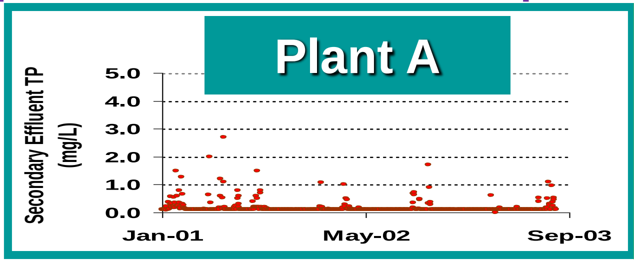
Sheikh et. al. , 2016

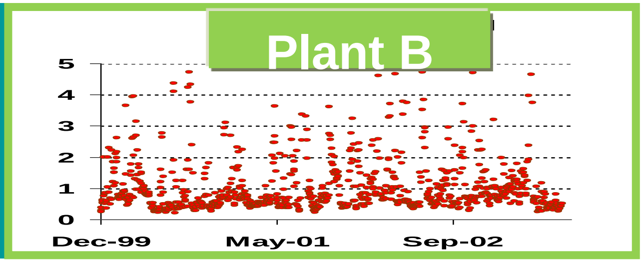
Alternative Strategies to Sustainably Achieve Extremely Low Effluent P Levels

- More holistic pollution management
- Non-point source regulation/control
- Further push limit of the more sustainable P removal technologies: EBPR
  - ✓ Able to achieve extremely low (<0.5 mg P/L) effluent P
  - ✓ Minimize economic/environmental costs
  - ✓ Promising technique for simultaneous P removal & recovery (less heavy metal content, higher bioavailability)

Challenges and Knowledge Gaps in EBPR

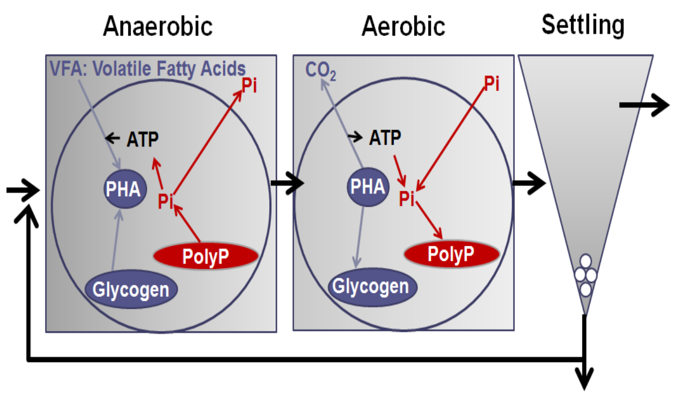
Unpredictable Performance Upsets





Mechanisms not fully understood

- EBPR design model not fully developed
- Factors governing EBPR stability not elucidated



Polyphosphate Accumulating Organisms (PAOs)

Unknown technology limit

How low can EBPR go?
How stable can EBPR perform at low P levels??

Identified Factors Affecting EBPR Performance/Stability

- Environmental Conditions
  - pH
  - T
- C-Substrate Supply
  - Bioavailable C/P ratio
  - Feeding rate
  - Substrate type (acetate, propionate, etc.)
- Operational Parameters
  - Oxygen supply
  - HRT
  - SRT

Identified Factors Affecting EBPR Performance/Stability

- Environmental Conditions
  - pH (7.0 ➡ 7.5-8.5)
  - T (35 ➡ 20°C)

Not Feasible

- C-Substrate Supply
  - Bioavailable C/P ratio
  - Feeding rate
  - Substrate type (acetate, propionate, etc.)
- Operational Parameters
  - Oxygen supply
  - HRT
  - SRT

Identified Factors Affecting EBPR Performance/Stability

- Environmental Conditions
  - pH
  - T
- C-Substrate Supply
  - Bioavailable C/P ratio (5 ➡ 38, if PAO favored kinetically)
  - Feeding rate
  - Substrate type (acetate, propionate, etc.)
- Operational Parameters
  - Oxygen supply
  - HRT
  - SRT

pH, T, DO, SRT etc.

Identified Factors Affecting EBPR Performance/Stability

- Environmental Conditions
  - pH
  - T
- C-Substrate Supply
  - Bioavailable C/P ratio
  - Feeding rate
  - Substrate type (VFA:acetate, propionate, etc.)
- Operational Parameters
  - Oxygen supply (DO in AE: 5 ➡ 3 mg/L)
  - HRT
  - ★ SRT (Not extensively investigated)

Most feasible to adjust

Identified Factors Affecting EBPR Performance/Stability

Substrate Supply
- Influent C/P ratio
- Substrates types

Operational Conditions
- Solid retention time (SRT)
- Configurations (e.g. Anaerobic/aerobic sequence etc.)

Environmental Conditions
- Temperature
- pH
- Metal Composition

→ **Microbial Ecology**:
➢ PAO v.s. GAO

→ **Performance & Stability**

- Polyphosphate Accumulating Organisms (PAOs)
- Glycogen Accumulating Organisms (GAOs)

Objectives

How low can EBPR go?

Combined impacts of SRT and influent C/P ratio on EBPR limit and long-term stability

Reveal the mechanisms of EBPR stability

EBPR System Operation and Monitoring

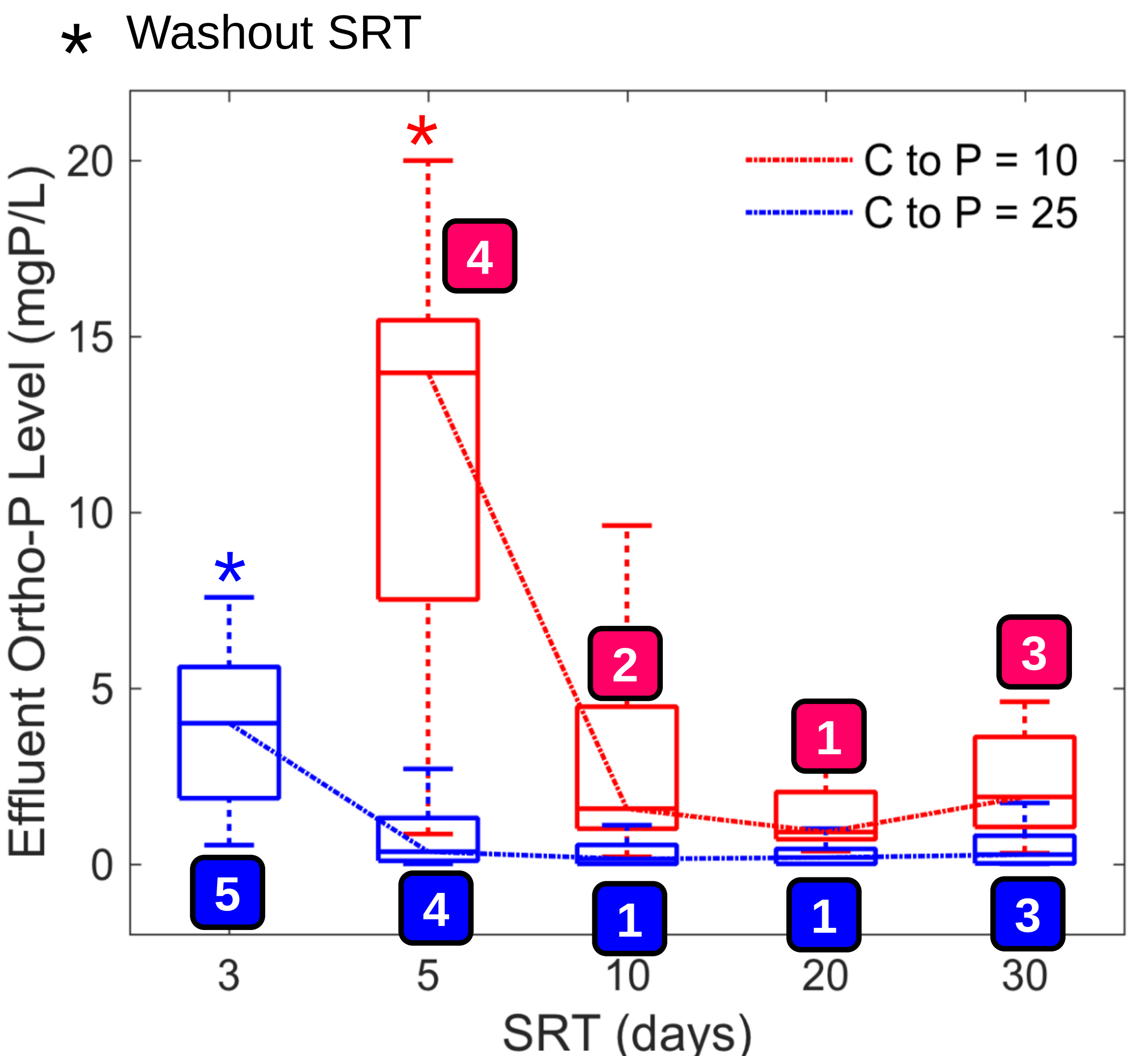
Acetate Fed Lab-Scale Sequencing Batch Reactors (SBRs)

- C-limiting condition influent C/P =10
- C non-limiting condition influent C/P=25

SRTs: 3 days, 5 days, 10 days, 20 days, 30 days

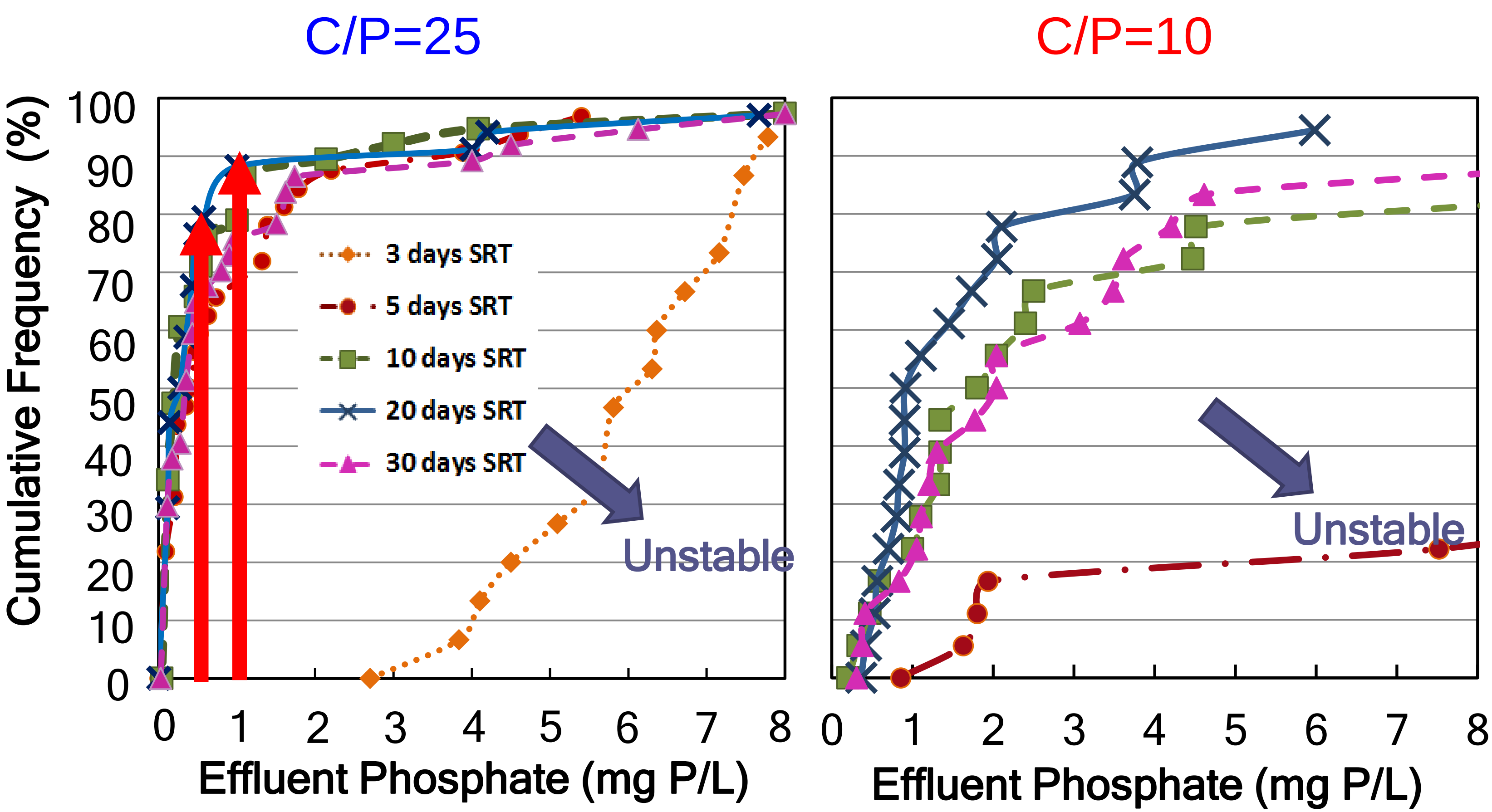
Long-Term Monitoring: >6 months

How SRT and C/P impact EBPR limit and stability



- **EBPR limit: <0.01-0.2 mg P/L**
- **For same SRT, higher C/P lead to higher stability**
- **For each C/P, optimal SRT range: Around 10-20 days SRT**

How SRT and C/P impact EBPR limit and stability



How SRT and C/P impact EBPR limit and stability

? Why not the shorter the better?

? Why optimal at 10-20 days SRT?

What really governs EBPR stability?

- *PAO vs. GAO competition?*
- *Select for different PAO or GAO identities?*
- *Functional pathway shift leading to activity/efficiency changes??*

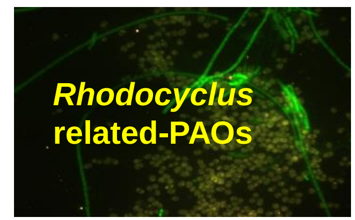
Mechanisms Governing EBPR Performance & Stability

Composition Structure

- **Functional group level**

Raman-Polymer Identification

- **Species level**

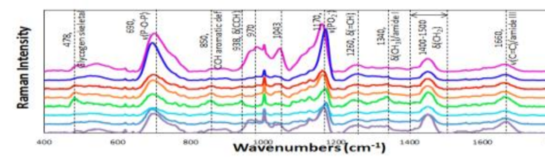


Quantitative-FISH

16S rRNA Gene Based Amplicon Sequencing

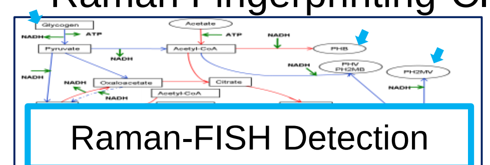
Metabolism/ Function

- **Phenotypic diversity**

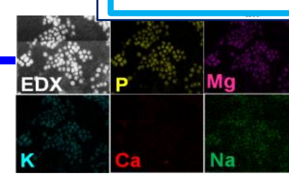


Raman Fingerprinting-Classification

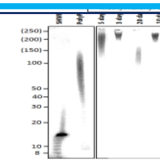
- **Pathway shift**



- **PolyP structure dynamics**



SEM/EDX



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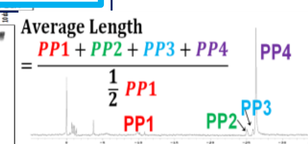
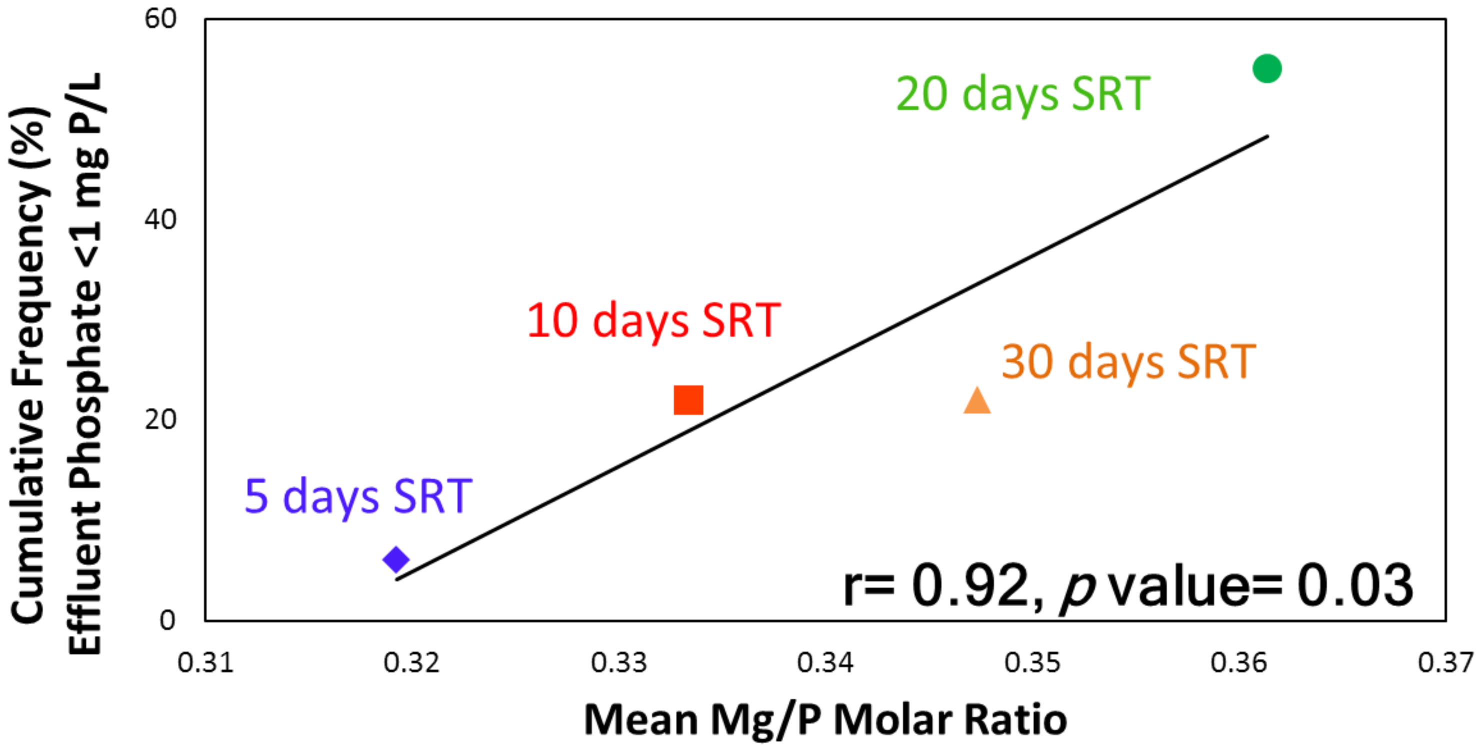


^{31}P-NMR

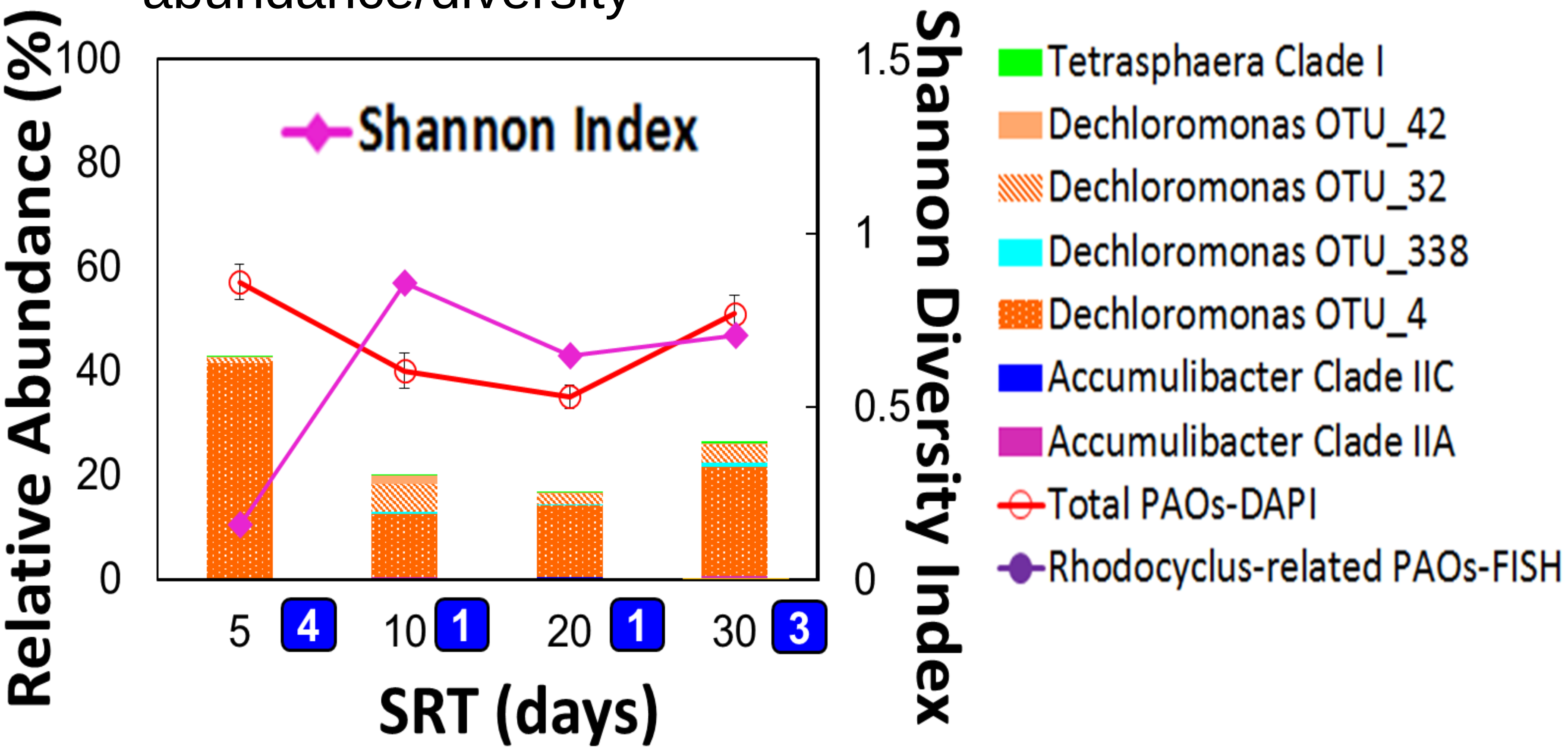
C-Limiting Condition

- ❑ Higher PAO%, higher P removal stability
- ❑ Higher Mg-PolyP content, higher P removal stability



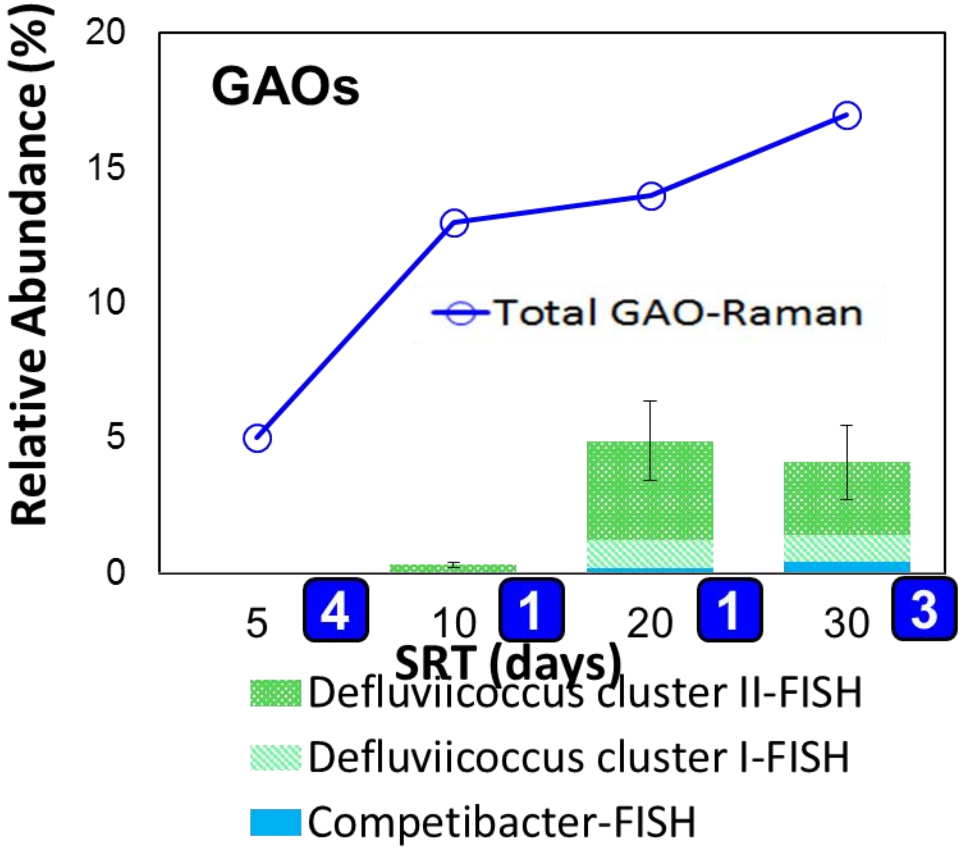
C-Non-Limiting Condition

- ❑ Stability **NOT** directly correlated with PAO abundance/diversity



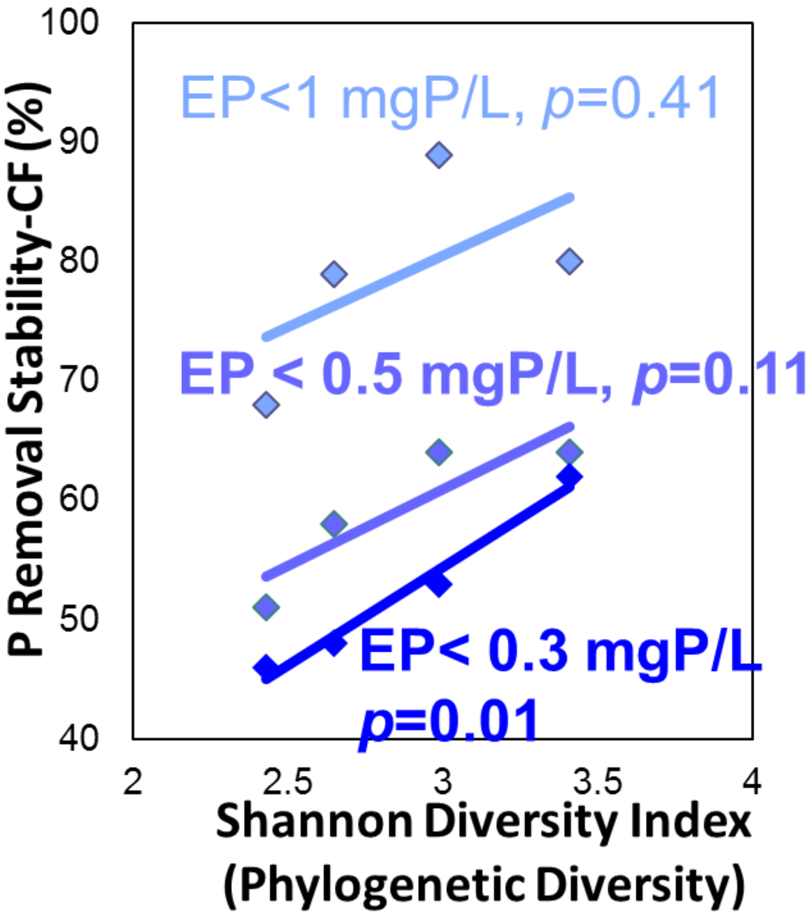
C-Non-Limiting Condition

- Stability **NOT** directly correlated with GAO abundance/diversity



C-Non-Limiting Condition

- Stability positively correlated with **overall community diversity**



Correlation is stronger for targeting lower effluent P levels

Conclusions

EBPR Limit: < 0.01 mg P/L

Stable EBPR:

- Sufficient C/P ratio
- 10- 20 days SRT (shorter for higher C/P)

EBPR Stability Governing Factor:

- C-Limiting: PAO%, Mg content etc.
- C-Non-Limiting: Microbial diversity

Acknowledgement

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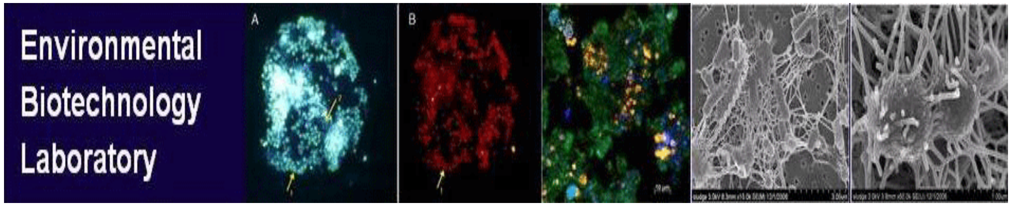

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Questions

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