World Water Congress XV
International Water Resources Association (IWRA)
Edinburgh, Scotland. 25 - 29 May 2015

University of Glasgow

# Measuring, Managing and Exploiting Microorganisms in Drinking Water Systems.


## Ameet J. Pinto


26/05/2015

@watermicrobe

www.pintolab.com

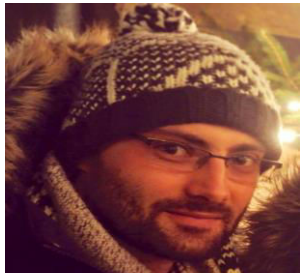
# Microbial Ecosystems in Infrastructure.

Jo Schroeder

Melina Bautista

Maria Sevillano

Rungroch Sungthong



Szymon Calus

Svetlana Perovic

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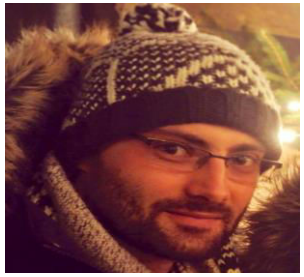

Szymon Calus

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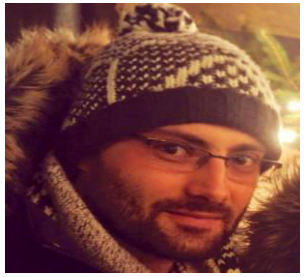

Szymon Calus

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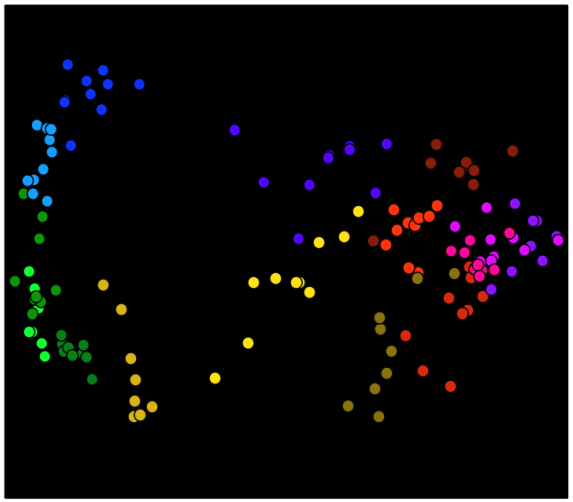
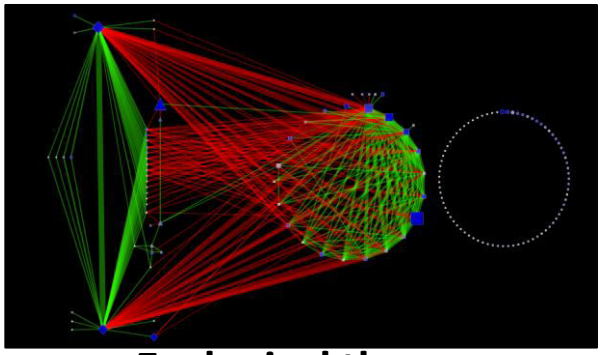
**Technology | Microbiology | Ecology**

Laboratory & Field work



Statistical analyses


Molecular methods



Ecological theory

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# Drinking Water Microbial Ecology.

# Drinking Water Microbial Ecology.

- **Broad implications for public health and wellbeing.**
- **Significant impact on industry.**
- **A vast unexplored potential.**

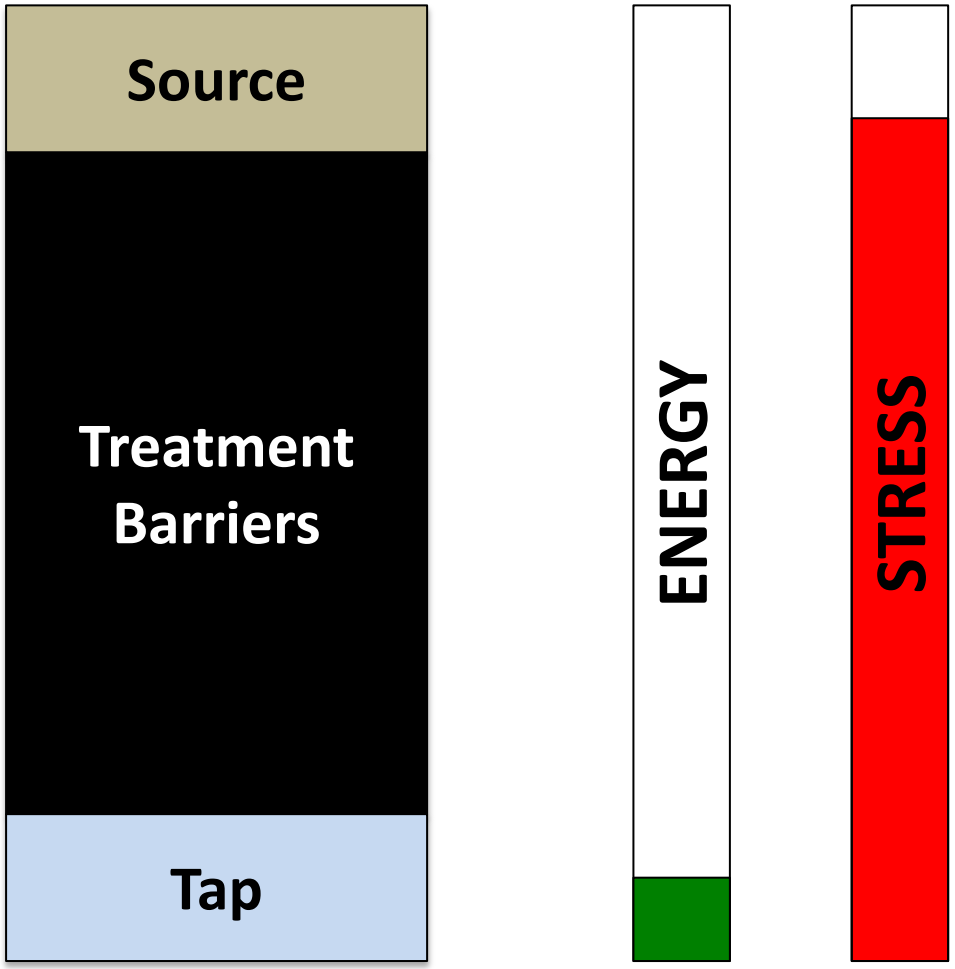
# Drinking water microbiology.

## What?

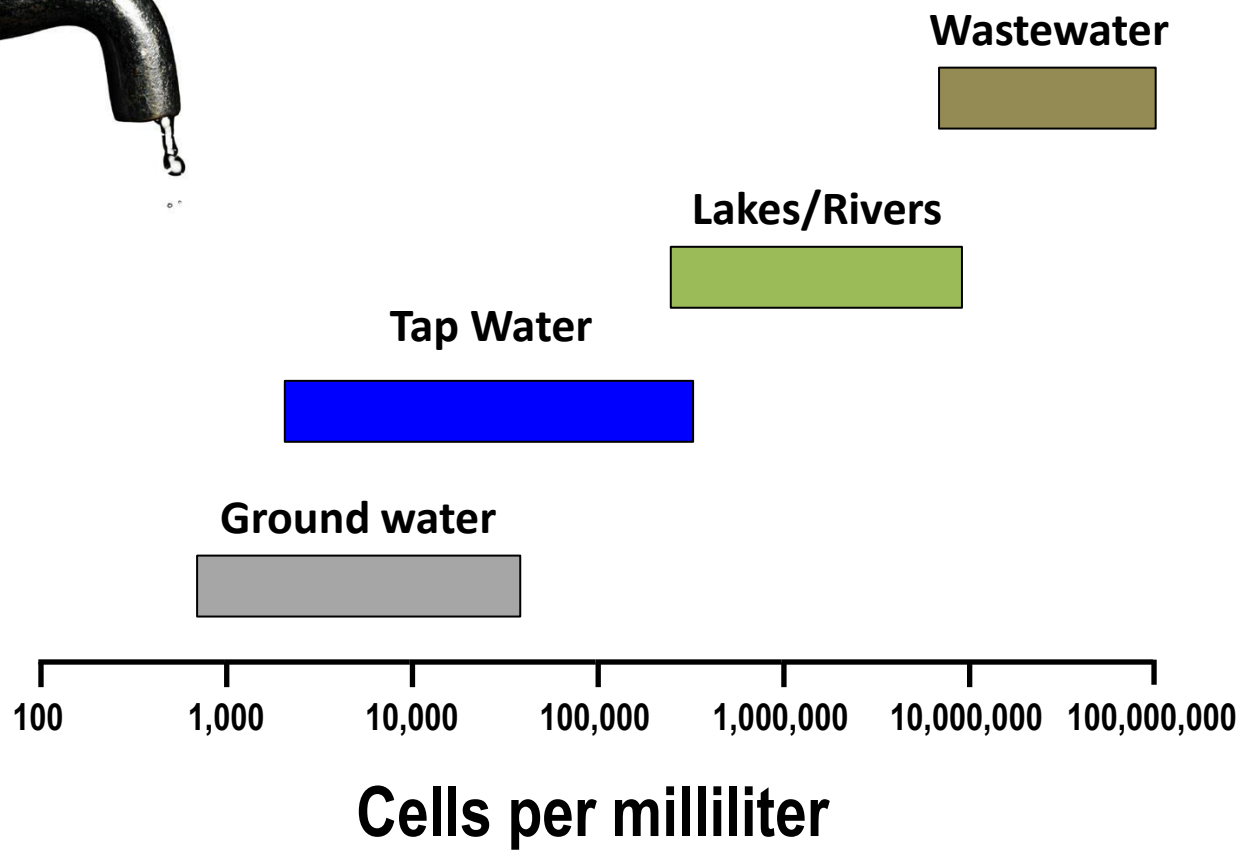
## How?

## Why?

# The drinking water environment is substrate-limited and chronically-stressed.

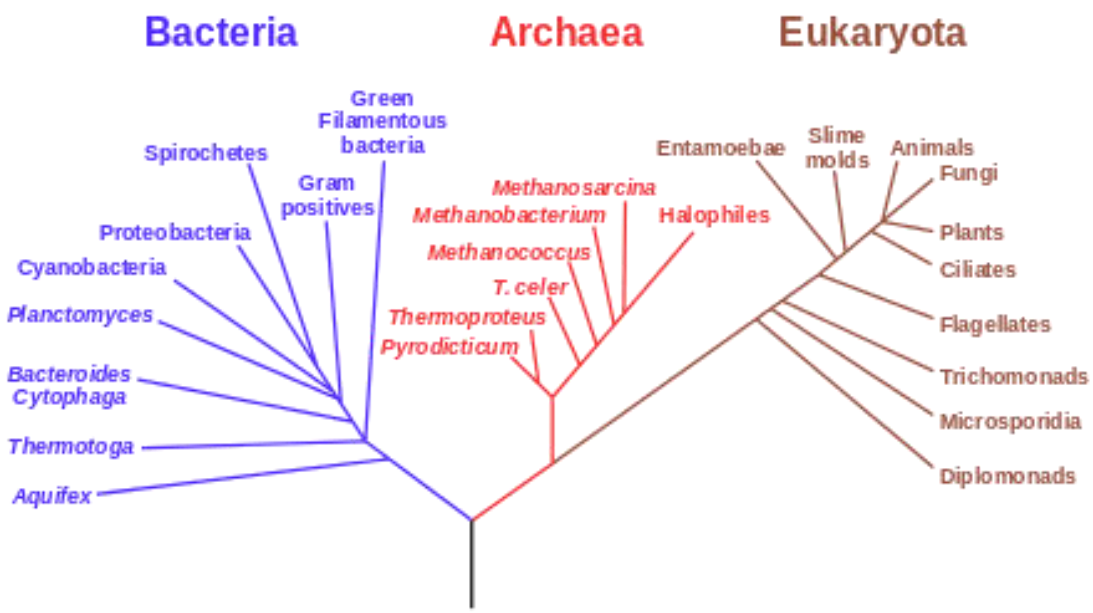


# Every liter of tap water contains millions of microbial cells.




Adapted from Hammes et al, 2010

# Microbial life at the tap is diverse.




$10^6$-$10^8$ cells per liter

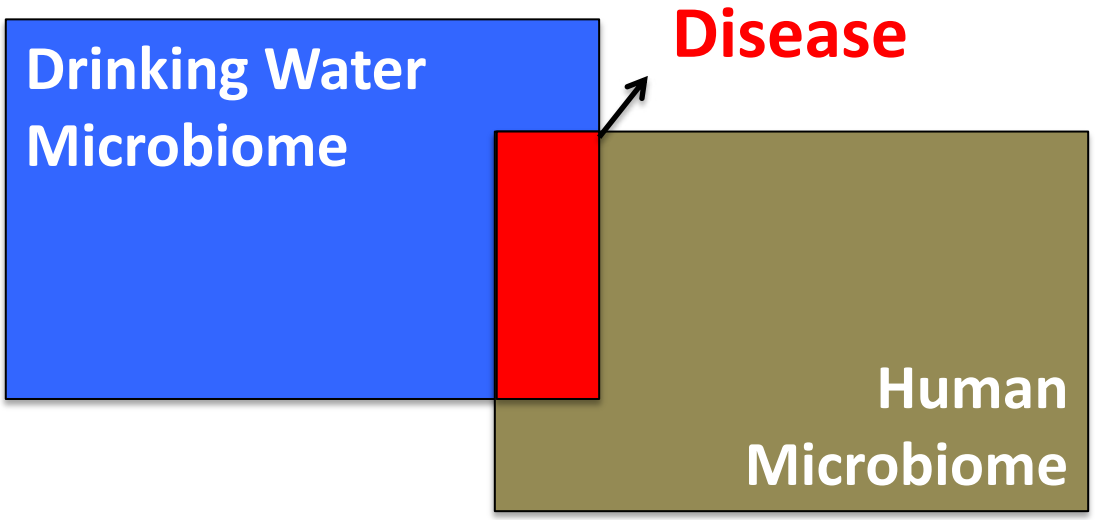
# Drinking water microbiology.

## What?

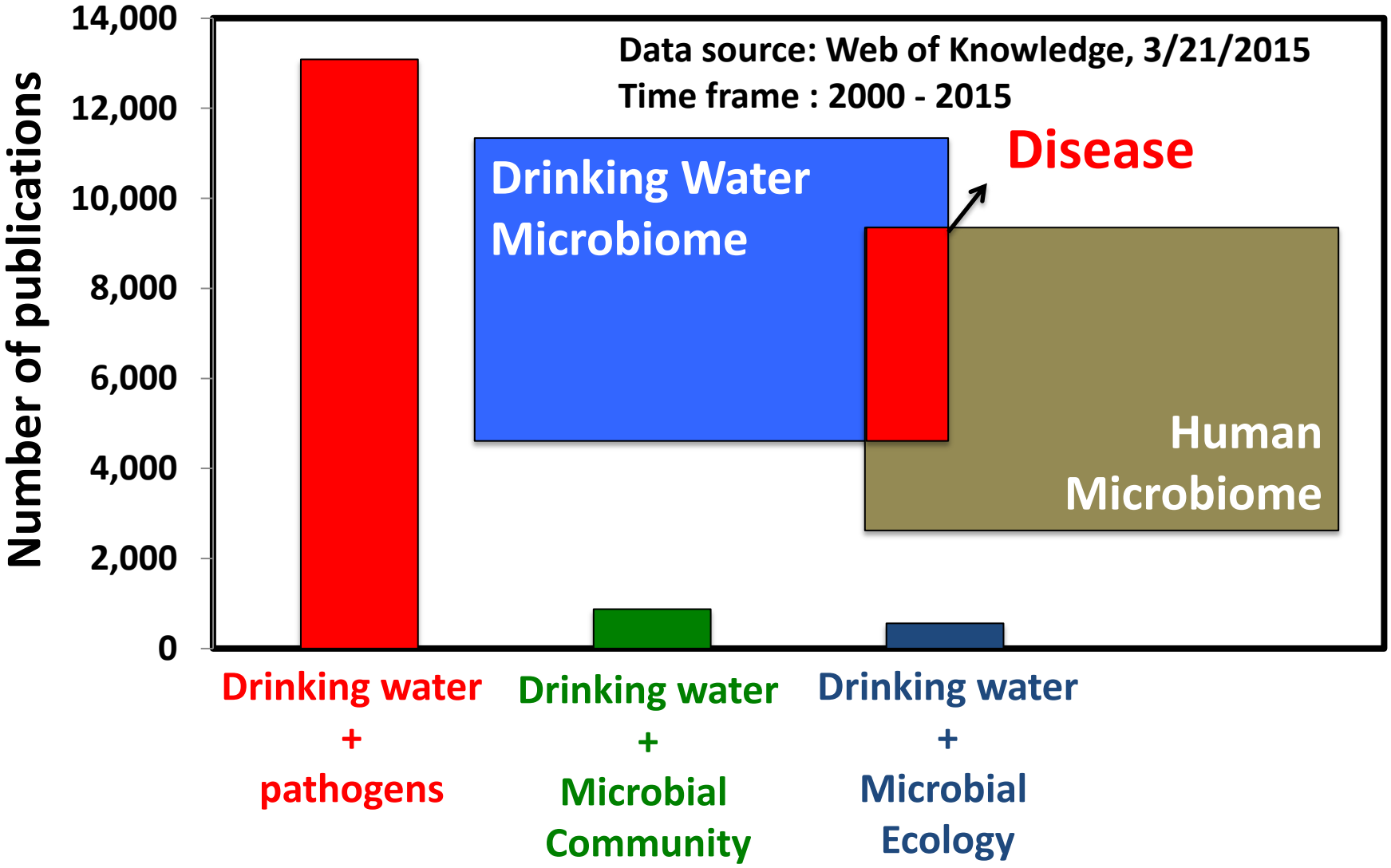
## How?

## Why?

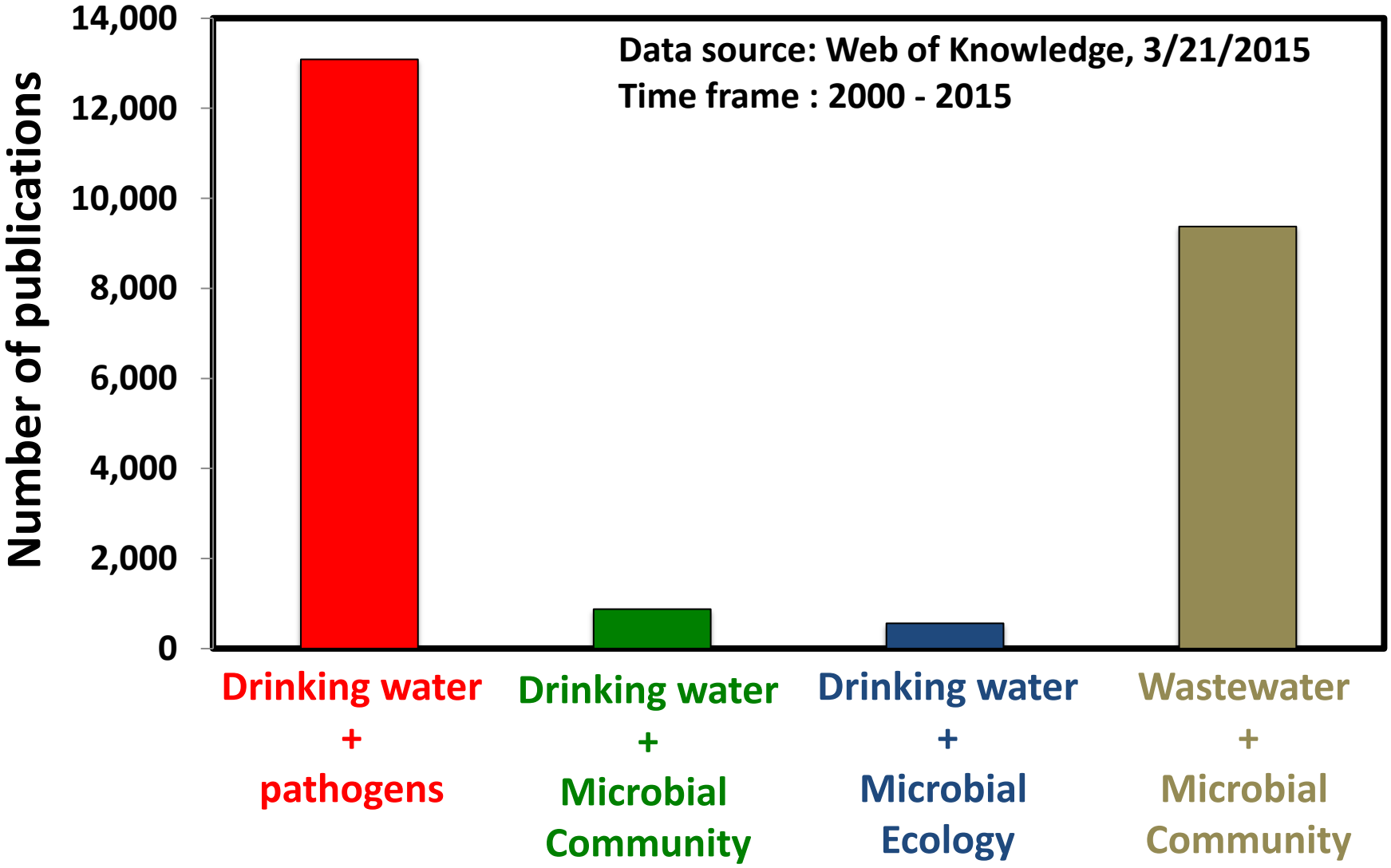
# Research has been driven by a narrow view of "why the drinking water microbiome matters".



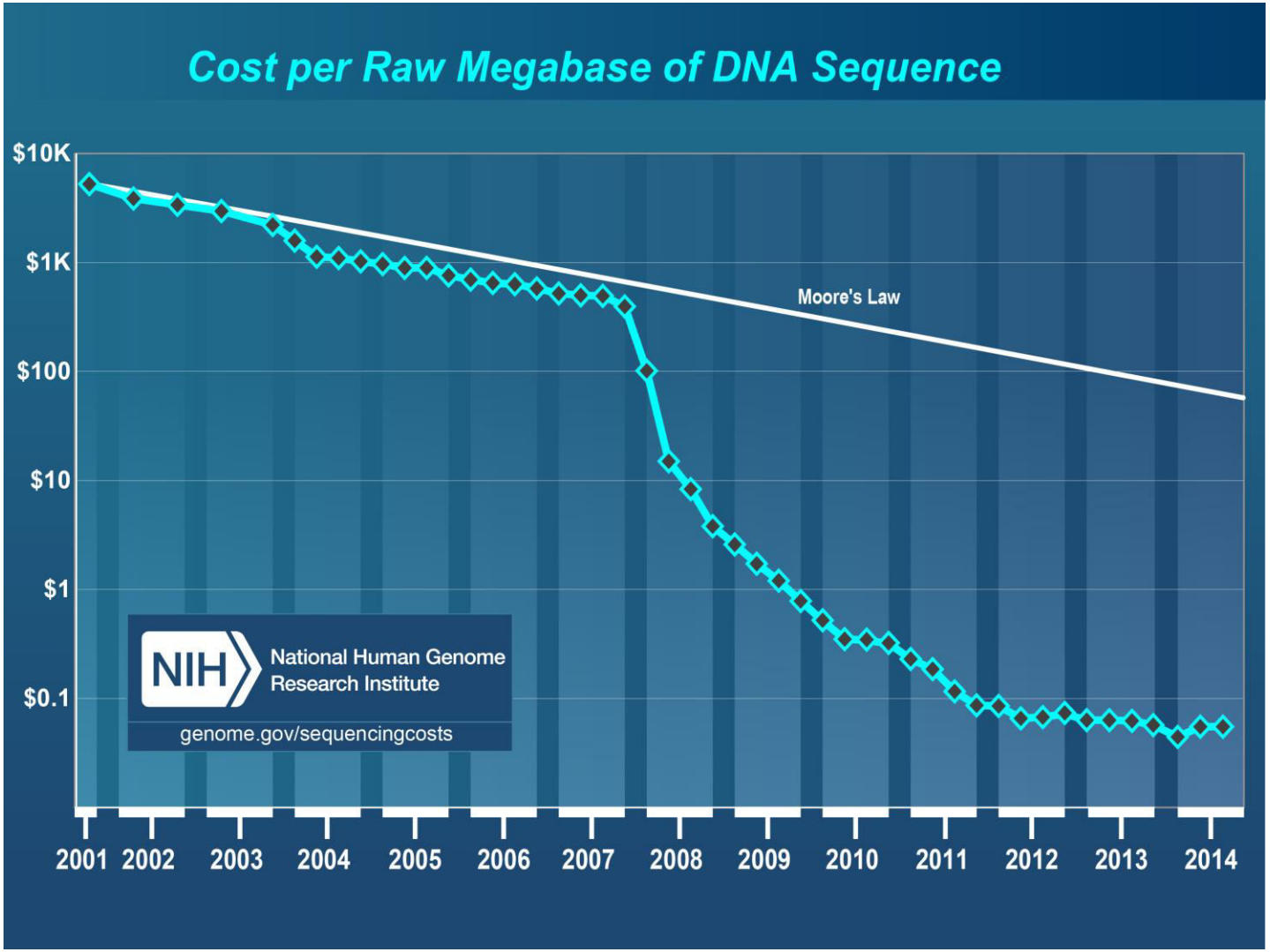
# Drinking water microbial studies have primarily focused on pathogens.



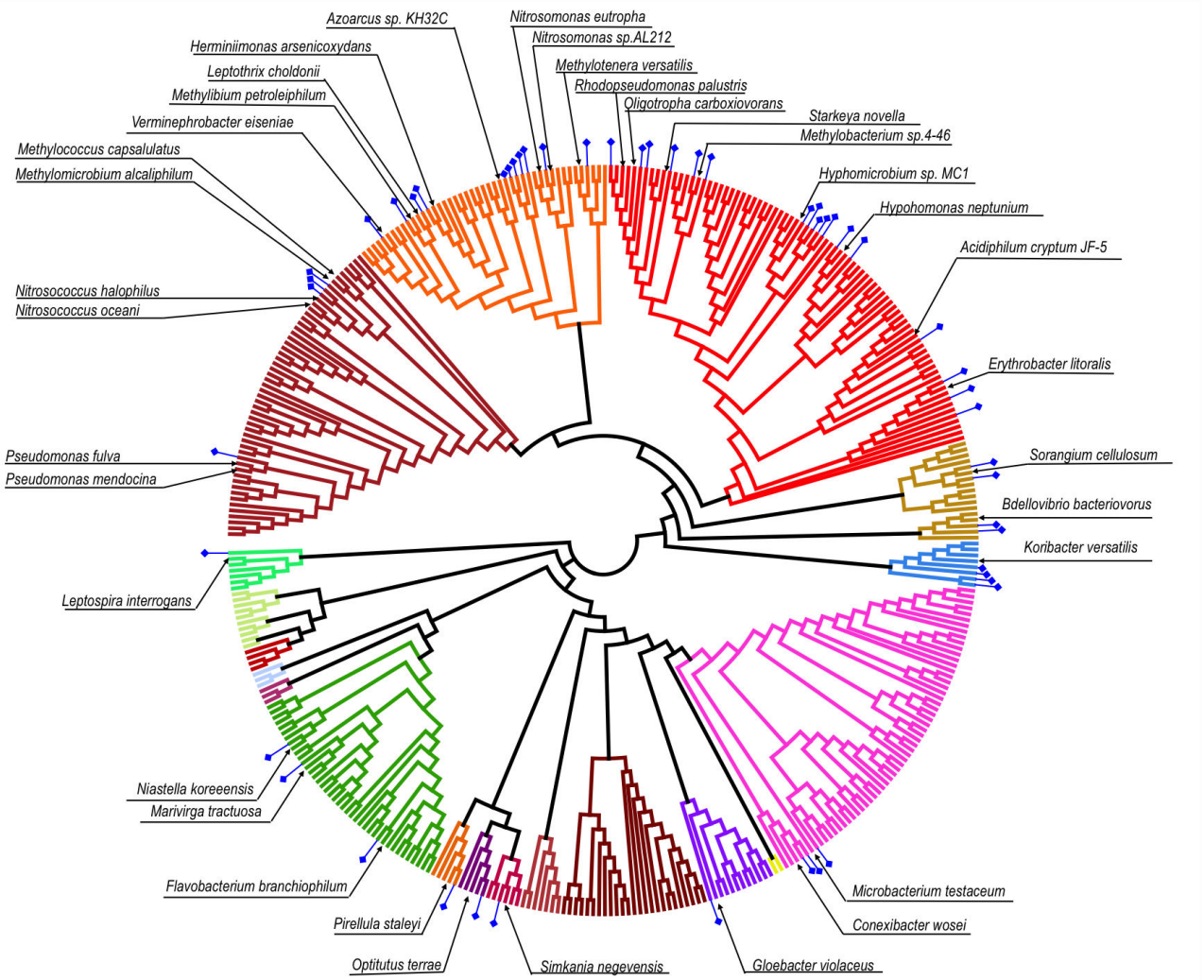
# Microbial community approach can help reshape out water infrastructure and policy.



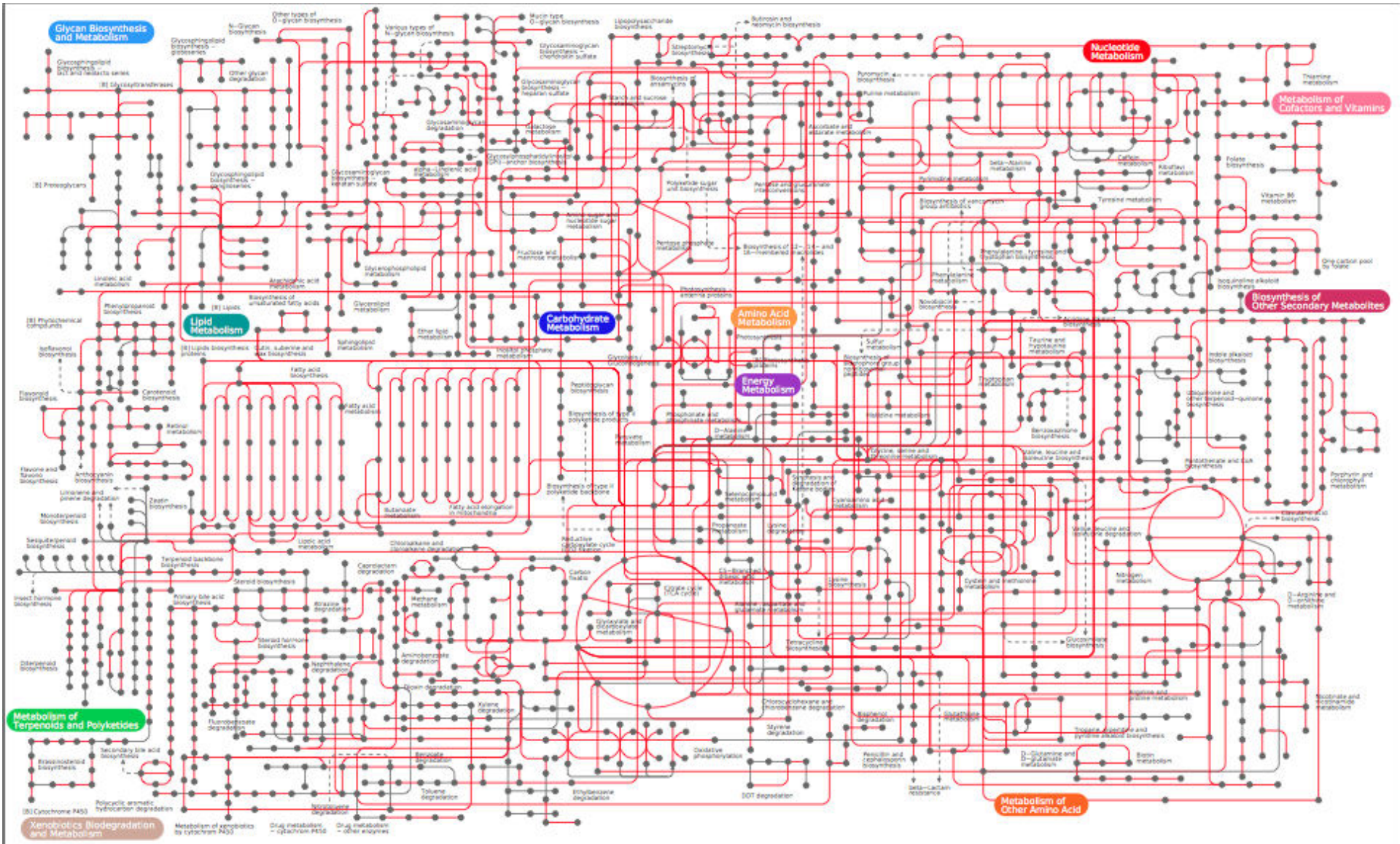
# A microbial community level understanding is feasible.



# Sequencing can not only reveal who is present in a sample,



# Sequencing can not only reveal who is present in a sample, but also what they can do.



# The possibilities of sequencing based monitoring are rapidly changing.

# The possibilities of sequencing based monitoring are rapidly changing.


# Sequencing in the field in real time.

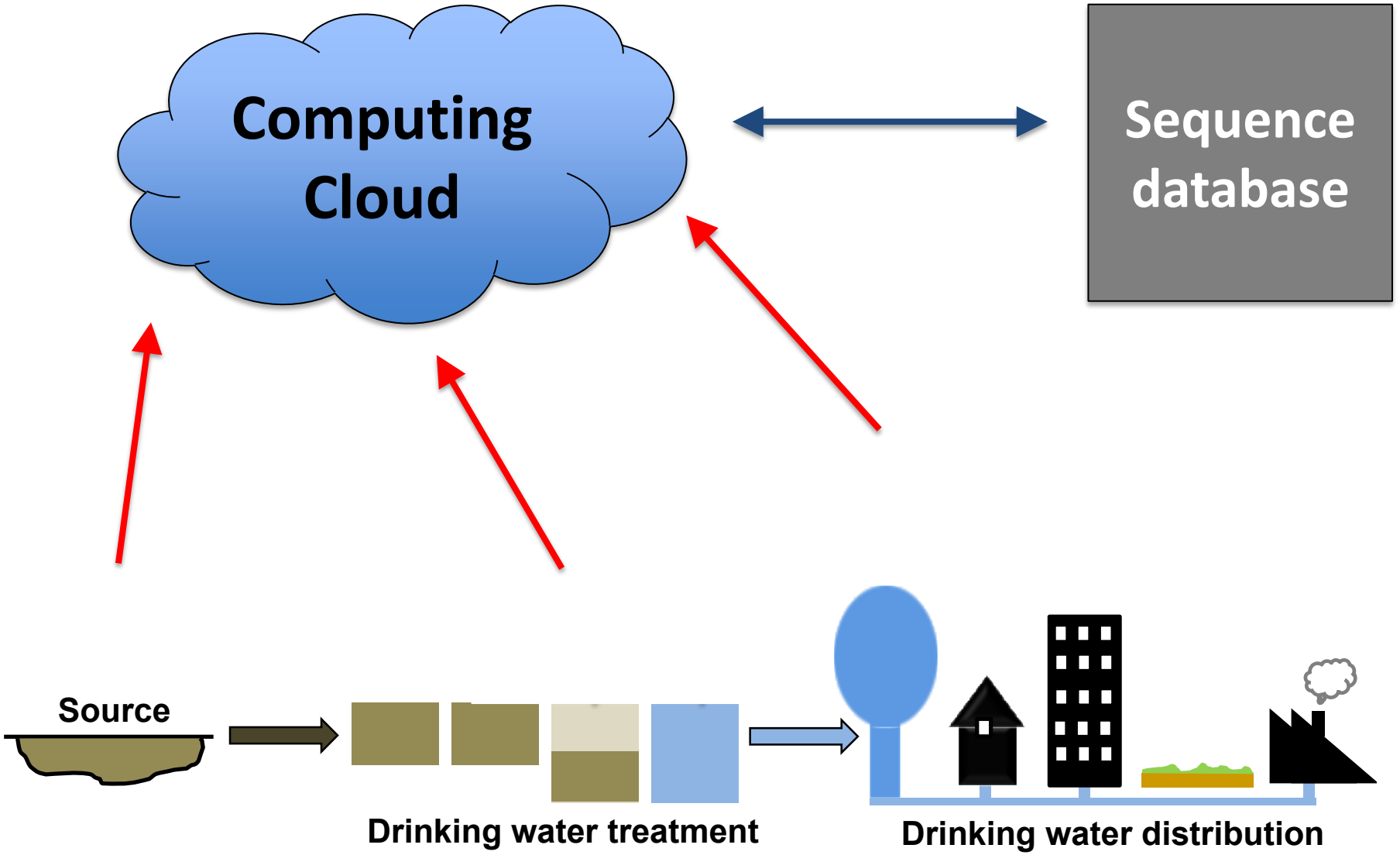

EMLab

European Mobile Laboratory Project

Background | Concept | Activities | Units | Partners | News & Events

http://theconversation.com/
www.nature.com

# We are developing pipelines for real-time monitoring of water microbiology.



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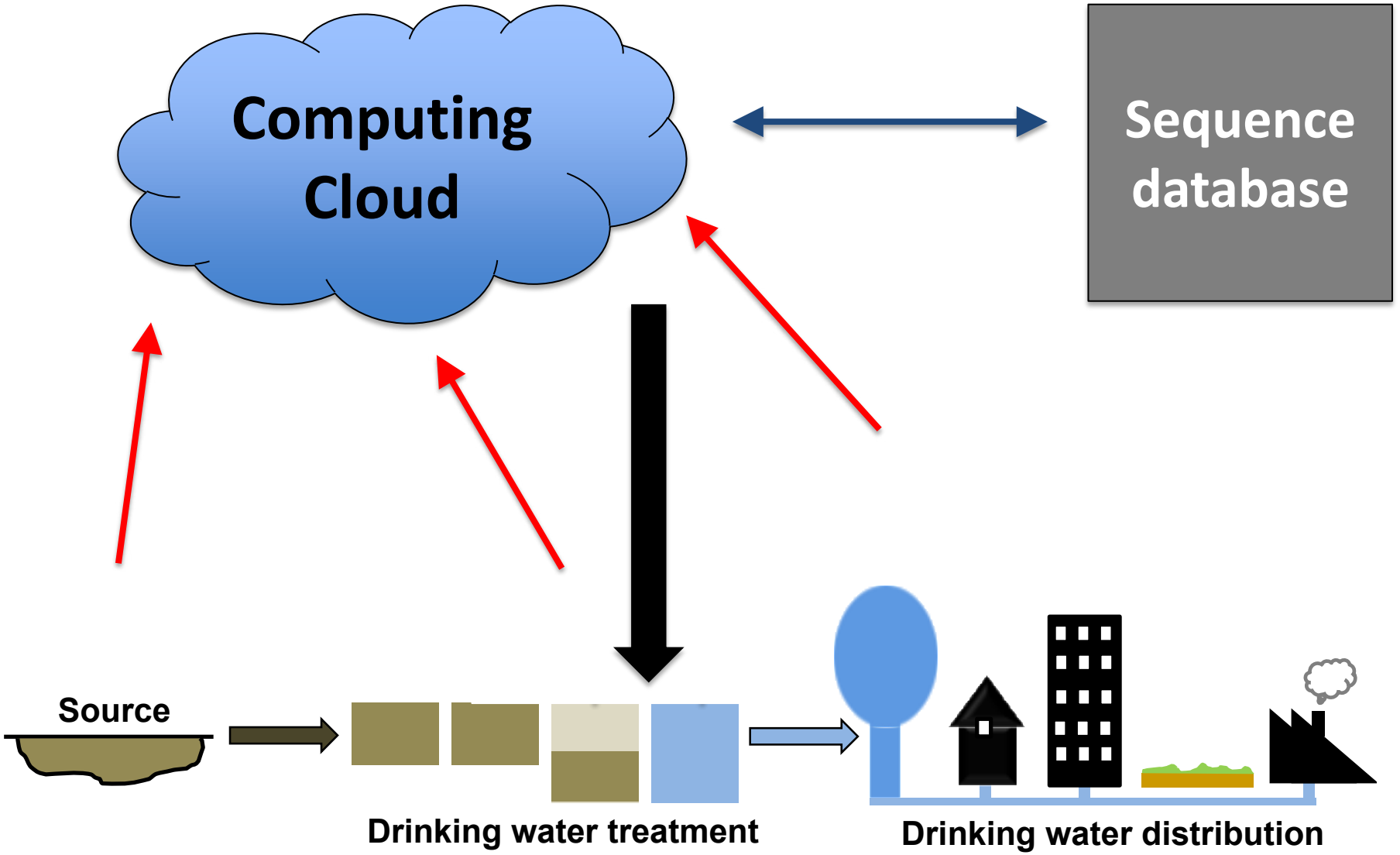


# Drinking water microbiology.

What?

**How?**

Why?

# Managing the impact of microbial communities in drinking water is central to safe water provision.

Disease

Infrastructure Damage

Aesthetic quality

Well managed

Compliance > 99.9%

Poorly managed

# Majority of microbial impacts are not yet well understood or managed.

**In UK,**
**25% of water is lost**
**170 main bursts per 1000 km**

**In USA,**
**15% of water is lost**
**150 main bursts per 1000 km**

**Infrastructure Damage**

**Aesthetic quality**

**Poorly managed**

# Integrate other microbial risks into disease monitoring framework.

**Disease**

**Infrastructure Damage**

**Aesthetic quality**

**Well managed**

**Compliance > 99.9%**

**Poorly managed**

# Is 99.9% compliance good?

**Disease**

**Well managed**

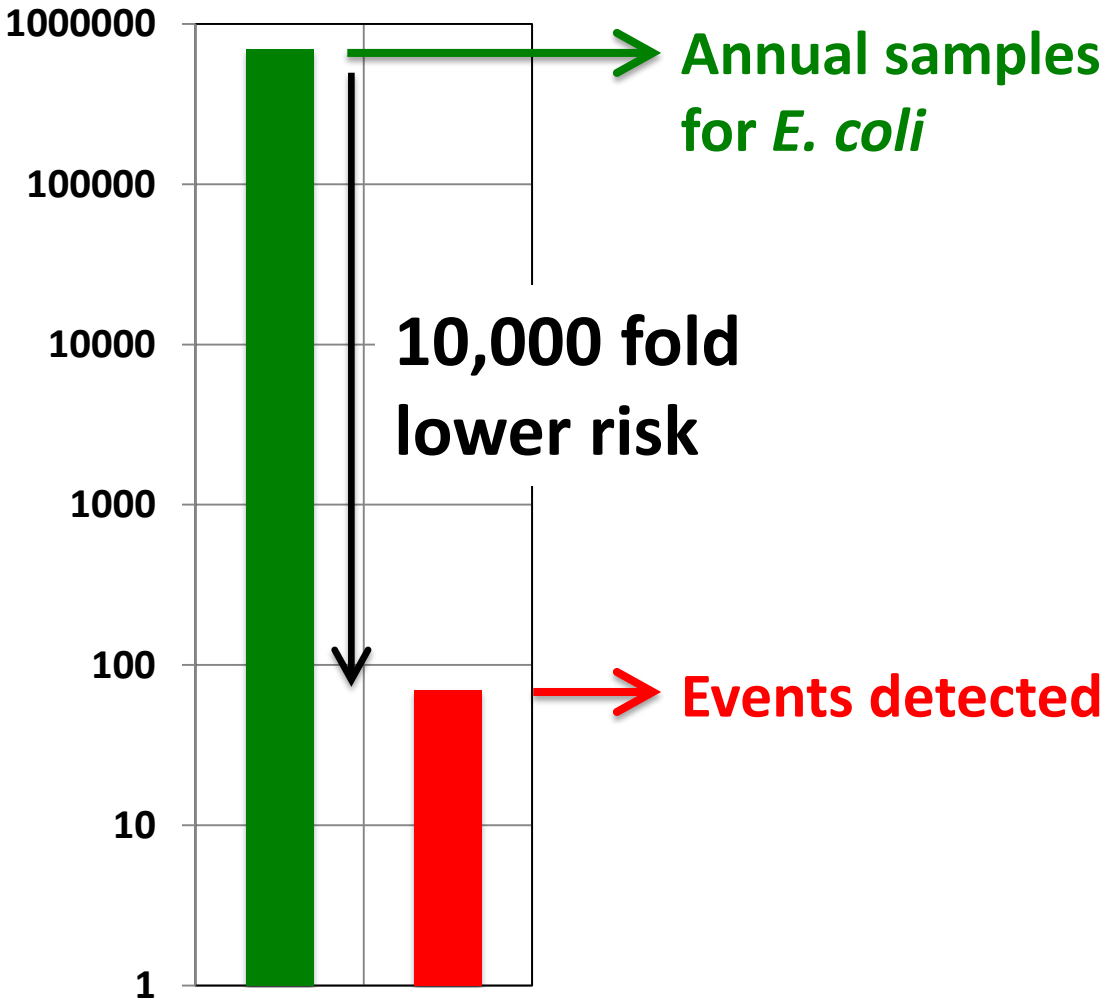
**Compliance > 99.9%**

# Is 99.9% compliance good?

**Disease**

**Well managed**

**Compliance > 99.9%**

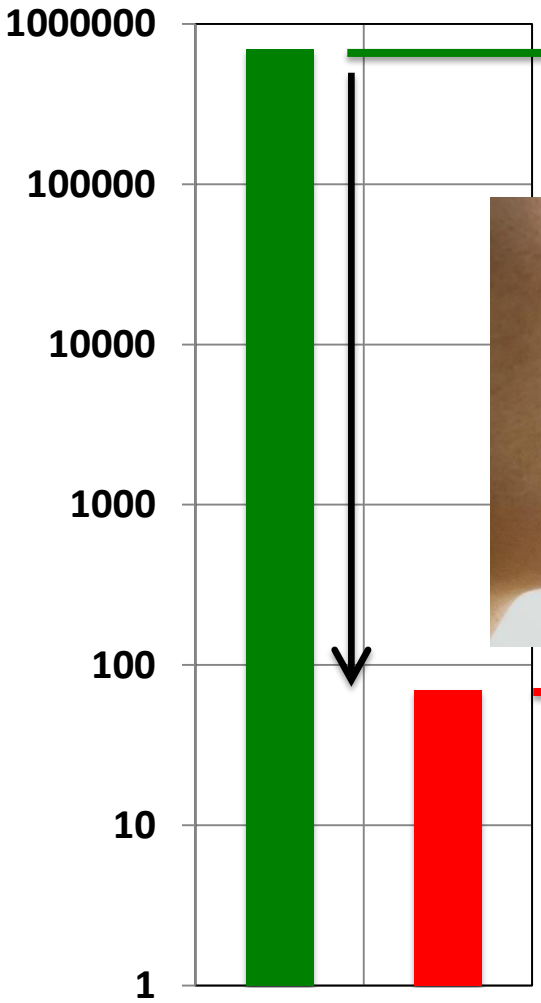


# Is 99.9% compliance good?

**Disease**

**Well managed**

**Compliance > 99.9%**




**Annual samples for *E. coli***

**Events detected**

**Data available after water is consumed**

# Water quality monitoring is an expensive & inefficient forensic exercise.

# Developing an alternative to this "Event Detection and Mitigation" paradigm.

**Disease**

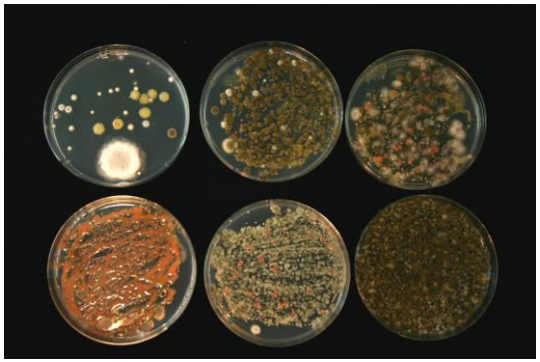
**Infrastructure Damage**

**Aesthetic quality**

# Event Prediction and Correction Approach.

**Comprehensive**

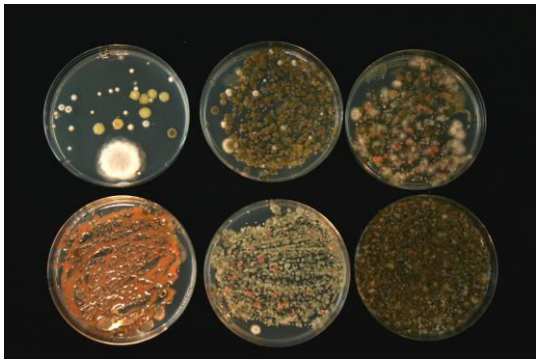


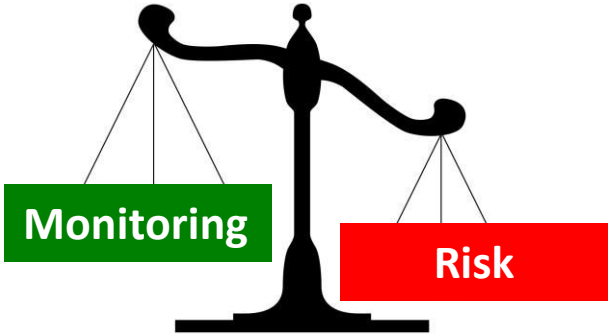
# Event Prediction and Correction Approach.

## Comprehensive



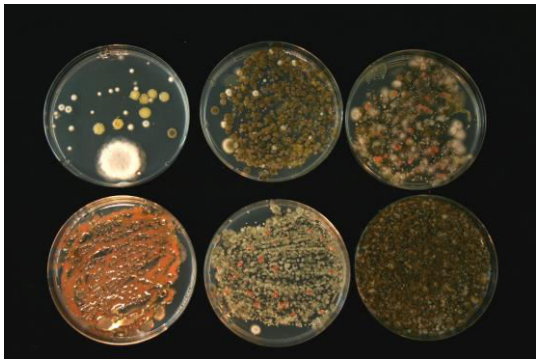
## Resource smart



# Event Prediction and Correction Approach.

## Comprehensive



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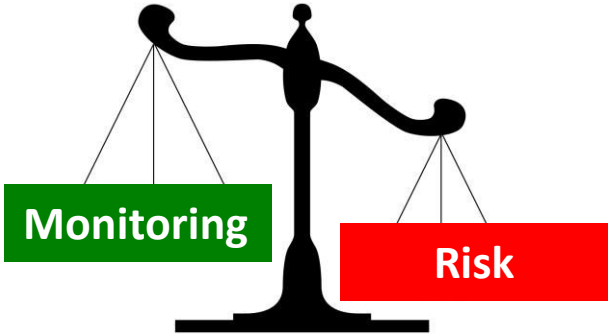



## Predictive

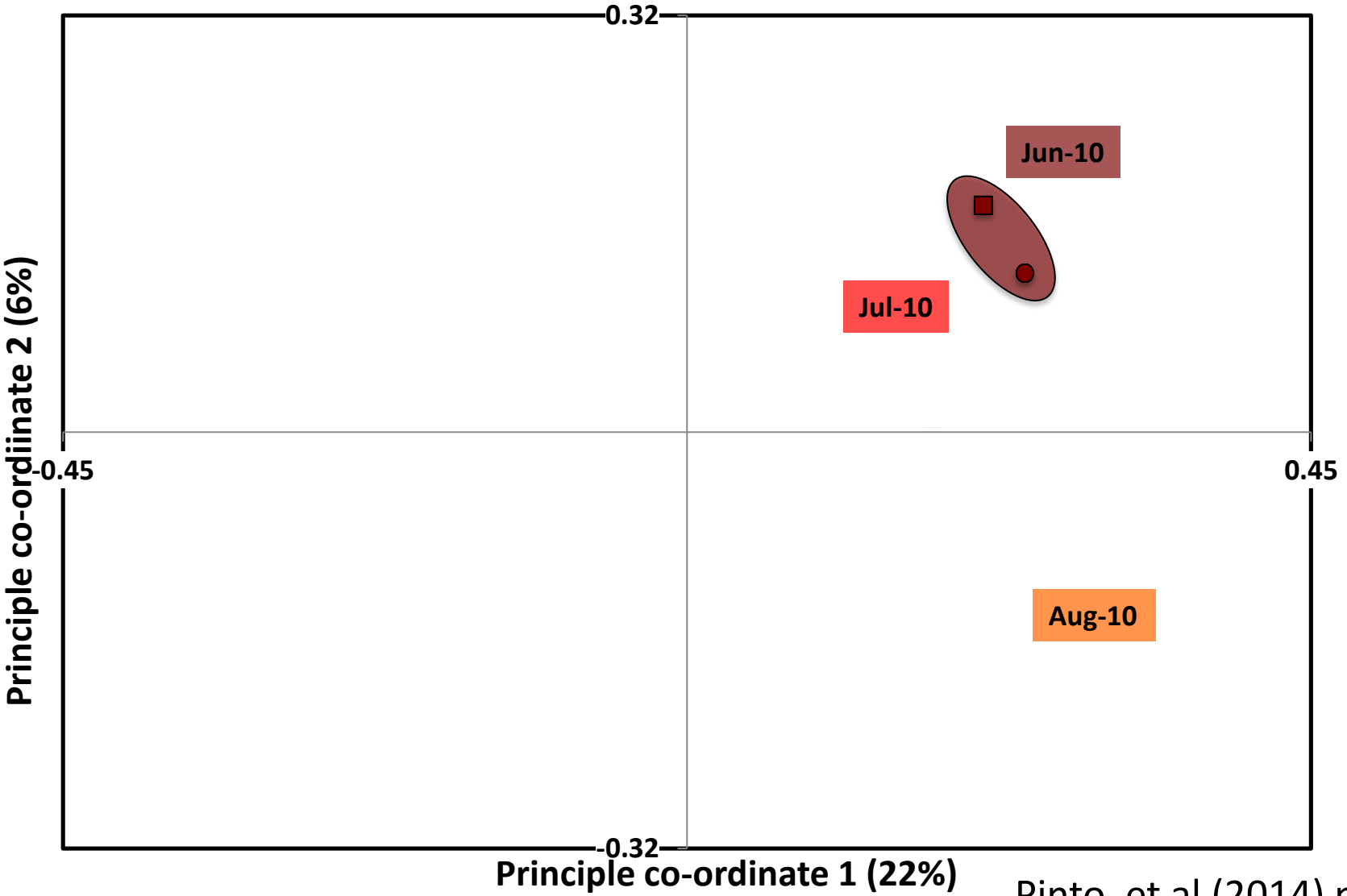
# Extract community level traits for exploitation in predictive framework.

Extract community level traits for exploitation in predictive framework.

# 6

key features of drinking water bacterial communities.

# Temporal change in community structure.




Pinto, et al (2014) mBio

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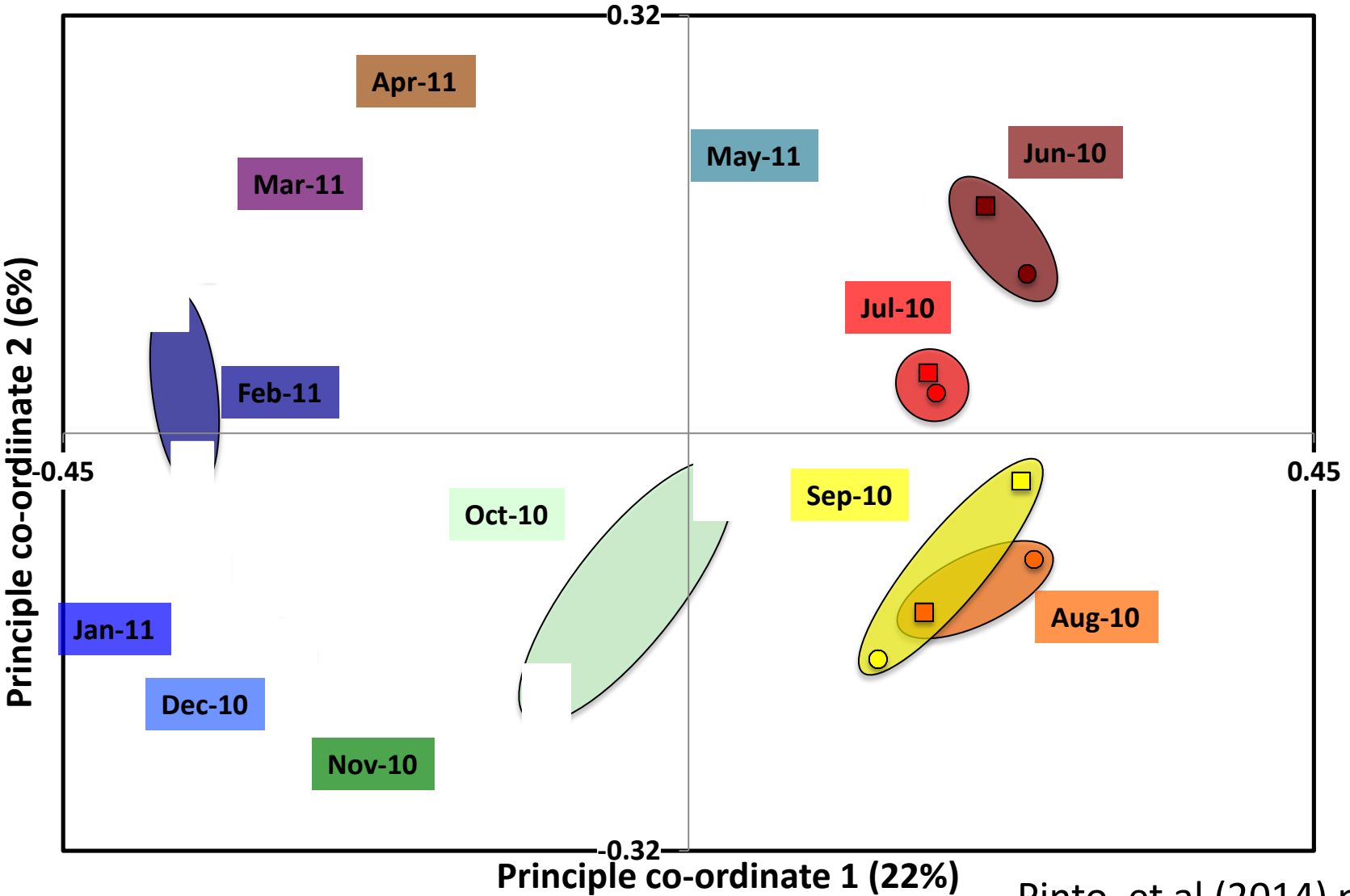


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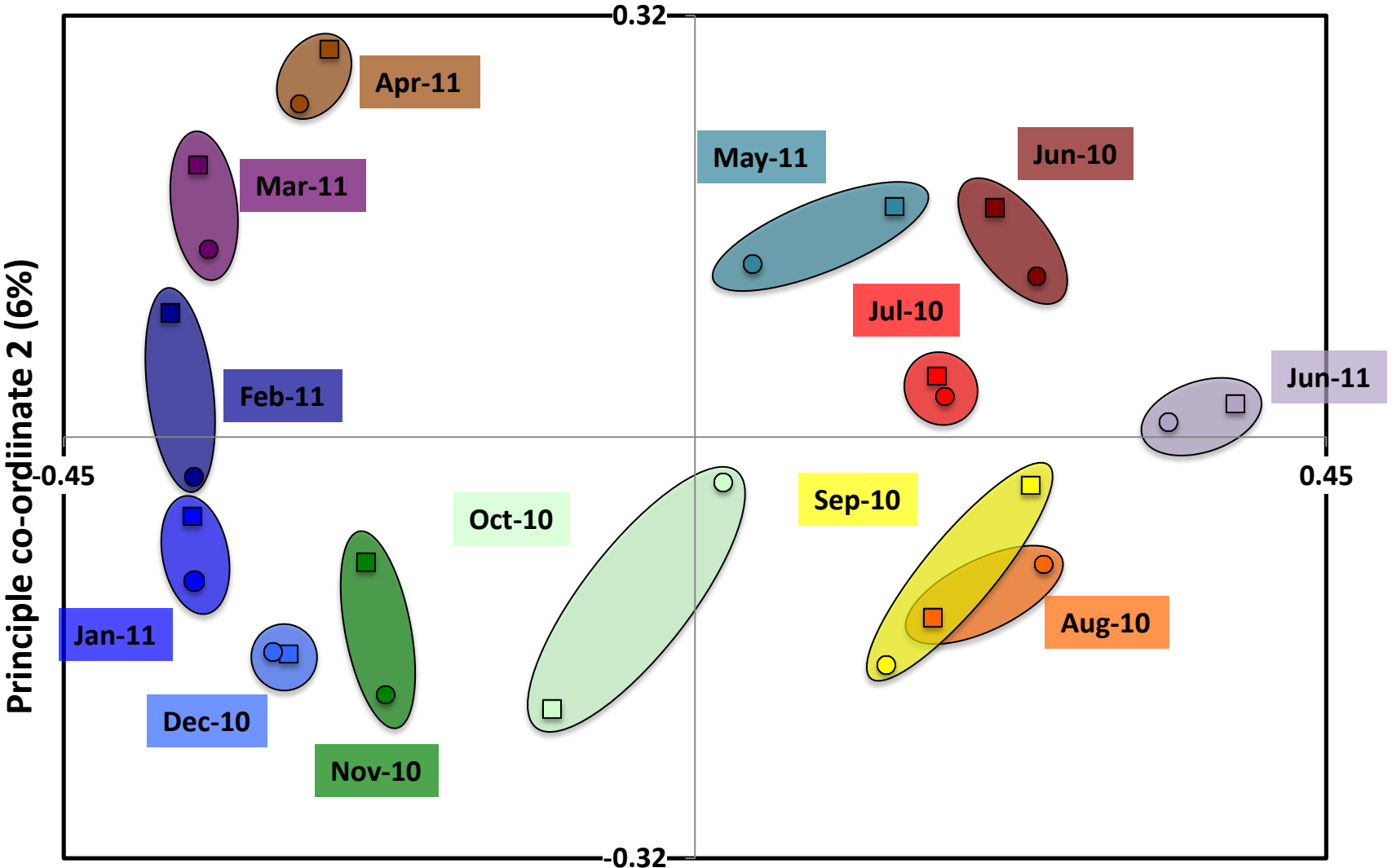


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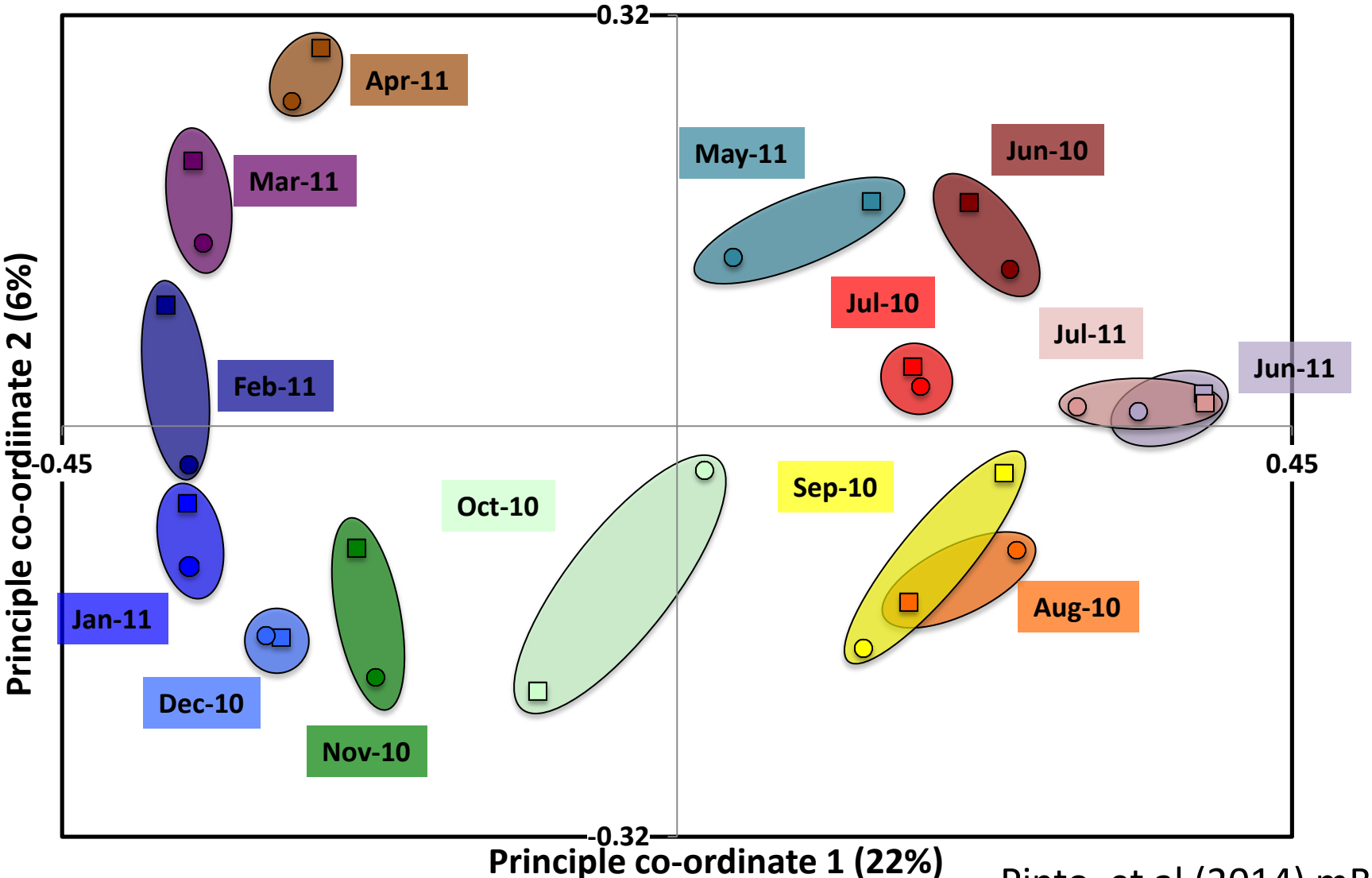


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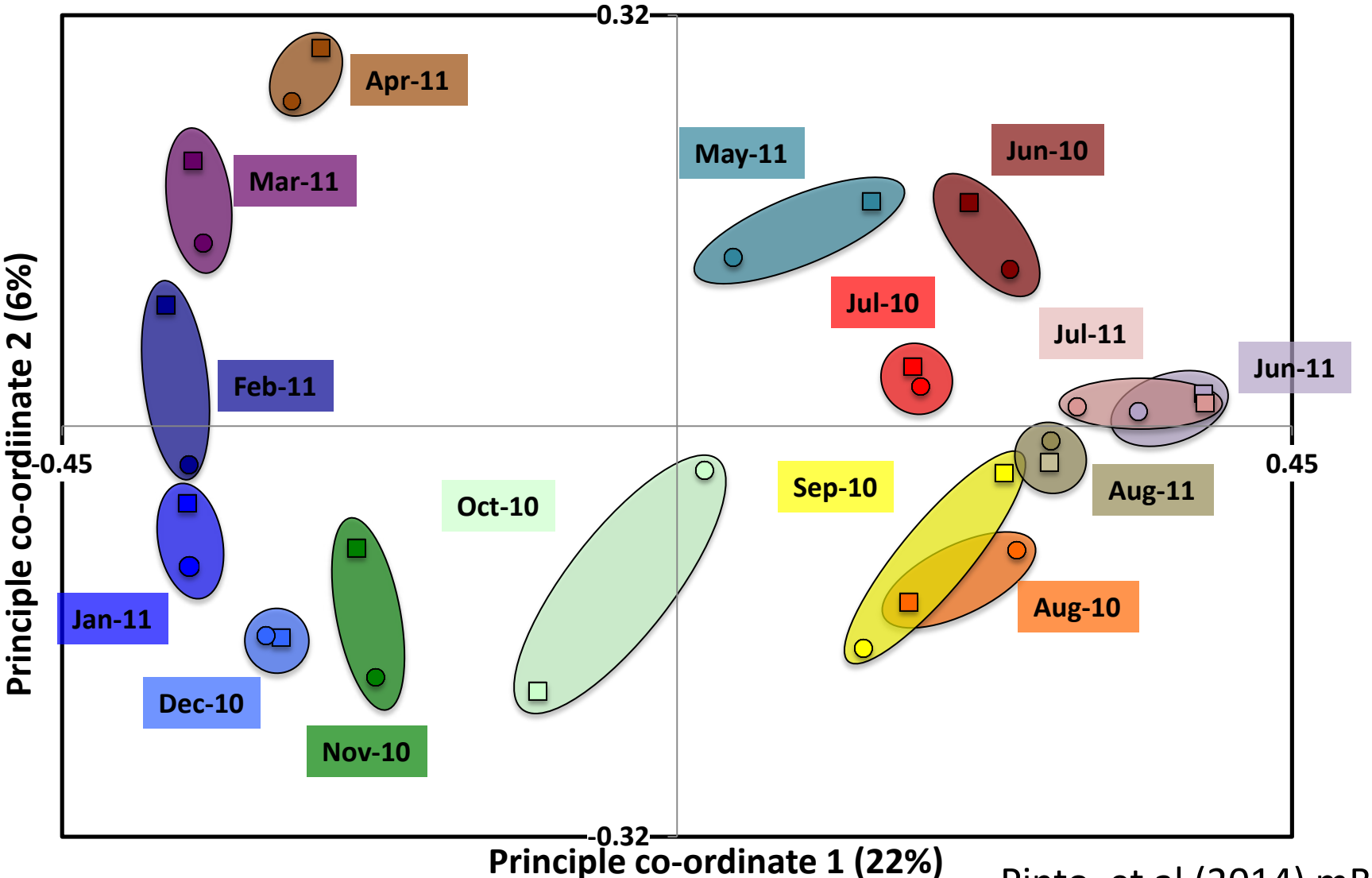
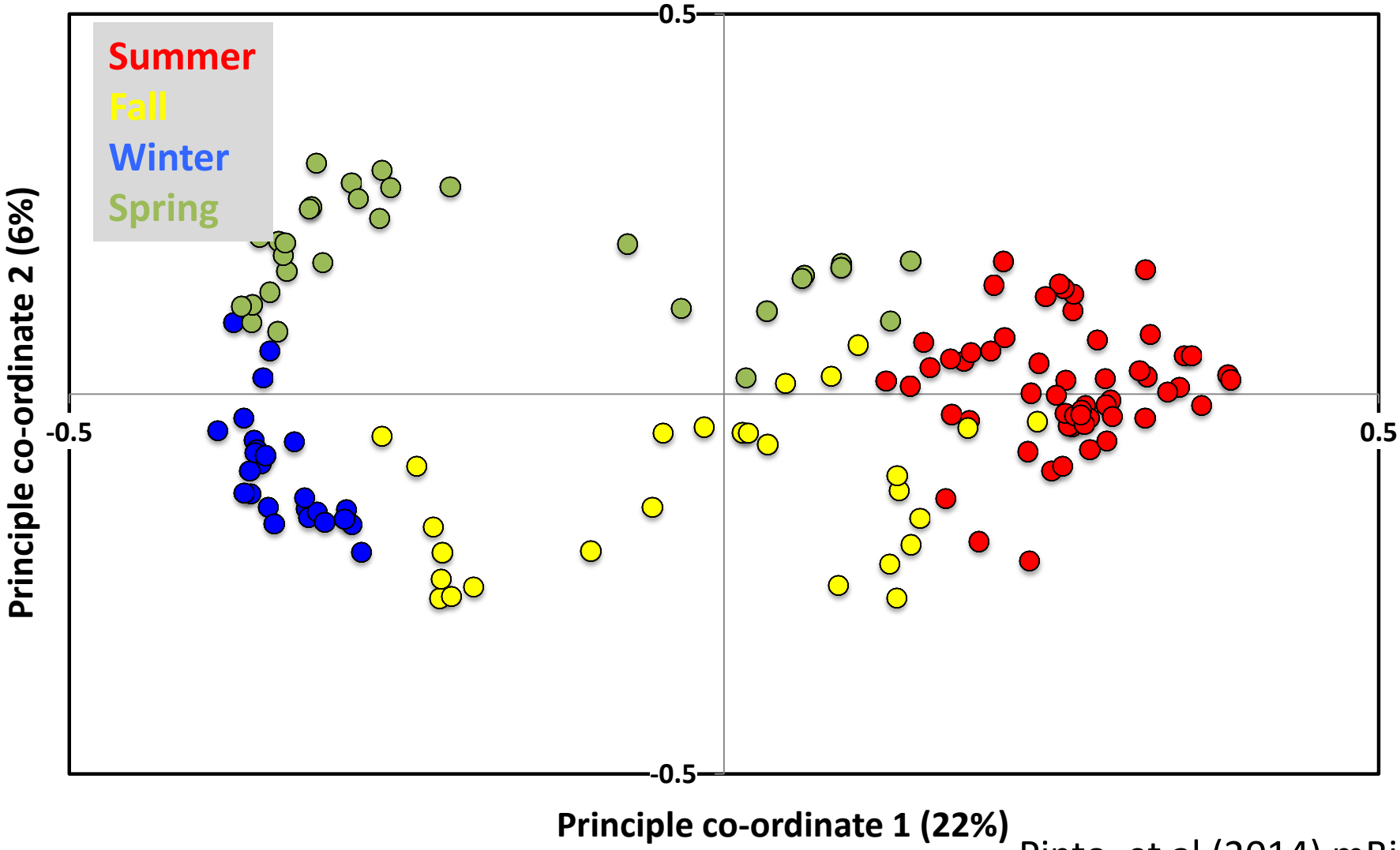


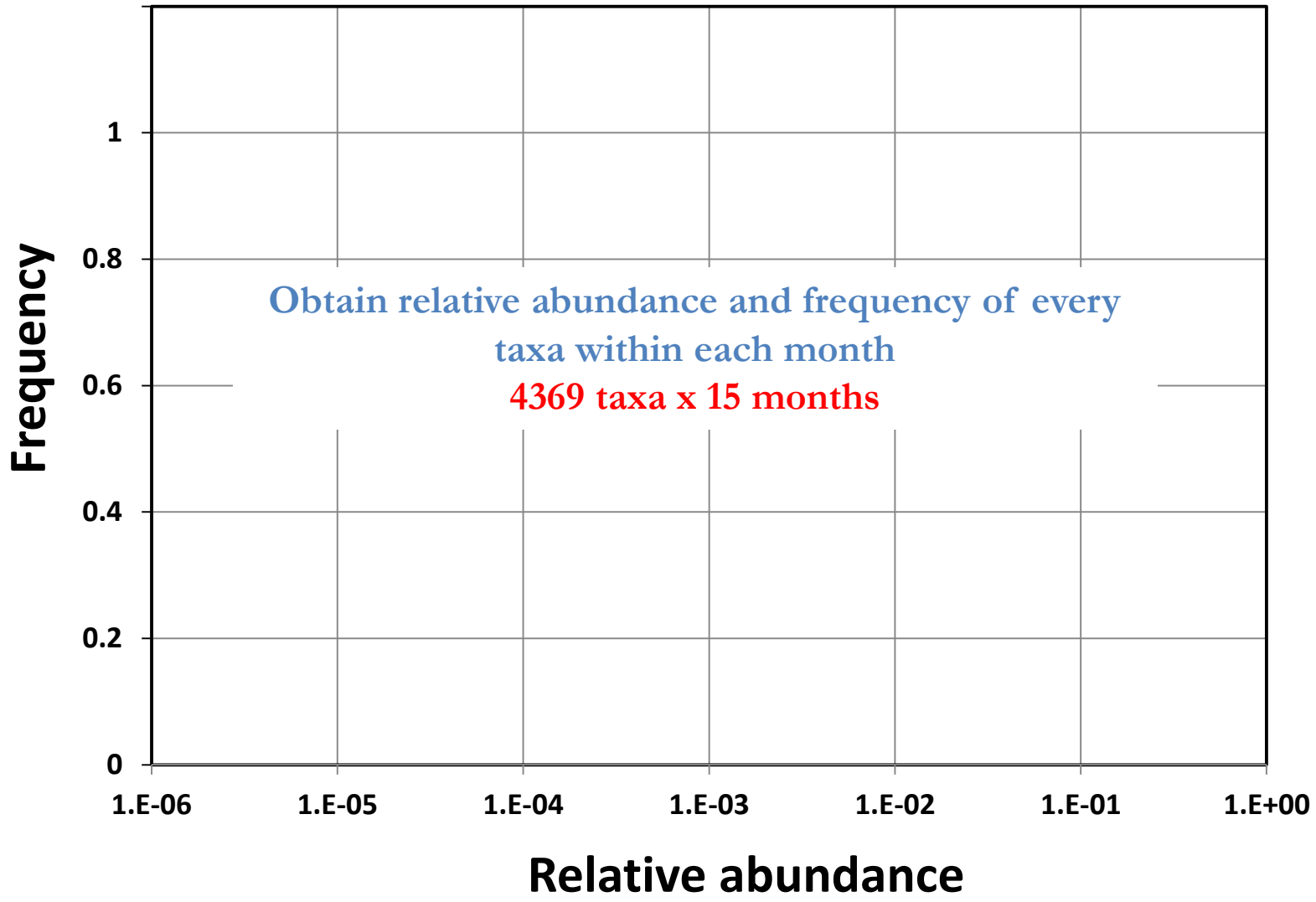

Pinto, et al (2014) mBio

# Annual cycling of drinking water community may a key feature guiding the predictive framework.



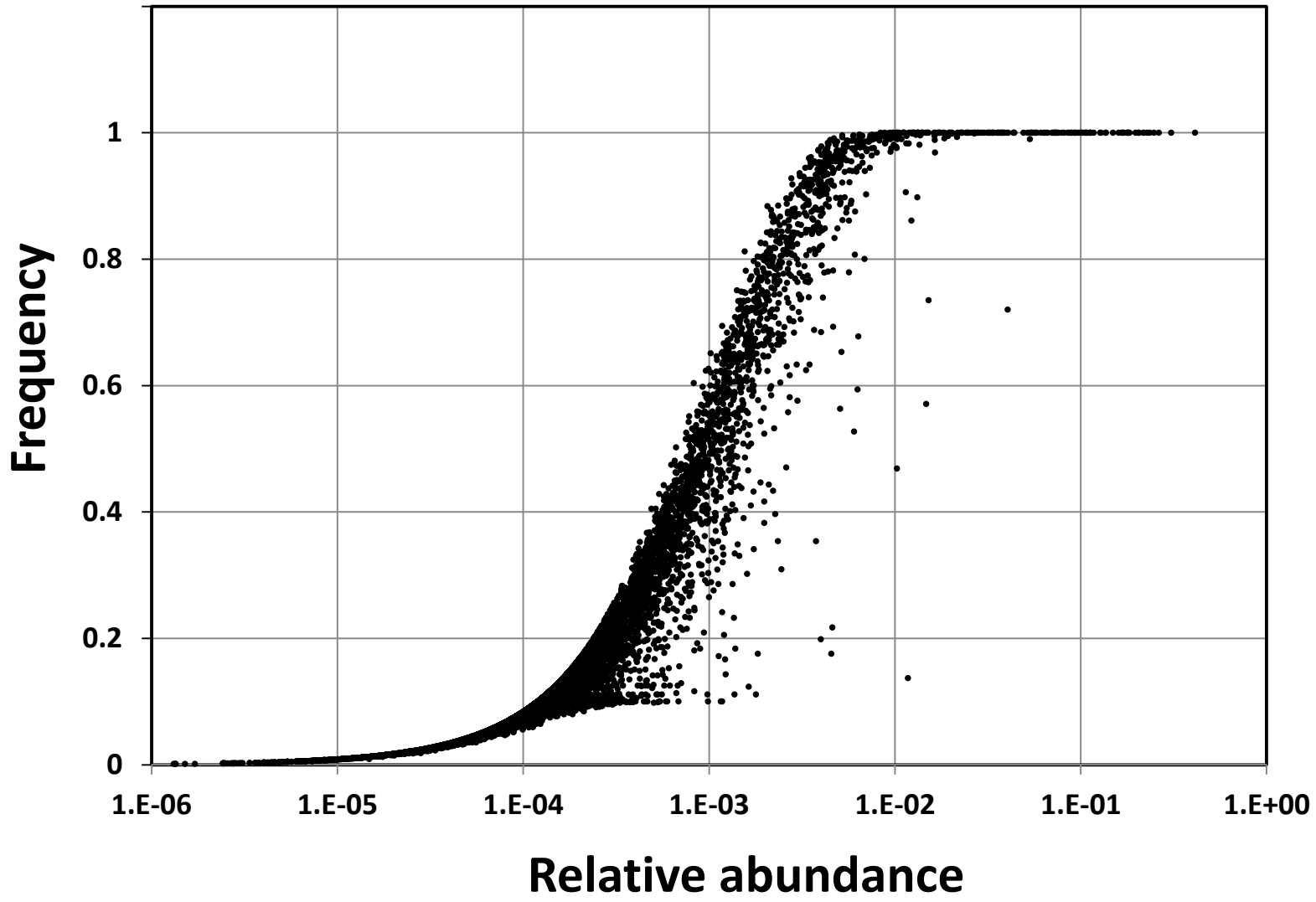

Pinto, et al (2014) mBio

# Bacterial communities exhibit relationship between frequency & abundance.




Pinto, et al (2014) mBio

# Proportionality between abundance and detection frequency can be exploited.

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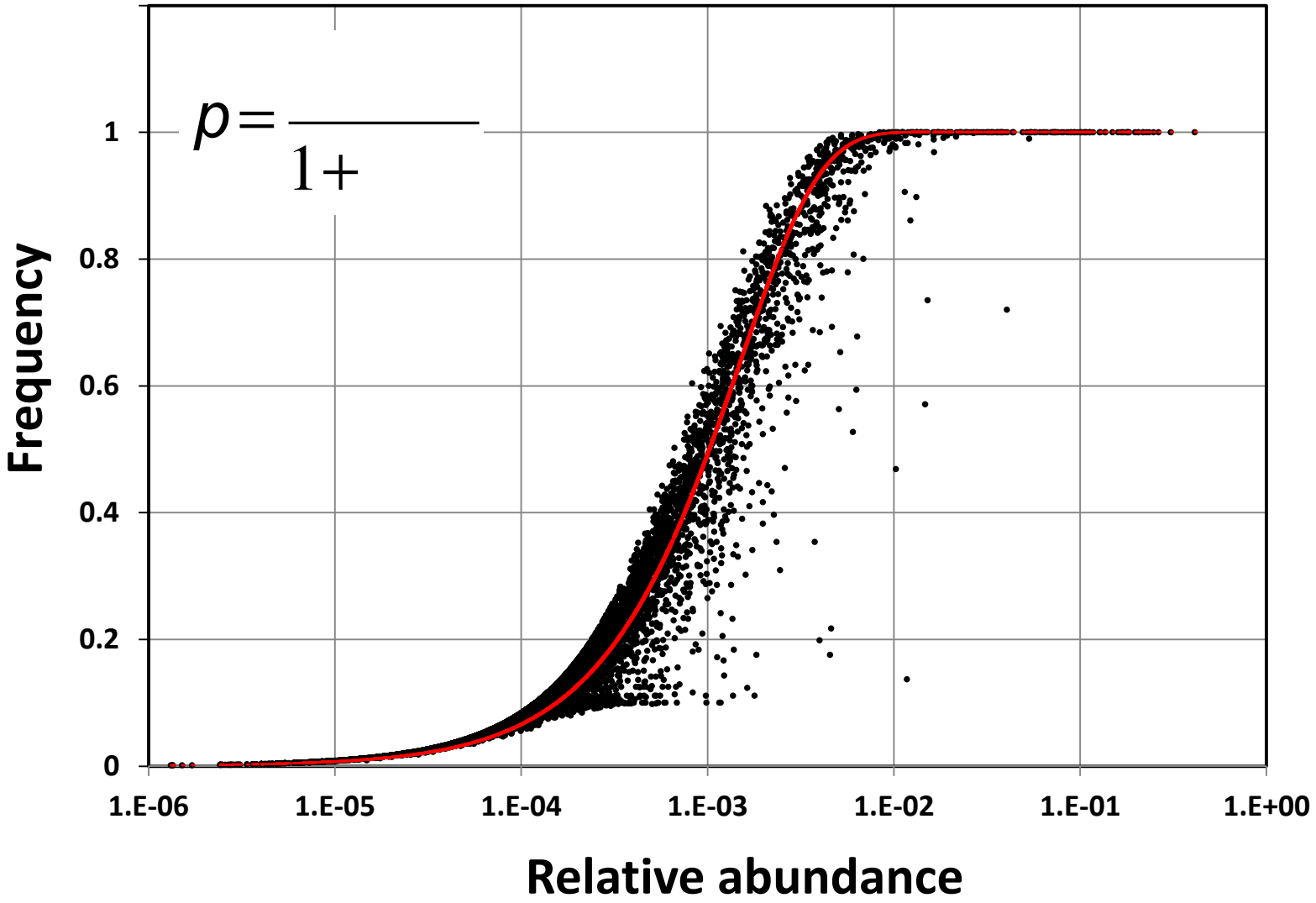


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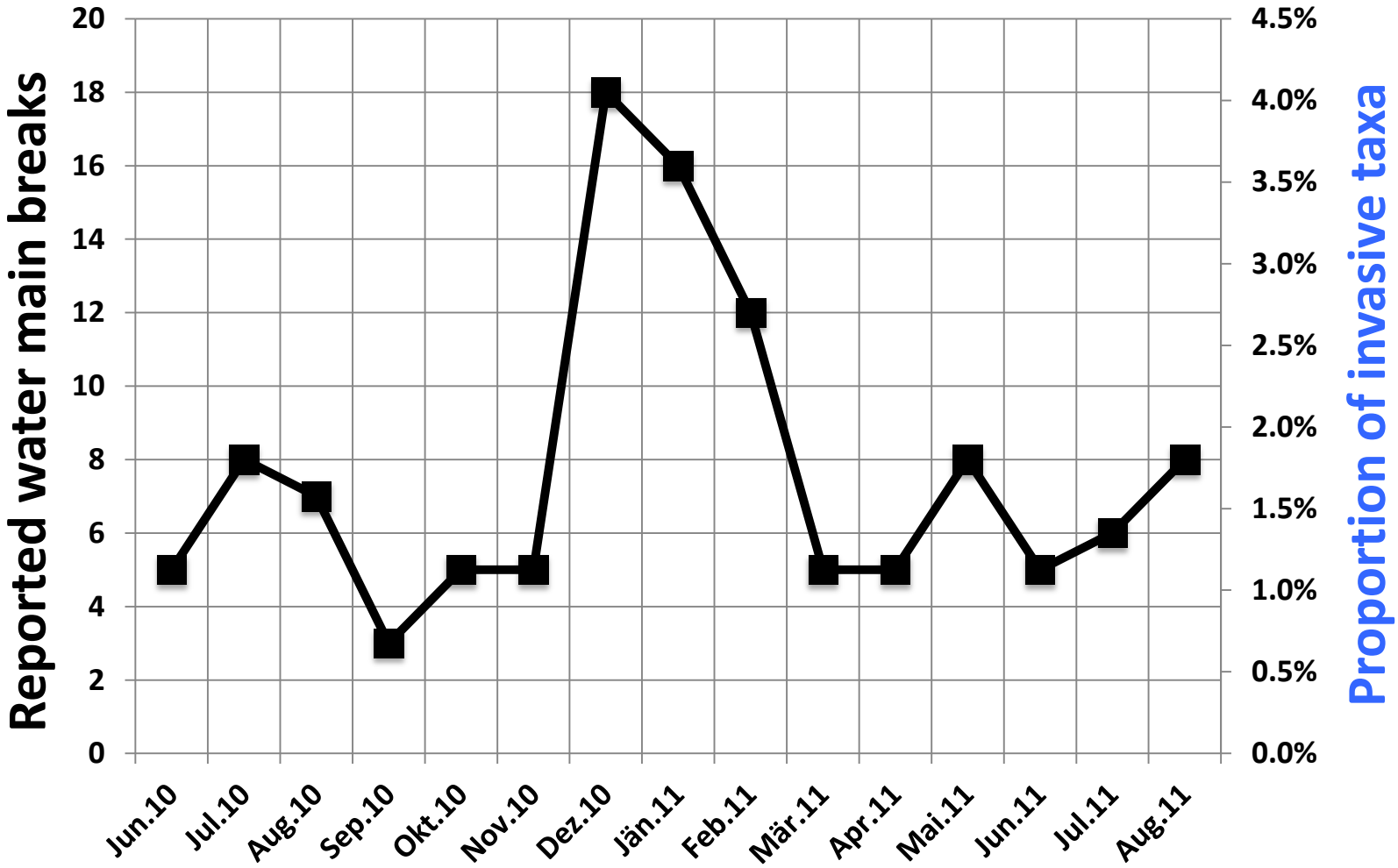
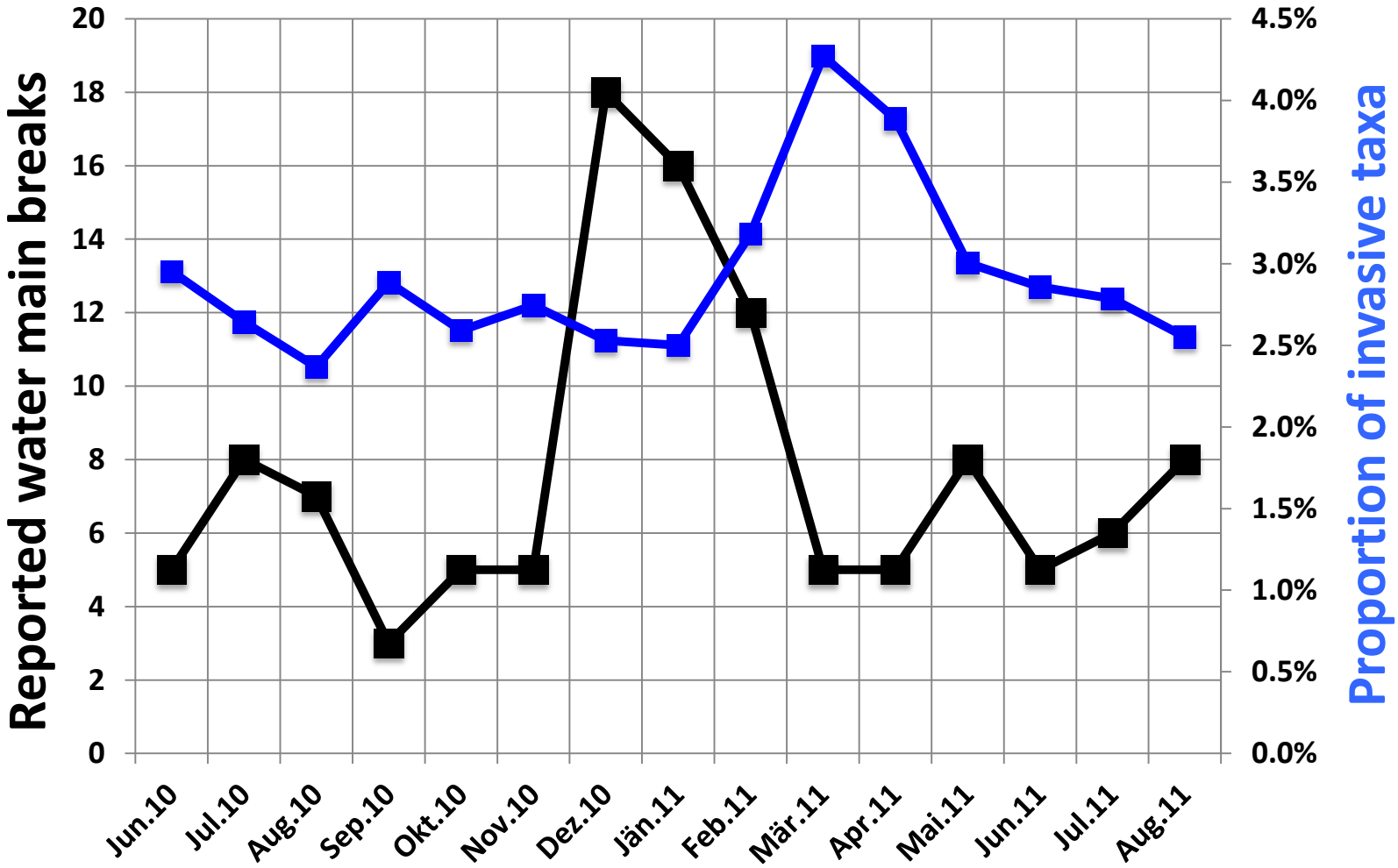
# Operational evidence




(Unpublished data)

# Operational evidence suggests that invasive OTUs may originate from water main breaks.

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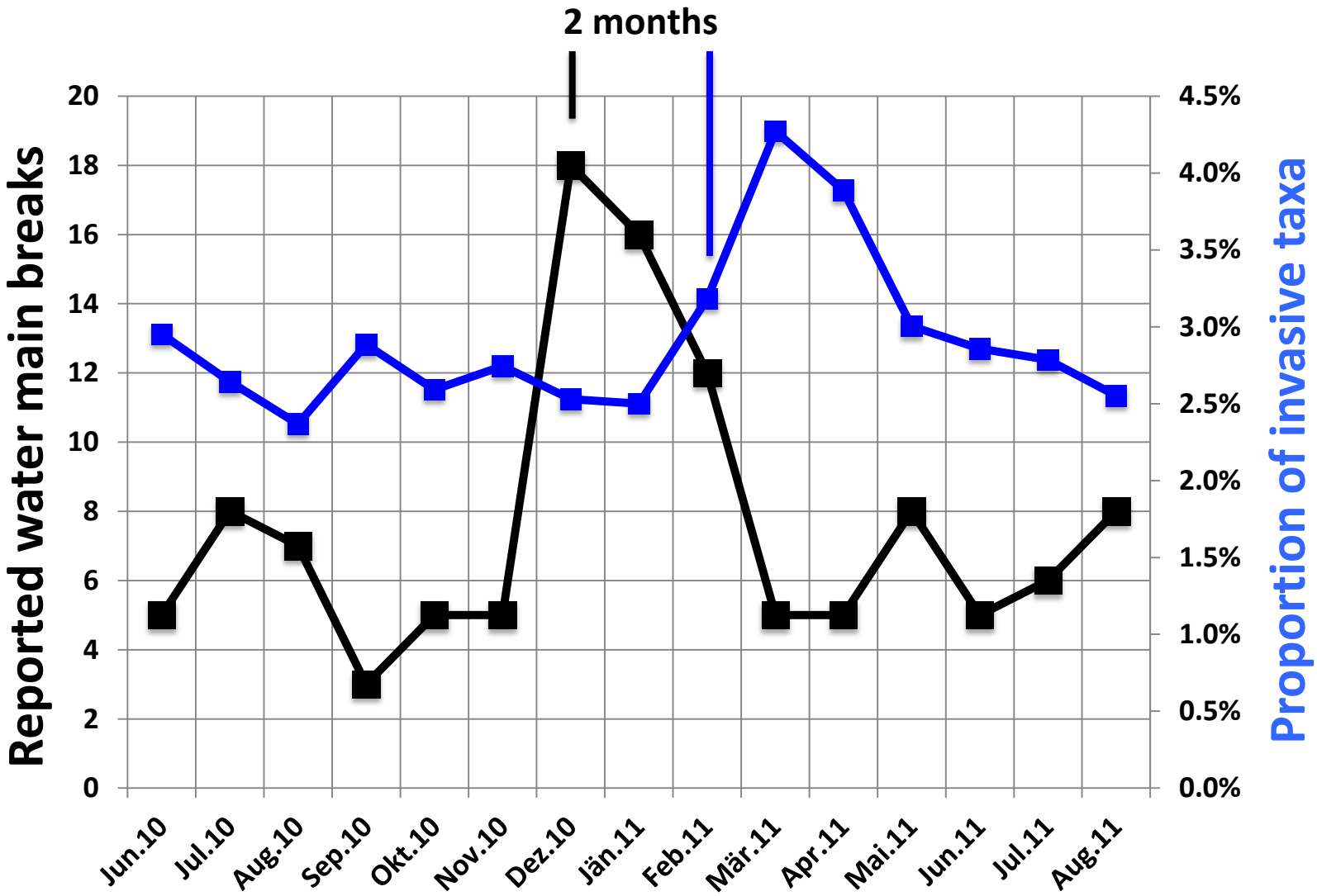



(Unpublished data)

# A protocol to develop a predictive framework for drinking water microbiology management.

RESEARCH ARTICLE

## Spatial-Temporal Survey and Occupancy-Abundance Modeling To Predict Bacterial Community Dynamics in the Drinking Water Microbiome

**Ameet J. Pinto,[a] Joanna Schroeder,[a] Mary Lunn,[a] William Sloan,[a] Lutgarde Raskin[b]**

Infrastructure and Environment Research Division, School of Engineering, University of Glasgow, Glasgow, United Kingdom[a]; Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, Michigan, USA[b]

**Path forward for a predictive microbial-management framework in DW systems.** Based on the findings in this study, we recommend five steps that will facilitate the development and testing of a predictive framework for microbial management in DW systems. First, we recommend that rather than conducting scattered sampling and analyses over a wide range of DW systems, gathering rich spatial-temporal data for select systems to first validate a framework for linking temporal, spatial, and occupancy-abundance features that can then be tested across multiple systems may be a better use of resources. The selection of these representative systems should capture a range of (i) water treatment processes, (ii) source water types and use patterns, and (iii) distribution system sizes and ages. Second, long-term multiyear temporal studies should focus on water leaving the DWTP to identify tem-












Pinto, et al (2014) mBio

# We are testing the robustness of the six features across multiple systems.


Scottish Water
Always serving Scotland

Targeted sampling

Vitens
oasen drinkwater
waternet
Pidpa
RAND WATER

Jo Schroeder



Melina Bautista

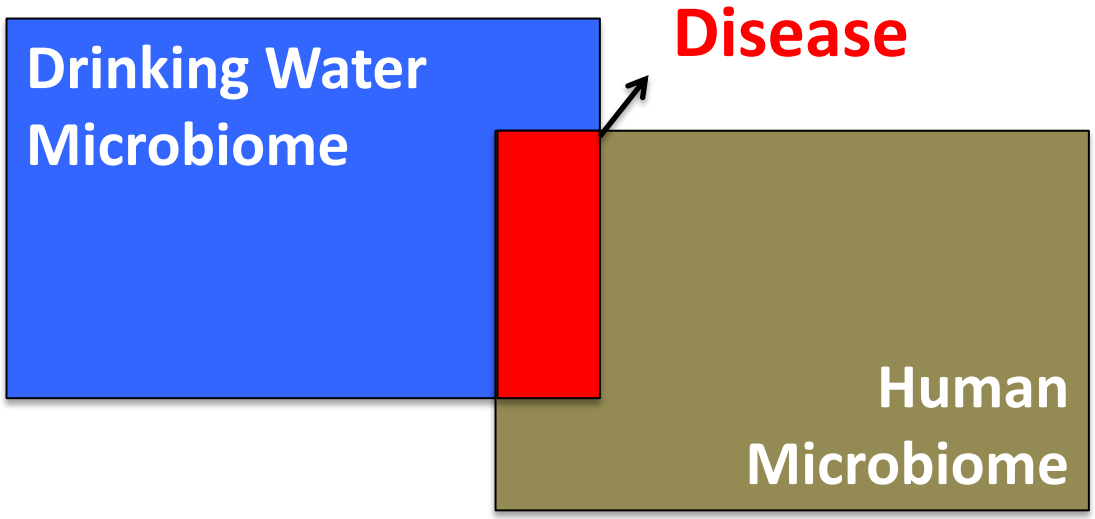
# Drinking water microbiology.

What?

How?

**Why?**

# If we can rapidly monitor and successfully predict, can we also beneficially manipulate?




Pinto et al (2012) ES&T

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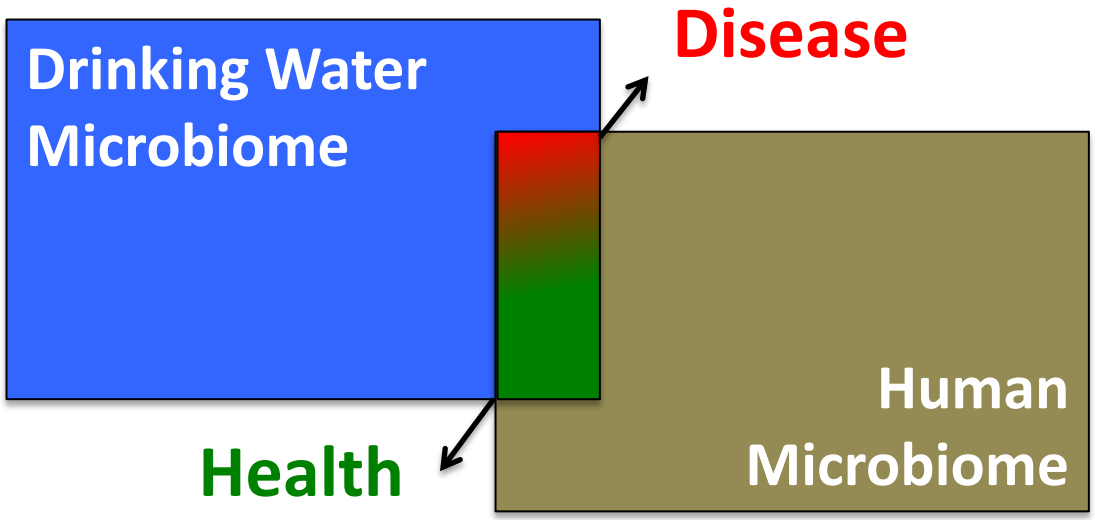


Pinto et al (2012) ES&T

# We suggested three options for beneficial manipulation of the drinking water microbiome.

ENVIRONMENTAL Science & Technology

Article

pubs.acs.org/est

## Bacterial Community Structure in the Drinking Water Microbiome Is Governed by Filtration Processes

Ameet J. Pinto,[†] Chuanwu Xi,[‡] and Lutgarde Raskin[†,*]

[†]Department of Civil and Environmental Engineering, University of Michigan

[‡]Department of Environmental Health Sciences, University of Michigan

In conclusion, the ability of the filter microbial community to shape the Ann Arbor drinking water microbiome and the capacity of the filter colonizing LC group to dominate it presents a possible opportunity to assist in controlling and managing the microbial quality of the DWDS. The correlations of the water quality parameters with the relative abundance of different bacterial groups clearly indicate the operational possibility to control the bacterial community structure by altering water quality parameters. For example, it may be possible to manipulate the filter colonizing LC group through various operational strategies to ensure that it is populated by (1) innocuous bacteria, (2) bacteria that can effectively outcompete risky bacteria (e.g., pathogens, corrosion, or odor causing bacteria) either on the filter or in the DWDS, or (3) bacteria that are beneficial to human health. Additionally, the

Pinto et al (2012) ES&T

# We suggested three options for beneficial manipulation of the drinking water microbiome.

ENVIRONMENTAL Science & Technology

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pubs.acs.org/est

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**~ 7000 word paper**

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**7 words to change the conversation**

bacteria that are beneficial to human health.

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Pinto et al (2012) ES&T

# Significant media attention on one aspect of beneficial manipulation.

TheScientist
EXPLORING LIFE, INSPIRING INNOVATION

## Drinking Better Bacteria

**Researchers analyzing the bacteria in municipal drinking water find simple measures can increase beneficial bacteria while reducing pathogenic strains.**

By Edyta Zielinska | August 9, 2012

Comment Like 0 Pin it +1 0 Link this Stumble Tweet this

Flickr Creative Commons, Anil Jadhav

Although most bacteria are removed from drinking water before it reaches our lips, a few strains survive the filtration and chlorination steps designed to clean the water. Researchers from the University of Michigan tracked down the sources of bacteria, and found that beneficial populations, could be selected by slightly changing the acidity of the water.

The main source of bacterial diversity, surprisingly, was the filters designed to remove the organic matter on which bacteria feed. These filters were shown to play a major role in shaping

NewScientist Health

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SPACE TECH ENVIRONMENT HEALTH LIFE PHYSICS&MATH SCIENCE IN SO

## Boosting bacteria in drinking water may improve health

12:50 10 August 2012 by William Ferguson

Every gallon of purified drinking water is home to hundreds of millions of bacteria. Water treatment facilities try to remove them – but perhaps encouraging some of the microbes to grow could benefit human health.

Lutgarde Raskin of the University of Michigan in Ann Arbor says that workers at water treatment facilities across the US try to destroy all of the bacteria in drinking water with infusions of chlorine and other disinfectants. But this is nearly impossible to achieve with the current technology.

The present approach also ignores the fact that the drinking water microbiome contains some bacteria that can be beneficial. For instance, nitrates that can contaminate drinking water could be converted by some bacteria into harmless nitrogen gas. Raskin and her team suggest that encouraging the growth of these bacteria in drinking water could actually improve the quality and safety of the product.

Between April and October 2010, the researchers analysed bacterial DNA in drinking water treated at municipal facilities in Ann Arbor. They wanted to work out exactly which bacteria were present, and what factors influenced the abundance of the various components of the bacterial community.

Like 190 Tweet 168 +1 3 Share 64

Bacterial benefits *(Image: Donald Iain Smith/Getty Images)*

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THE WIRE NEWS FROM THE ATLANTIC

## Bacteria in Drinking Water is Healthy; Quasicrystal Came From Space

DAVID WAGNER

AP

ACS News Service Weekly PressPac: August 08, 2012

## Leveraging bacteria in drinking water to benefit consumers

"Bacterial Community Structure in the Drinking Water Microbiome Is Governed by Filtration Processes"
*Environmental Science & Technology*

Contrary to popular belief, purified drinking water from home faucets contains millions to hundreds of millions of widely differing bacteria per gallon, and scientists have discovered a plausible way to manipulate those populations of mostly beneficial microbes to potentially benefit consumers. Their study appears in ACS' journal *Environmental Science & Technology*.

Credit: Comstock/Thinkstock

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Flickr Creative Commons, Anil Jadhav

Although most bacteria are removed from drinking water before it reaches our lips, a few strains survive the filtration and chlorination steps designed to clean the water. Researchers from the University of Michigan tracked down the sources of bacteria, and found that beneficial populations, could be selected by slightly changing the acidity of the water.

The main source of bacterial diversity, surprisingly, was the filters designed to remove the organic matter on which bacteria feed. These filters were shown to play a major role in shaping

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## Boosting bacteria in drinking water may improve health

12:50 10 August 2012 by William Ferguson

Every gallon of purified drinking water is home to hundreds of millions of bacteria. Water treatment facilities try to remove them – but perhaps encouraging some of the microbes to grow could benefit human health.

Lutgarde Raskin of the University of Michigan in Ann Arbor says that workers at water treatment facilities across the US try to destroy all of the bacteria in drinking water with infusions of chlorine and other disinfectants. But this is nearly impossible to achieve with the current technology.

The present approach also ignores the fact that the drinking water microbiome contains some bacteria that can be beneficial. For instance, nitrates that can contaminate drinking water could be converted by some bacteria into harmless nitrogen gas. Raskin and her team suggest that encouraging the growth of these bacteria in drinking water could actually improve the quality and safety of the product.

Between April and October 2010, the researchers analysed bacterial DNA in drinking water treated at municipal facilities in Ann Arbor. They wanted to work out exactly which bacteria were present, and what factors influenced the abundance of the various components of the bacterial community.

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Bacterial benefits *(Image: Donald Iain Smith/Getty Images)*

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## Bacteria in Drinking Water is Healthy; Quasicrystal Came From Space

DAVID WAGNER

AP

ACS News Service Weekly PressPac: August 08, 2012

## Leveraging bacteria in drinking water to benefit consumers

"Bacterial Community Structure in the Drinking Water Microbiome Is Governed by Filtration Processes"
*Environmental Science & Technology*

Contrary to popular belief, purified drinking water from home faucets contains millions to hundreds of millions of widely differing bacteria per gallon, and scientists have discovered a plausible way to manipulate those populations of mostly beneficial microbes to potentially benefit consumers. Their study appears in ACS' journal *Environmental Science & Technology*.

Credit: Comstock/Thinkstock

# Is this desirable or feasible?

TheScientist
EXPLORING LIFE, INSPIRING INNOVATION

## Drinking Better Bacteria

**Researchers analyzing the bacteria in municipal drinking water find simple measures can increase beneficial bacteria while reducing pathogenic strains.**

By Edyta Zielinska | August 9, 2012

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Flickr Creative Commons, Anil Jadhav

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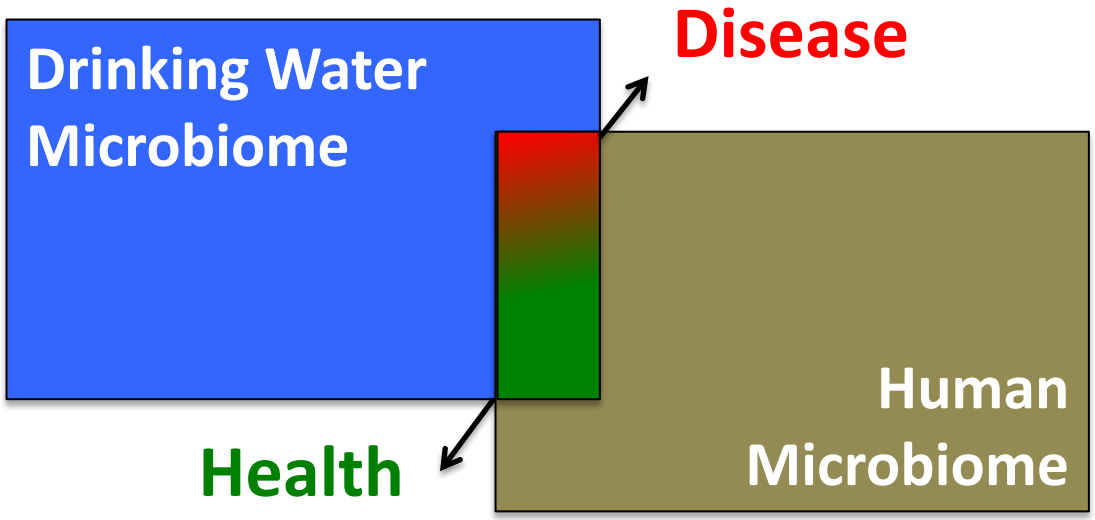
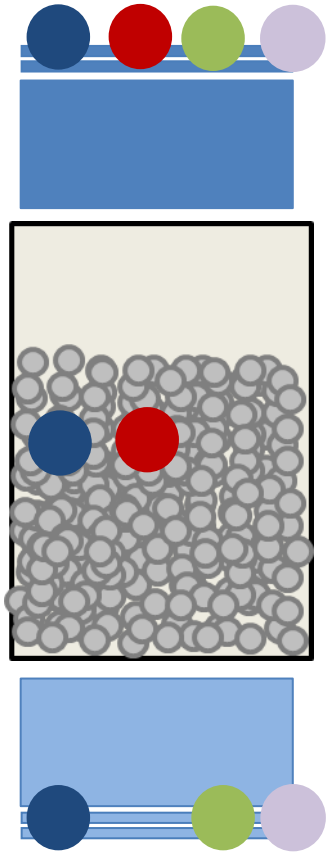
Credit: Comstock/Thinkstock

# Engineering microbial communities on the filter to seed the distribution system.



# Acknowledgements





**Lutgarde Raskin** **William Sloan**

**John LiPuma** **Mary Lunn**

**Greg Dick** **Joanna Schroeder**



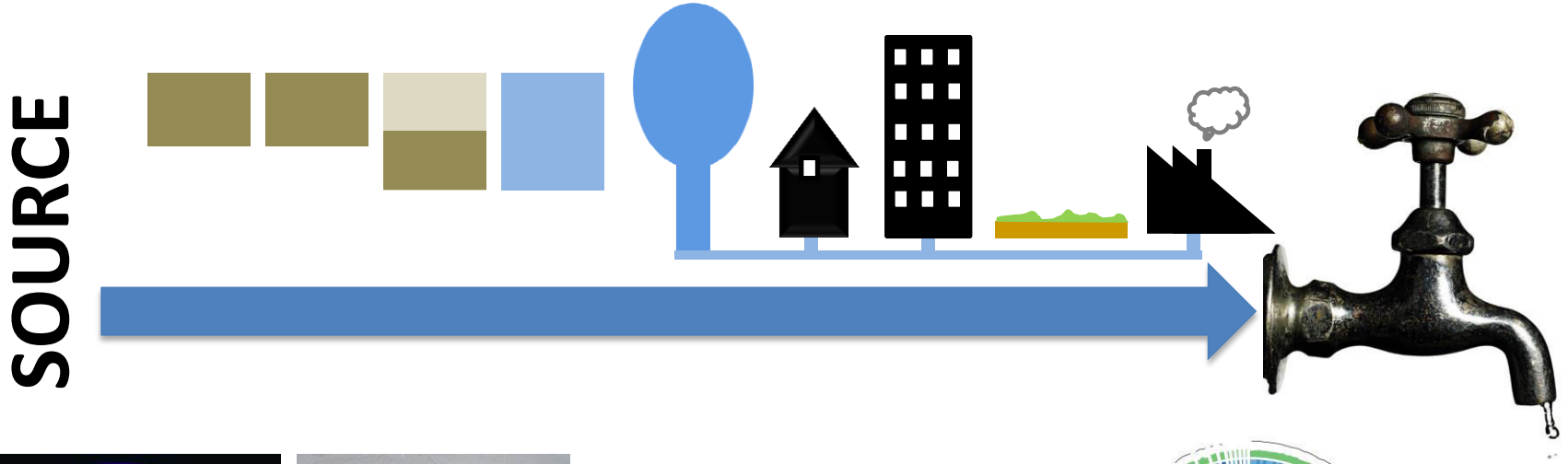


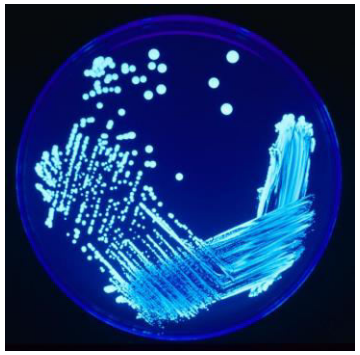






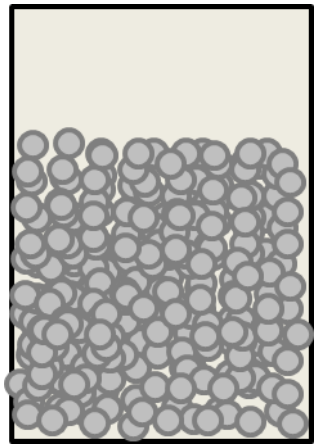
# Managing & Exploiting Drinking Water Microbiome to Minimize risks and Maximize benefits.

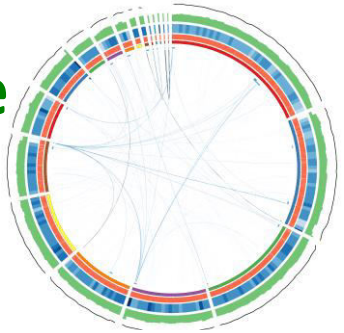


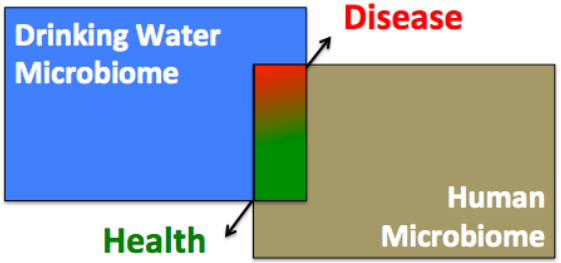



**Minimize**

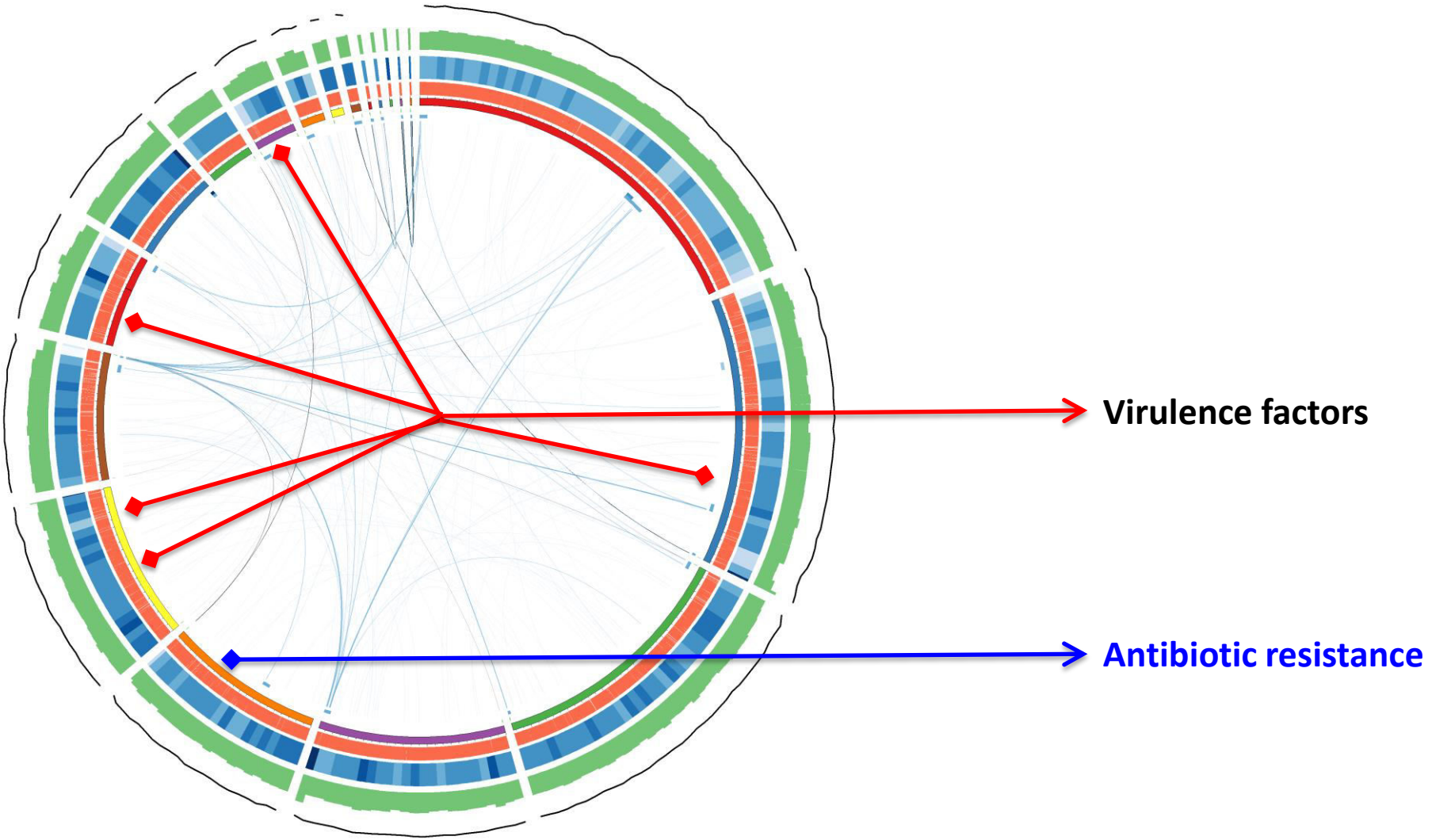
**Maximize**



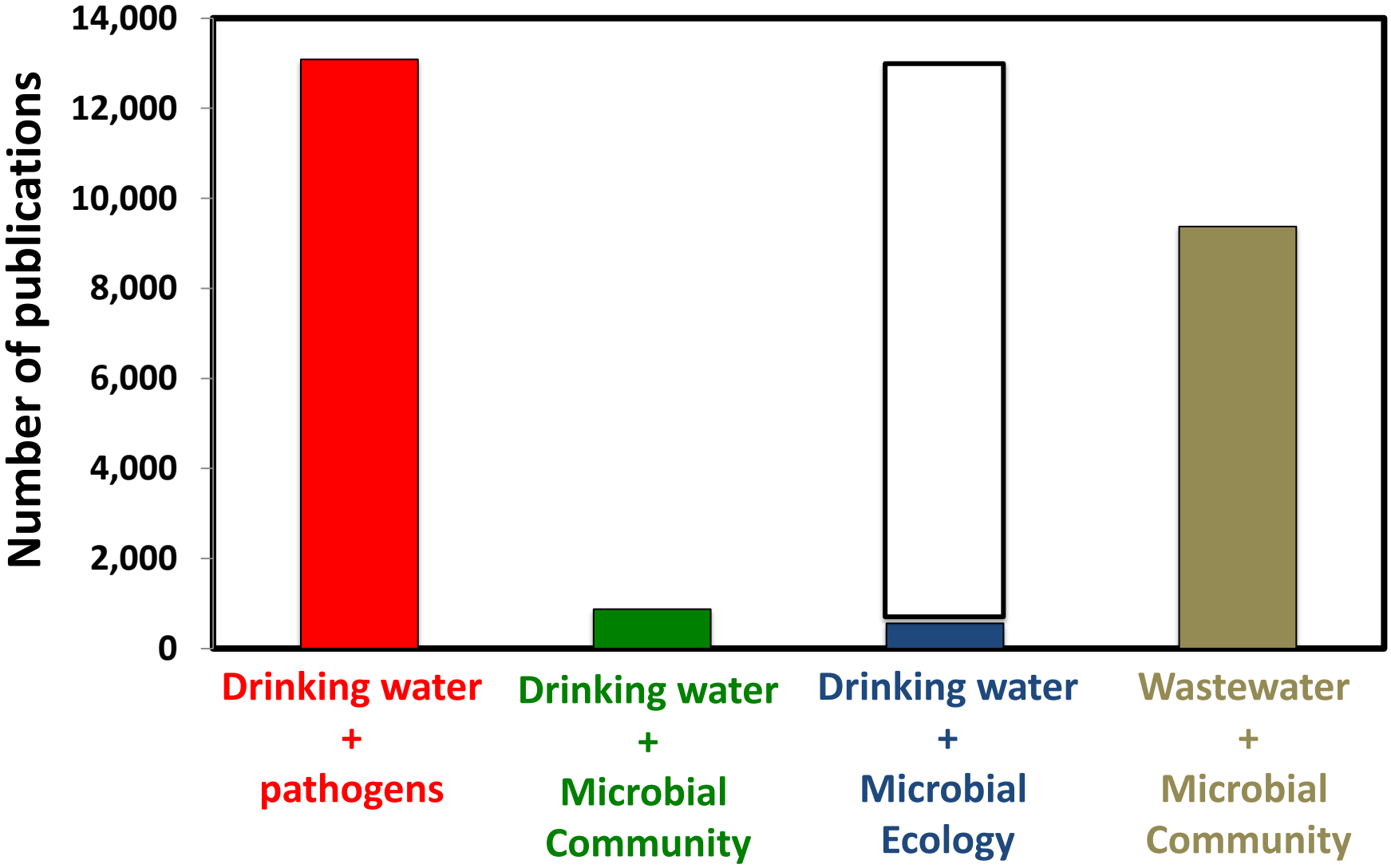




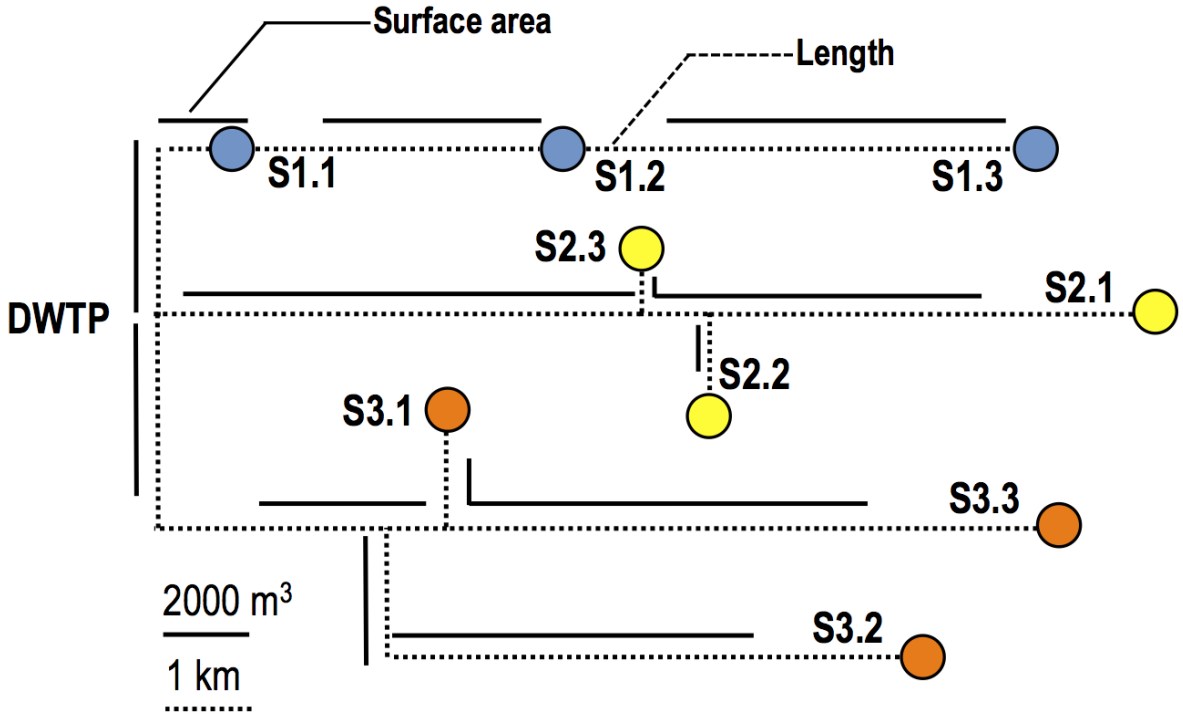
# Sequencing can not only reveal who is present in a sample, but also what they can do.



# Immense potential to do things differently and reshape our water policy and infrastructure.

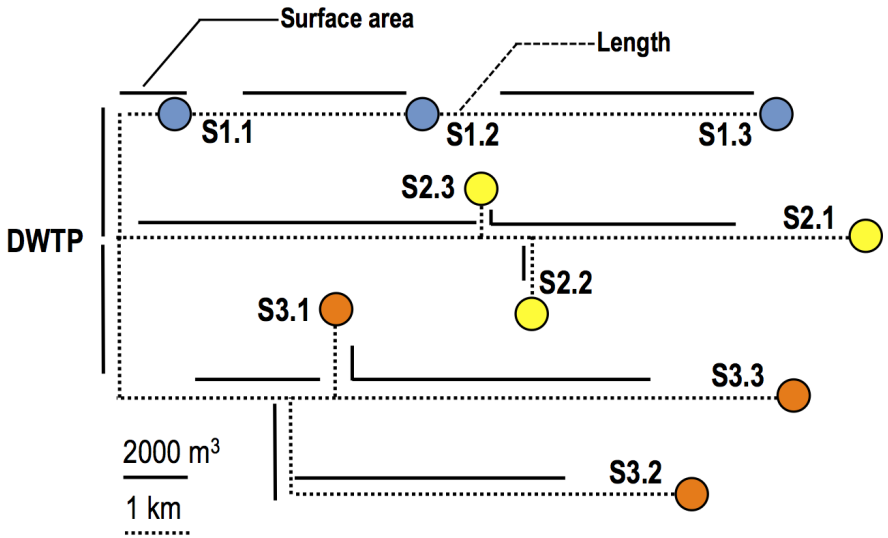


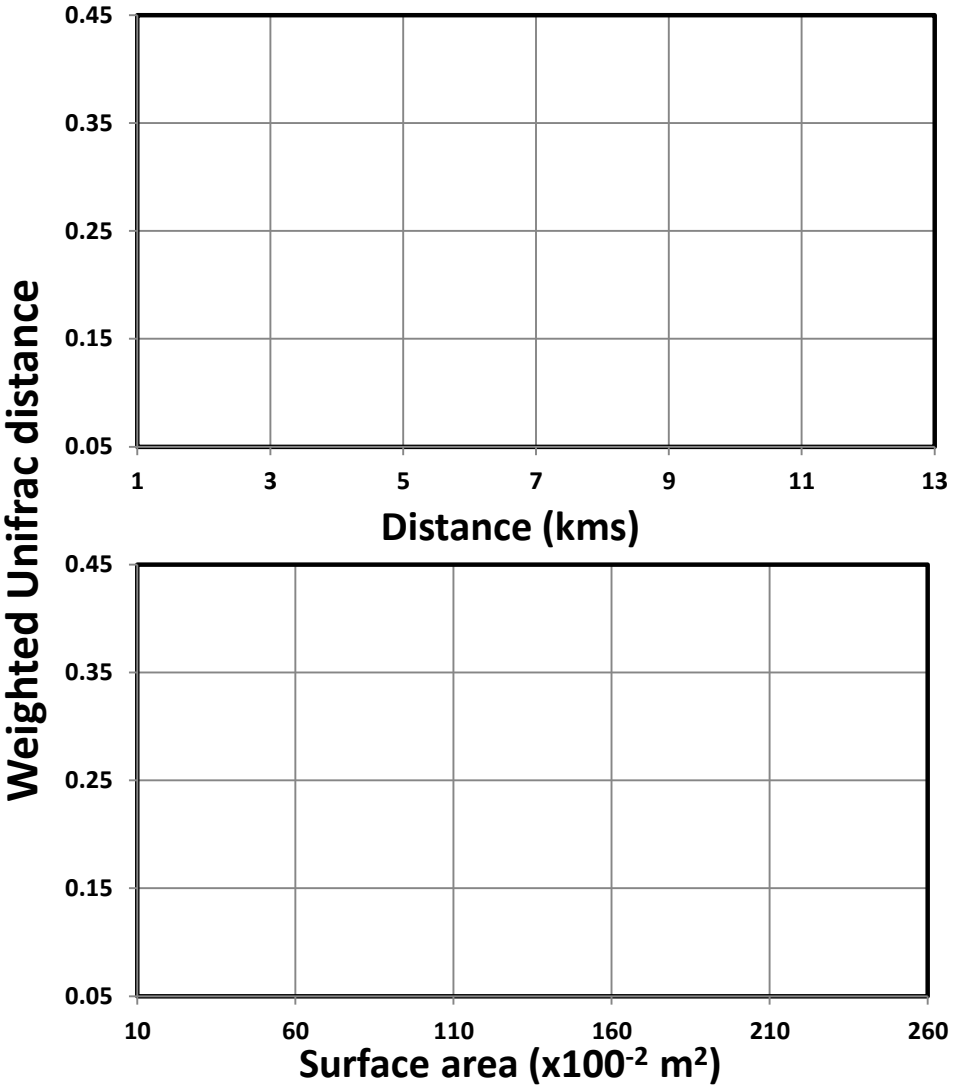
# How does microbial community change in the distribution system?




881 pipe sections
5 pipe materials
46 km in length
72088 $m^2$ of pipe surface area
Pipe ages: 8 months – 91 years

# How does microbial community change in the distribution system?



# Distance decay along linear flow path.