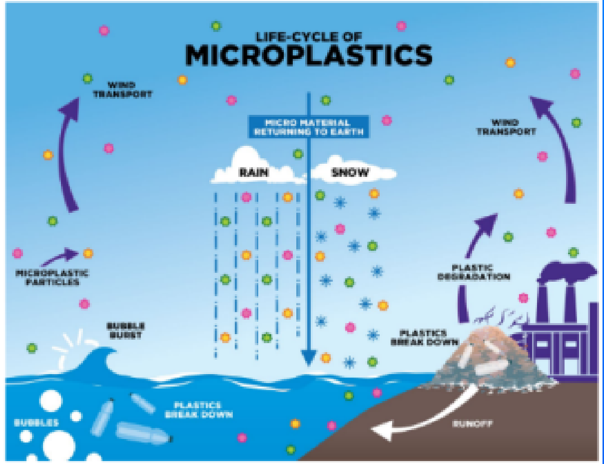
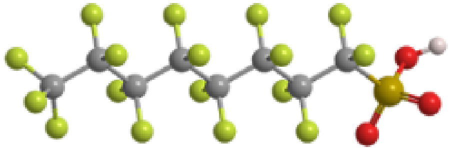
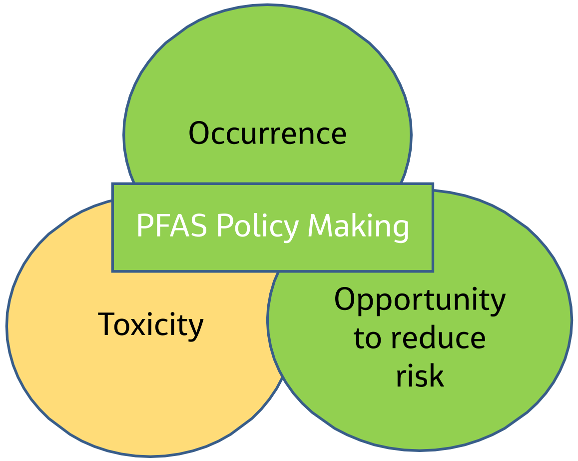
Microplastics – The State of Science and Uncertainties on Risk-Based Management

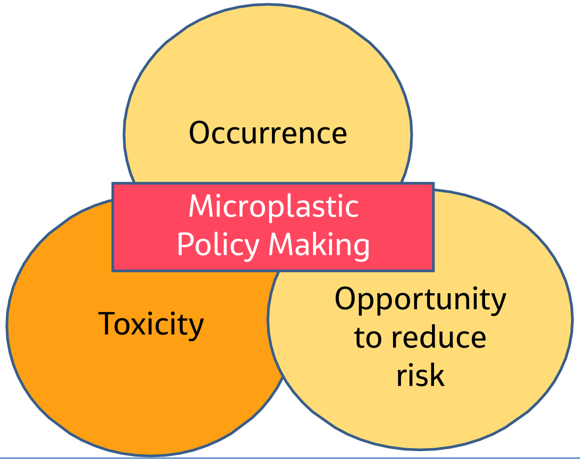


https://ysjournal.com/airborne-microplastics-a-global-issue-with-implications-for-human-health/

PFAS  vs. Microplastics 

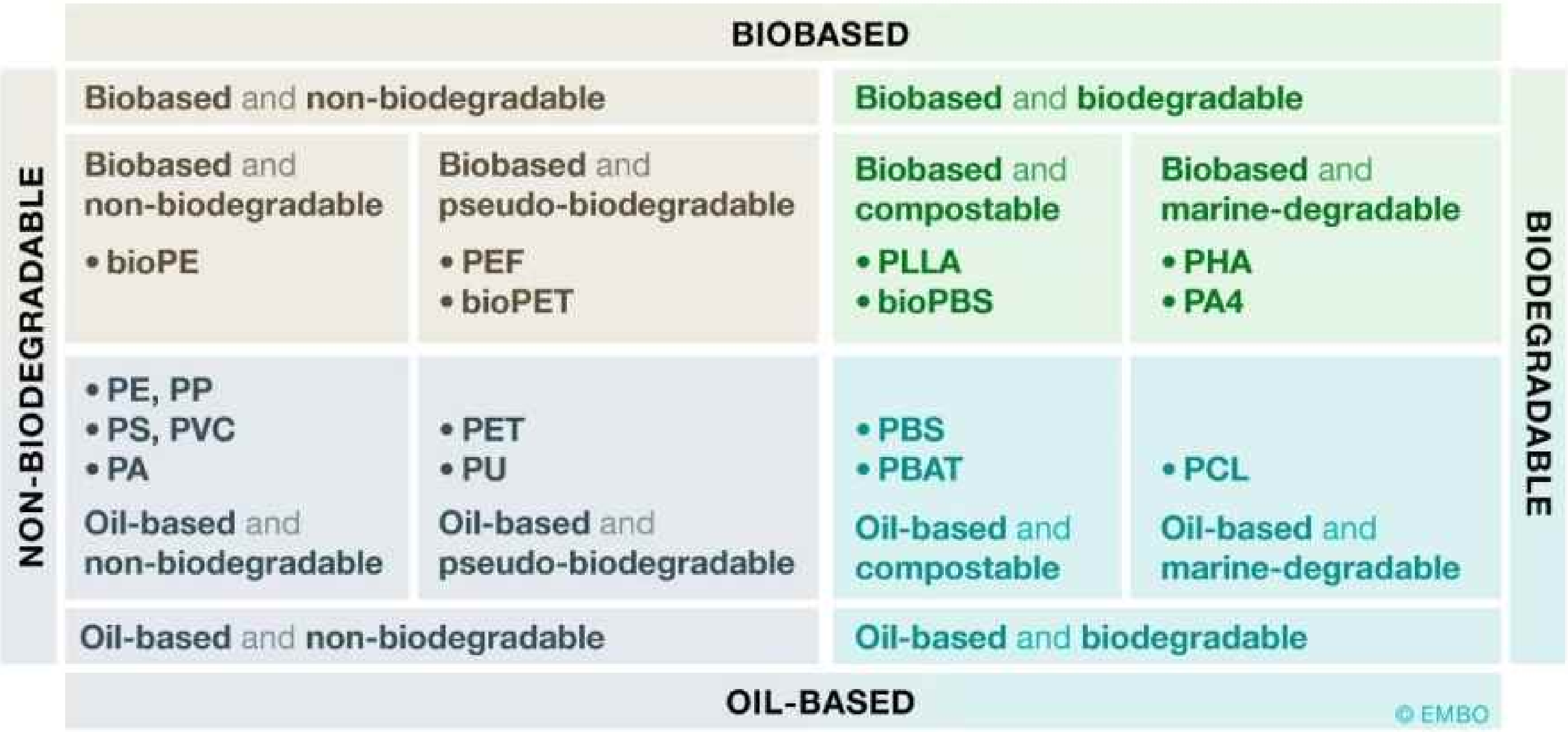
PFAS	Microplastics
Common: ubiquitous, persistent, not readily degradable	
PFAS are unique by their chemistry, charges, surfactant properties	Microplastics are unique by shapes, sizes, polymer composition, sorbed and added chemicals, biofouling when aged and weathered (Coffin 2023)
MCLs established	Limited SOPs on how MPs should be analyzed MPs risks (size vs composition) are still under study Is it a risk to GW?





Low readiness  High readiness

Types of Plastics




PE


PEF


PU


PVC


PP

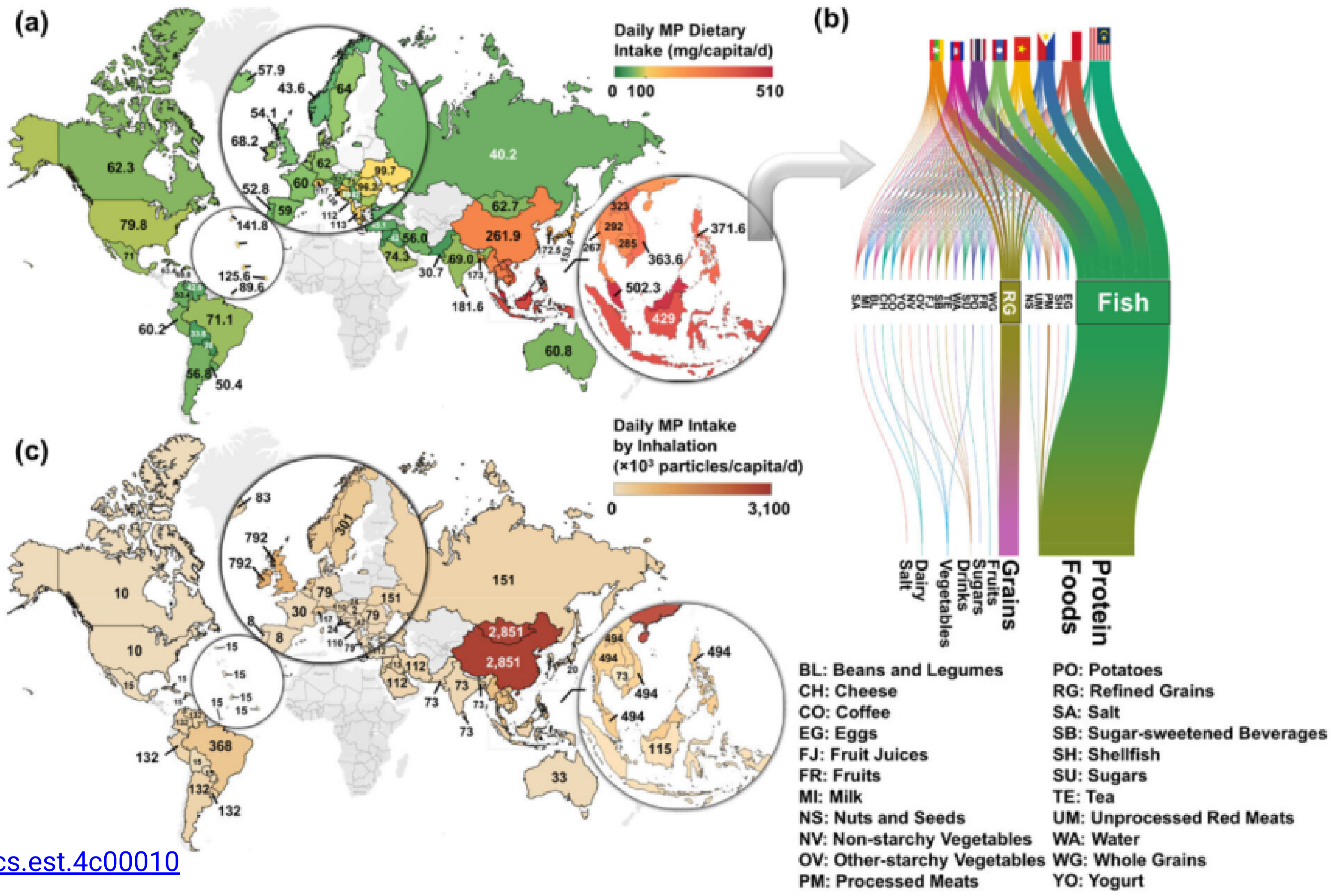

PHA


PET

Per capita daily MP dietary and inhalation uptake rates at the country level in 109 industrialized and developing countries within Asia, Europe, Africa, and North and South America, focusing on the world's major coastlines that are affected by plastic pollution. (a) Per capita MP dietary uptake at the country level. (b) Per capita MP dietary uptake rates at the country level by food types in Southeast Asian countries. (c) Per capita MP inhalation uptake at the country level.

Dietary intake

Intake by inhalation



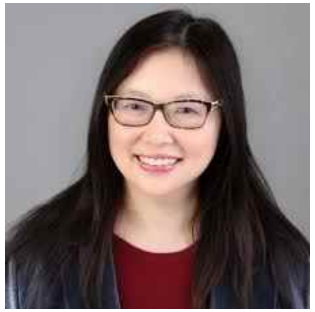
https://doi.org/10.1021/acs.est.4c00010

Panel Discussion

- How to Analyze?
- Can we tell what microplastics are made of and where they come from?
- How are the risks associated with size, plastic composition and additives?
- How much we know about MP mitigation?
- How plastic degradation can be measured?
- Are MPs the hosts of other contaminants?

This Panel

Introduction → Presence/Abundance Analysis → Why it matters? Regulations and Risk → How to Mitigate? Treatment and Remediation → R&D on MPs Degradation and Interactions with Co-Contaminants



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10-min Q&A

Q&A

Sampling and Analysis of Microplastics is a unique challenge

They are particles

- Representative sample?

They come in many shapes, sizes and composition and wear, discolour

- Much complexity

Given low levels of concern, may need to process 1000s of liters of sample

- Increases complexity

They are ubiquitous

- Blanks/background

We need count and characterize individually: Time consuming

- Most other contaminants are measured in bulk

We don’t have any reasonable solutions in the 1nm – 10 um range (nano)

SGS

Analysis – Many options, no single solution

Microscopy	FTIR/Raman	LDIR	Pyrolysis GC-MS
• Counting technique typically • Microscopy – 50um • SEM – 10 um • Microscopy with staining – 3 um? • Is it a plastic? Differentiating still a challenge • Microscopy with staining potential for first pass screening method • Hours per sample	• Characterize plastics by type and provenance • FTIR (20 um) and Raman (1um) methods available, but time consuming • ASTM/SCCWRP methods in progress • Automation in progress to support large scale studies • Days per sample	• Use of laser direct imaging (LDIR) • Characterize and counts particles down to 10 um • Faster than FTIR/Raman • $$$ Instrument costs, single vendor • Hours per sample	• Scalable method to report total plastic by plastic type • Not limited by size • Does not count, but measures mass of plastic by GC-MS • Maybe more amenable to regulation due to ease of use? • Specialized techniques needed to lower reporting limits • Hours per sample

Microplastics (itrcweb.org) and more

Available and upcoming standard methods

Agency	Technique	ID	Matrix	Particle sizes	Status
CA Waterboards	IR (FTIR/LDIR etc)	?	Drinking water	> 50 um	Published and seeking accredited labs
CA Waterboards	Raman	?	Drinking water	> 20 um	Published and seeking accredited labs
ASTM	Sampling/collection	D8332-20	Aqueous	< 5 mm	Published
ASTM	Sample Preparation	D8333-20	Aqueous		Published
ASTM	IR FTIR/LDIR etc)	WK87463	Aqueous	>10 um?	Initiated
ASTM	Pyrolysis	D8401-24	Aqueous	Bulk	Published
ASTM	Dynamic image particle size and shape analyzer	D8489-23e1	Aqueous	5-100 um	Published

Typical Aqueous workflow

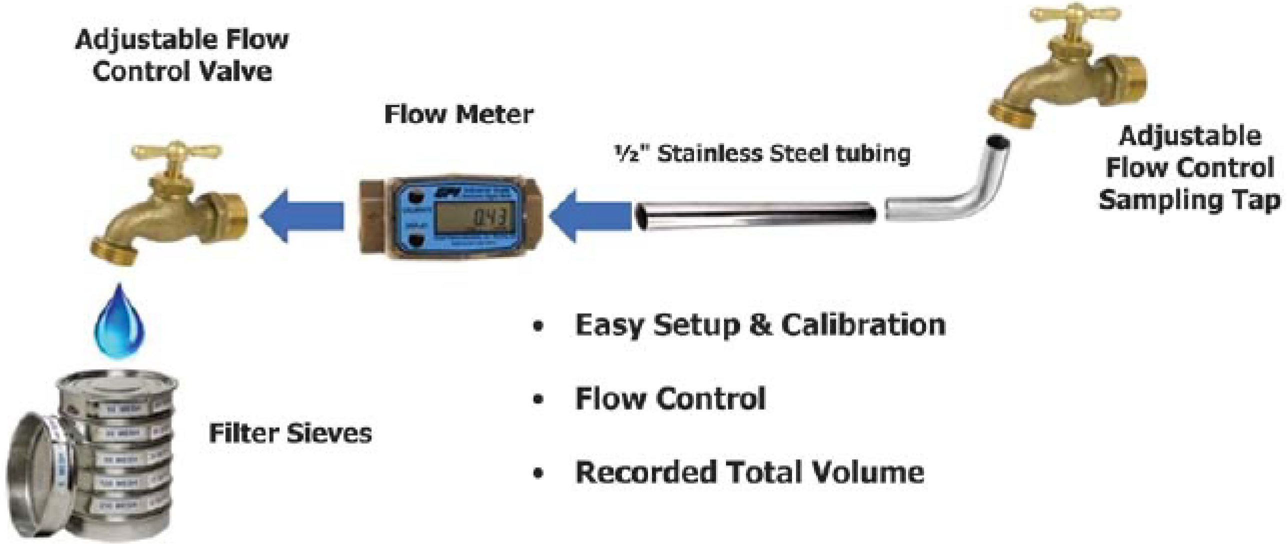

FIG. 2 Water Sampling Apparatus for Pressurized Systems

ASTM D8332-20 and D8333-20

Collect and size separate sample

- Sieve setup depends on particle bins

Prepare sample

- Multiple digestion and concentration options depending on interferences

Count/measure/characterize

- FTIR, LDIR Raman, Pyrolysis etc.

Sampling and Analysis Challenges to solve

- Beyond water, all methods are academic, no standardization on collection, preparation or analysis
- Representative sampling, avoiding background, building plastics-light labs etc.
- Scale and cost: Counting is time consuming, automation/AI still early, costs are high $$$-$$$$
- Commercial labs still hesitant to build due to lack of familiarity, labor intensiveness and investment needed in pastics-free spaces

Risk-based Regulatory Approaches to MP Management

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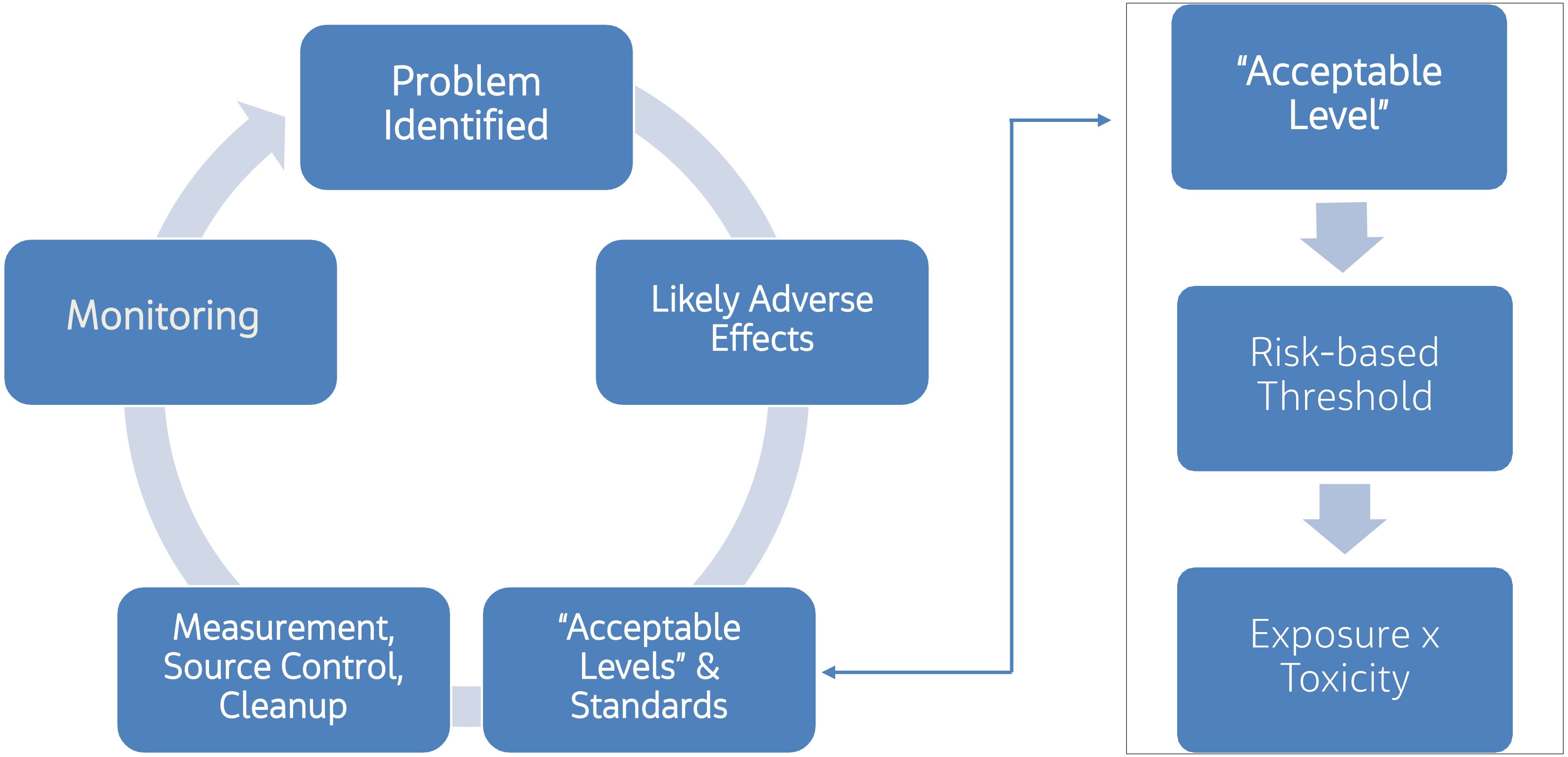
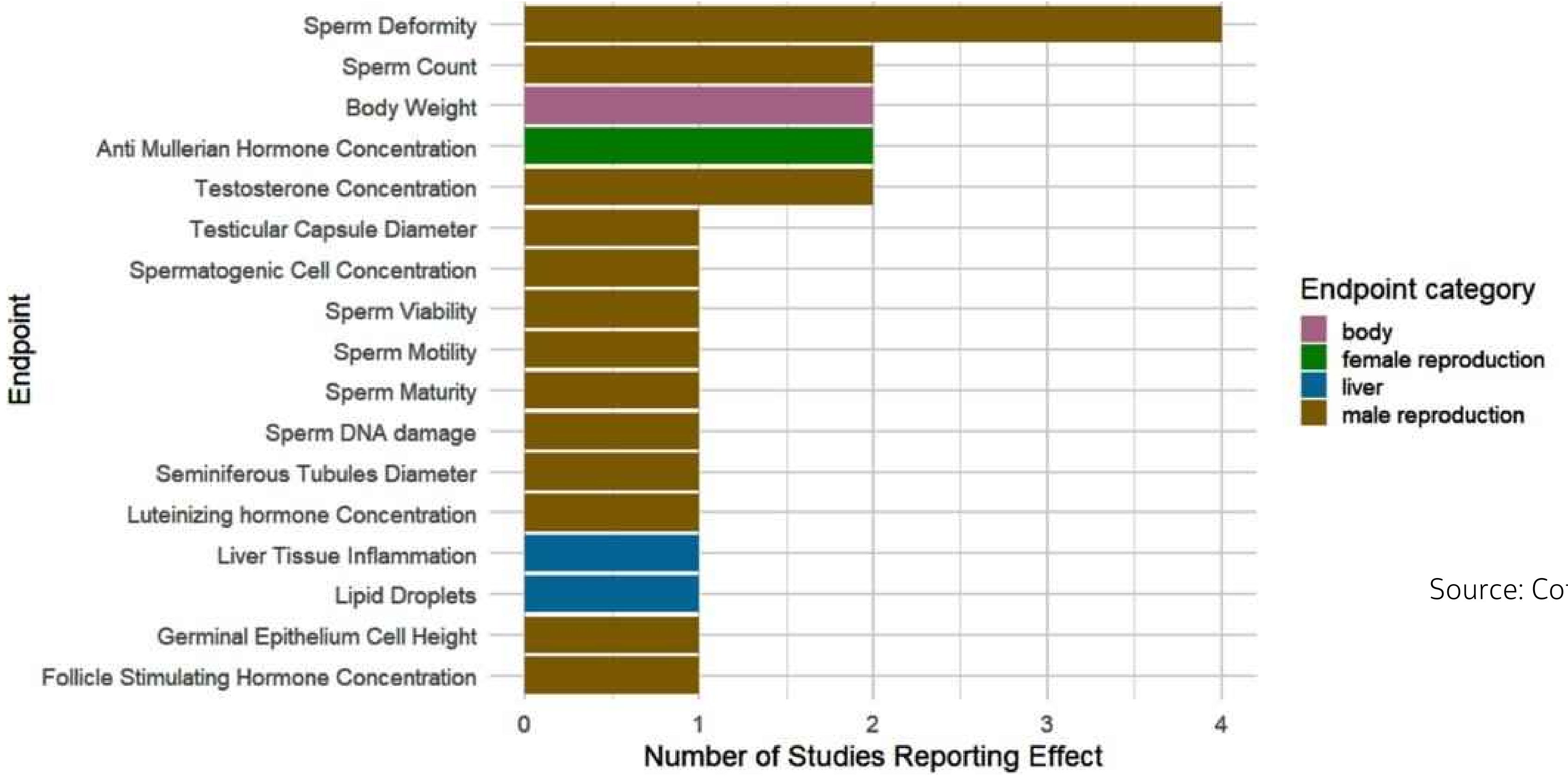
Microplastics: The State of the Science and Uncertainties in Risk-Based Management

June 4, 2024
Battelle Chlorinated Conference
Denver, CO

Typical Regulatory Policy and Actions



MP - Potential Human Health Effects



Source: Coffin et al 2022

High variability, uncertainty and gaps in available effects data

Potential Ecological Effects

- Physical particles
  - A few larger particles vs many smaller particles

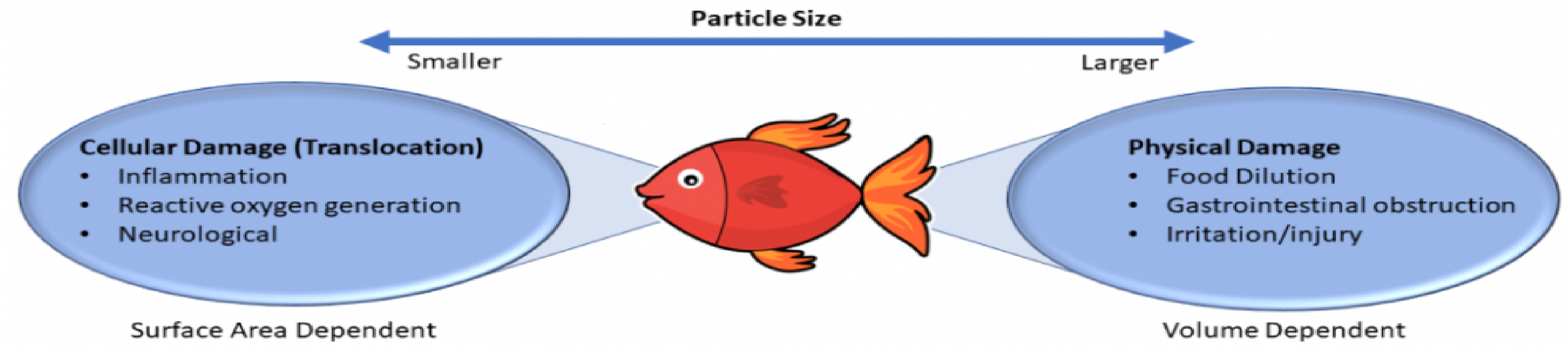


Figure 4-3. Conceptual diagram of aquatic organisms exposed to MP showing surface area and volume dependent toxicological endpoints in relation to MP particle size.
Source: Microplastics Team, created using concepts described in Mehinto et al. (2022)

- Chemical adsorption/constituents
  - Heavy metals, PAHs, PCBs, OCPs, PFAS
- Biological vectors
  - Pathogens
  - Disease potential

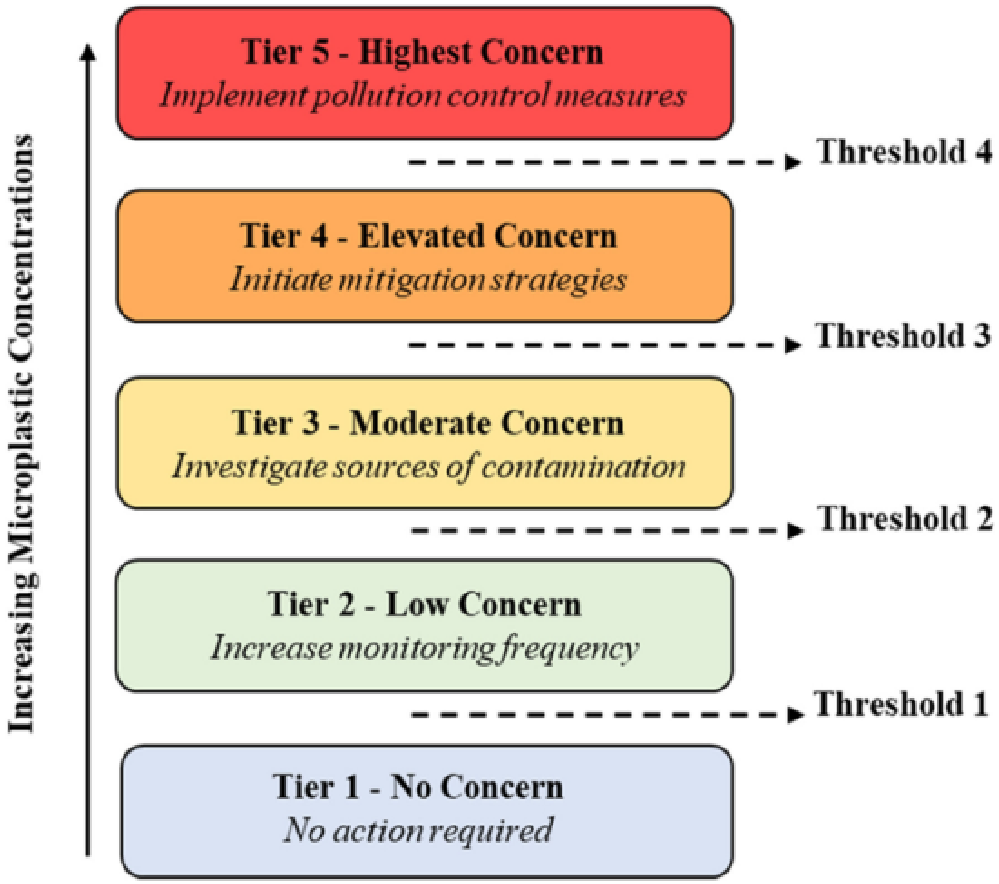
Align comparisons

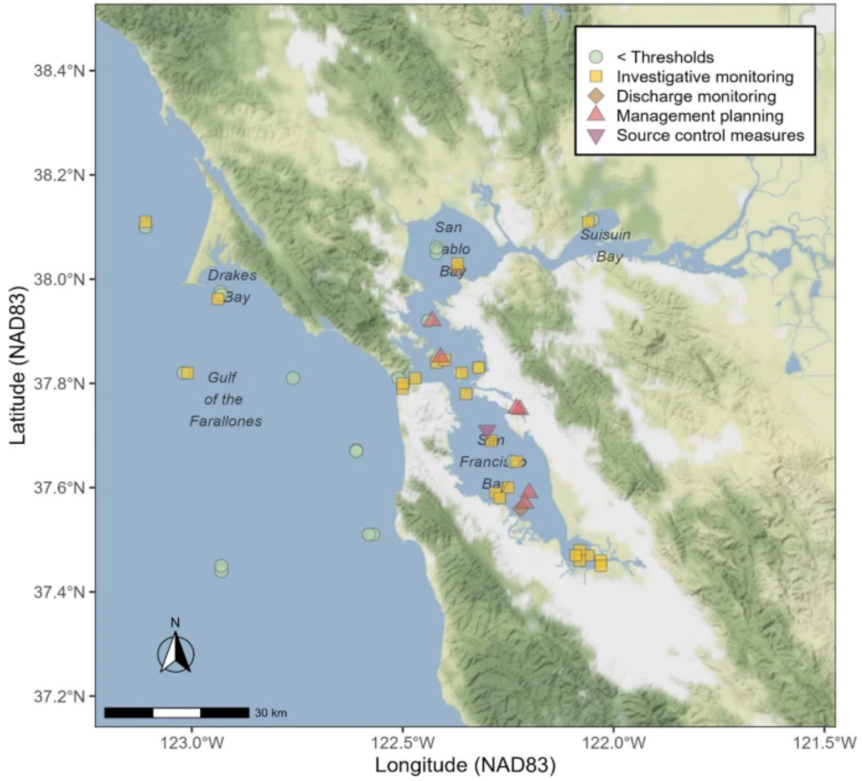
Source: ITRC Microplastics Training, 2024

MP - Regulatory Efforts

- Focus on Products
  - Phase out plastics (macro and micro) – single use plastic bags, food packaging
  - Recycling mandates e.g., restaurant utensils
  - Bans on MP in cosmetics, detergents, medicines, medical devices
- Focus on Environment
  - Monitoring, tracking, debris removal
  - California example

San Francisco Bay – Preliminary Risk Screening





Sources: Mehinto et al, 2022, Coffin et al, 2022

Potential Use for Impaired Water Body Identification (CWA, Section 303(d))

California - Preliminary Numeric Thresholds

Threshold - Particles/L (95% Cl)	Food Dilution (1-5,000 um)	Tissue Translocation (1-83 um)
1 – Investigative monitoring	0.3	60
2 – Discharge monitoring	3	312
3 – Management planning	5	890
4 – Source control measures	34	4110

Threshold – Mass (mg/L)	Food Dilution (1-5,000 um)	Tissue Translocation (1-83 um)
1 – Investigative monitoring	0.05	10
2 – Discharge monitoring	0.4	51
3 – Management planning	0.9	146
4 – Source control measures	6	676

Source: Mehinto et al, 2022. Threshold 1 is the lower 95% Cl of the HC5 and Threshold 2 is median HC5 for cellular endpoints; Threshold 3 is median HC5 and Threshold 4 is HC10 for organismal endpoints including mortality ;
Low to moderate level of confidence; Subject to Updates and Revisions

Mitigation and Abatement of Microplastics

Yasemin Kunukcu, Ph.D, P.E.

Vice President/Senior Remediation Specialist

The Best Defense is Good Offense

- Mitigating/Preventing MP from entering the environment
    - Reduction of plastic packaging and increasing the reuse
    - Improvements in plastics production at an industrial level including life cycle assessments (LCA)
    - Reduce consumption of plastics
        - Product Substitution
        - Education/Awareness
    - Improving disposal of waste
        - Source Collection and Post-Separation Disposal
        - Reuse &/or Repurposing
        - Waste to Energy and Feedstock
        - Landfilling
        - Bio-based and Biodegradable Plastic Alternatives
        - Electronic Waste Recycling
        - Enhancing Distribution/Storage/Transportation
        - Stormwater Control
- More studies necessary to achieve removal of MP in different media

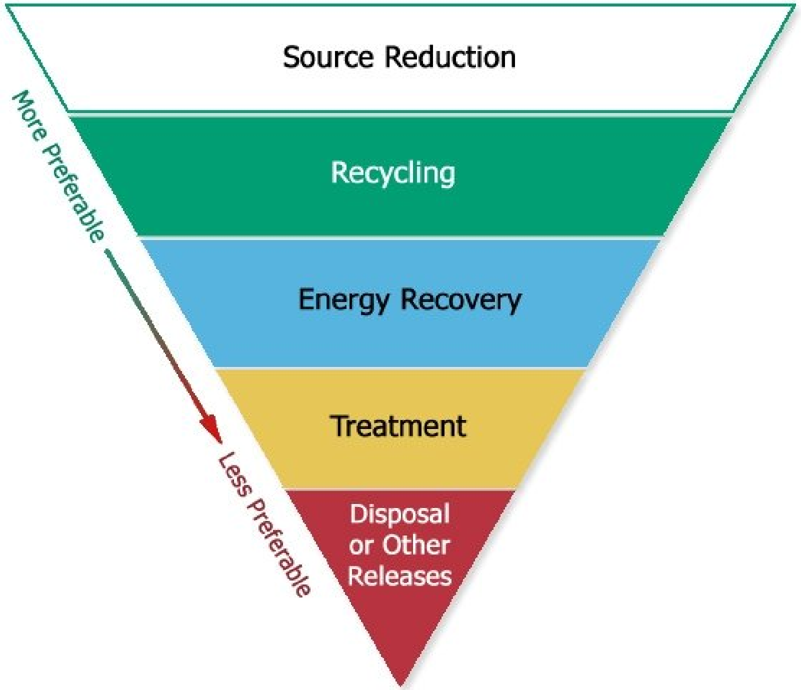
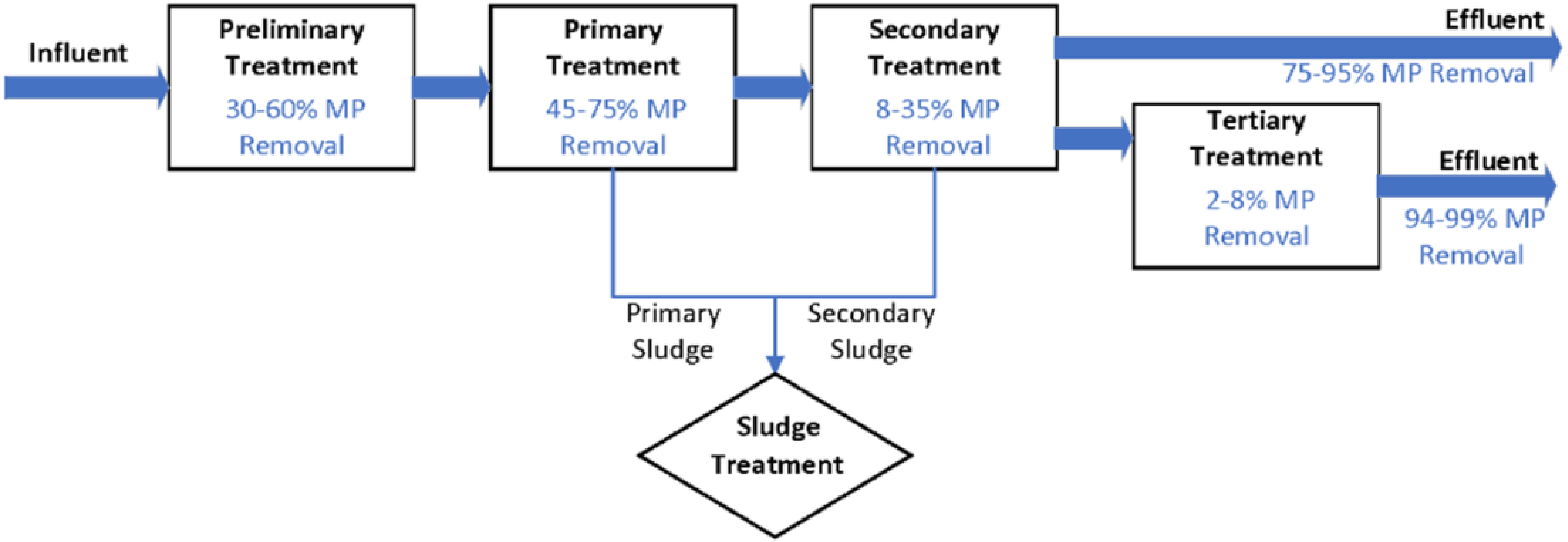


Fig. 1: Waste Management Hierarchy (Source: USEPA, 2024)

Estimation of MP Removal in WWTPs



Source: Figure 6-5 (modified ITRC MP Guidance Document, 2023)

Cycling of MPs in WWTPs

Sludge	Membranes	Filtration Concentrate
• Landfill • Incineration • Agriculture • Cement, glazed tiles and ceramic[1,2,3] • Lime stabilization • Composting • Anaerobic digestion • Thermal drying	• Reusing ROs for NF and UF[4] • As geotextile for stabilizing rocks and retarding grass • No studies available prior to their reuse and recycling	• Electrodialysis and shear enhanced NF/RO to remove nutrients[5] • UV and TiO_2 in photo-oxidative removal of diclofenac (> 95%), ibuprofen (> 95%) and naproxen (< 65%) from the concentrate of a nanofiltration • No studies available targeting the microplastics

1. Dahhou, M., El Moussaouiti, M., Arshad, M.A., Moustahsine, S., Assafi, M., 2018. Synthesis and characterization of drinking water treatment plant sludge- incorporated Portland cement. J. Mater. Cycles Waste Manag. 20, 891–901. https://doi.org/10.1007/s10163-017-0650-0
2. Cremades, L.V., Cusidó, J.A., Arteaga, F., 2018. Recycling of sludge from drinking water treatment as ceramic material for the manufacture of tiles. J. Clean. Prod. 201, 1071–1080. https://doi.org/10.1016/j.jclepro.2018.08.094
3. Rodríguez, N.H., Ramírez, S.M., Varela, M.T.B., Guillem, M., Puig, J., Larrotcha, E., Flo- res, J., 2010. Re-use of drinking water treatment plant (DWTP) sludge: characterization and technological behaviour of cement mortars with atomized sludge additions. Cem. Concr. Res. 40, 778–786. https://doi.org/10.1016/j.cemconres.2009.11.012
4. E.O. Mohamedou, D.B. Penate Suarez, F. Vince, P. Jaouen, M. Pontie, New lives for old reverse osmosis (RO) membranes, Desalination. 253 (2010) 62–70. 10.1016/j.desal.2009.11.032.
5. Arola, K., Van der Bruggen, B., Mänttäri, M., Kallioinen, M., 2019. Treatment options for nanofiltration and reverse

Conclusions

- Source reduction critical in reducing MP in the environment
- Improve disposal of waste
- Considering different strategies simultaneously
- Existing treatment technologies have varied success
- Management of wastes produced during the treatment of MPs
- Further research on existing and new technologies is necessary

Microplastic R&D Priorities

Dr. Mengyan "Ian" Li
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2024 Battelle Conference
Denver, CO
June 4th, 2024

SERDP SON FY25

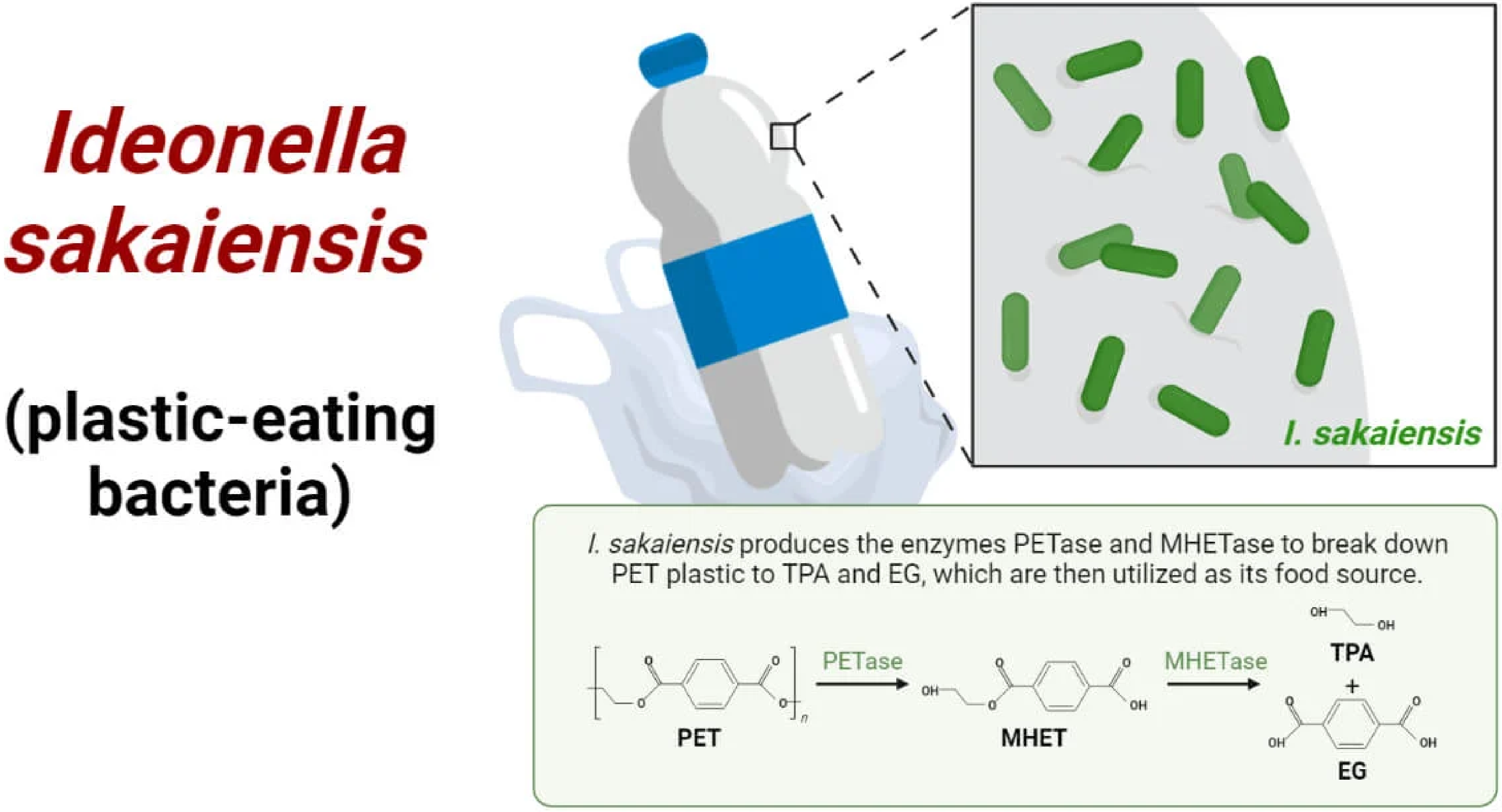
- Develop improved **analytical methods** for detecting and quantifying microplastics in environmental samples, as well as to detect and quantify COCs sorbed to microplastics in environmental samples.
- Improve the fundamental understanding of **fate and transport** processes of microplastics in surface water, stormwater, soil, sediment, and groundwater under varying natural and engineered conditions.
- Determine the impact of **sorbed COCs** on both the fate and transport of microplastics and the COCs with emphasis on mechanistic processes.
- Improve understanding of the **degradation** process of microplastics in the environment, including the evaluation of environmental factors and physical and chemical composition characteristics that may affect degradation rates.
- Develop **remedial strategies** for microplastics with sorbed COCs, such as PFAS, including a systematic assessment of the necessity for treatment train approaches.

Is Biodegradation of Plastics Possible?

Yes

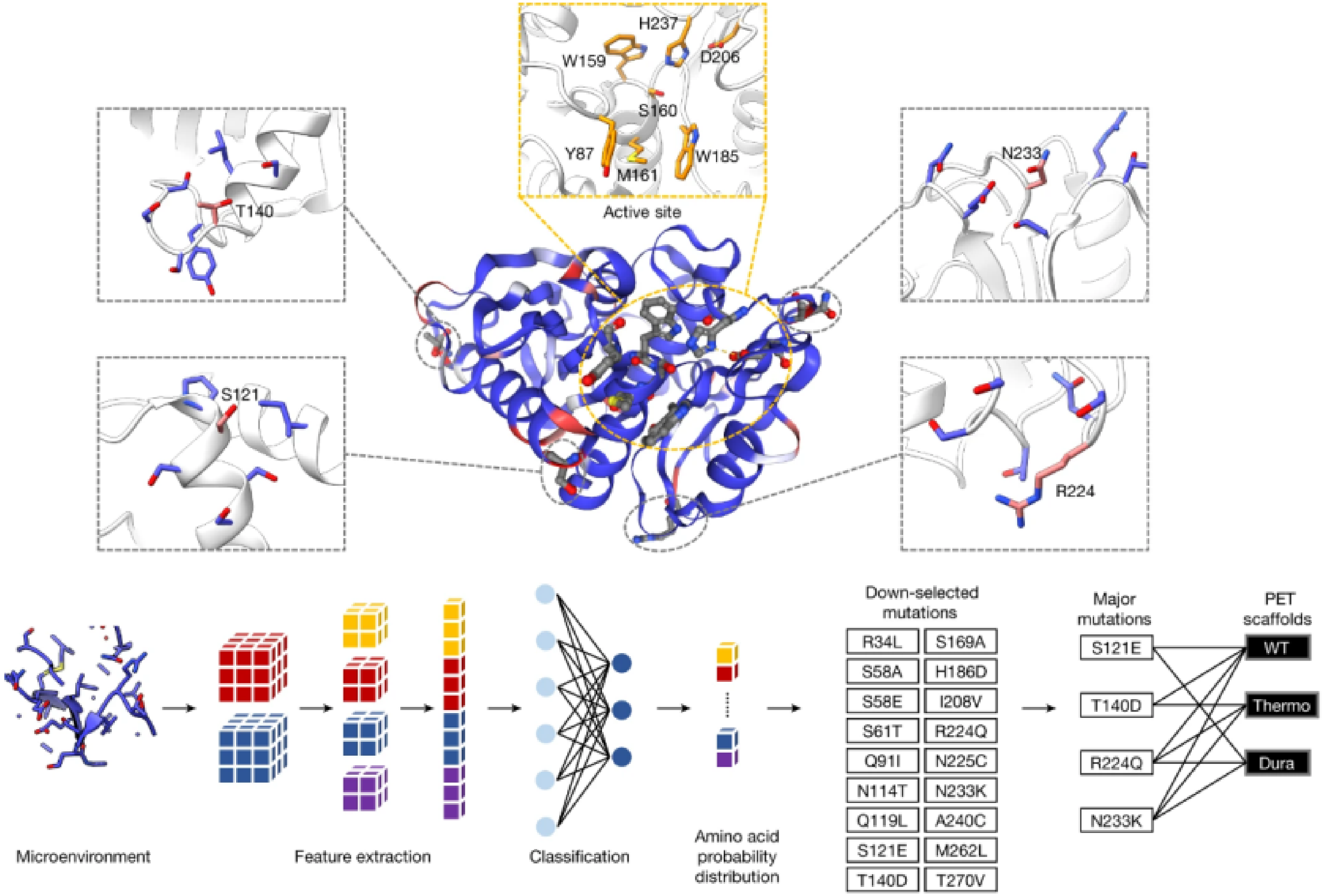
particularly after weathering

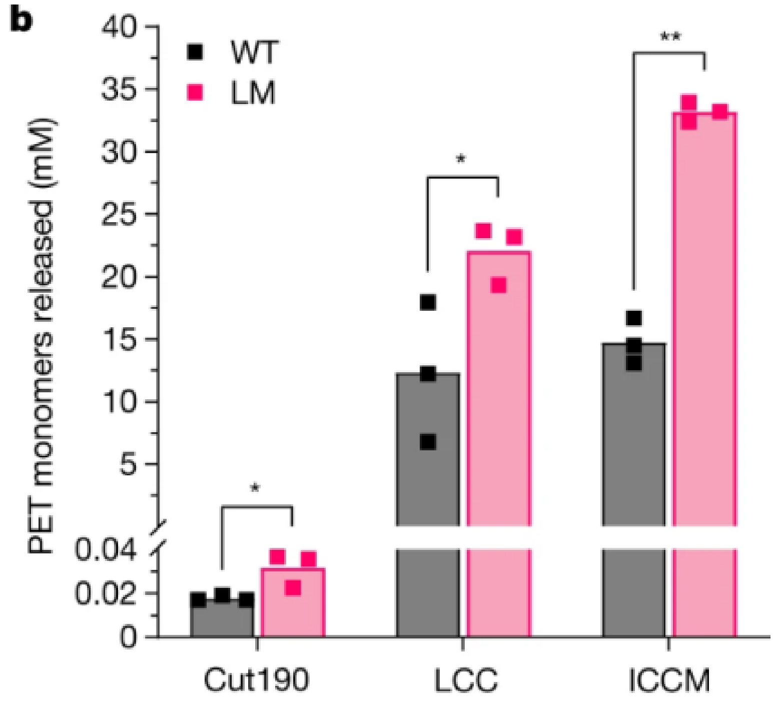
Some bacteria think plastic is fantastic



Yoshida *et al*., Science, 2016

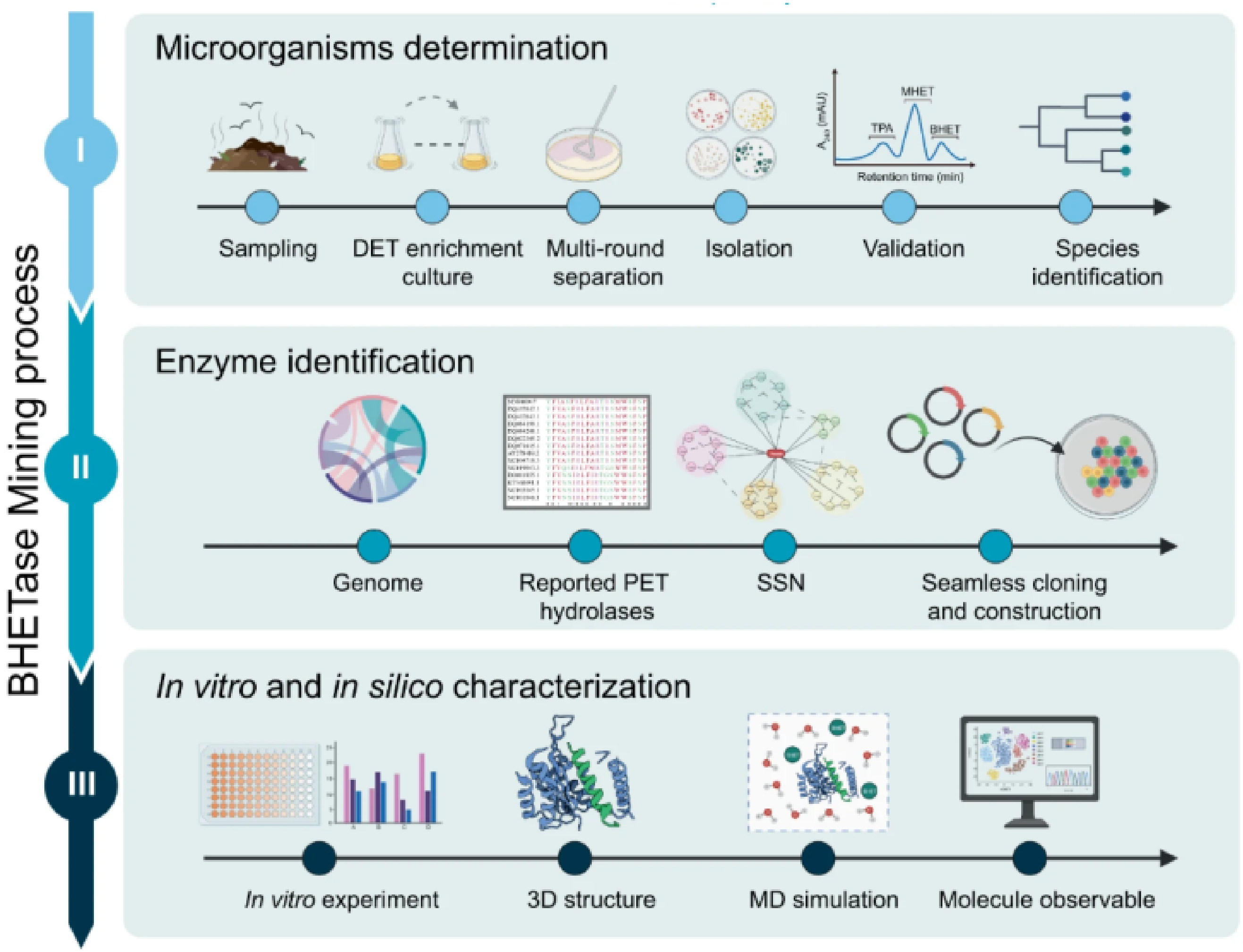
Machine learning-aided engineering of hydrolases for PET depolymerization





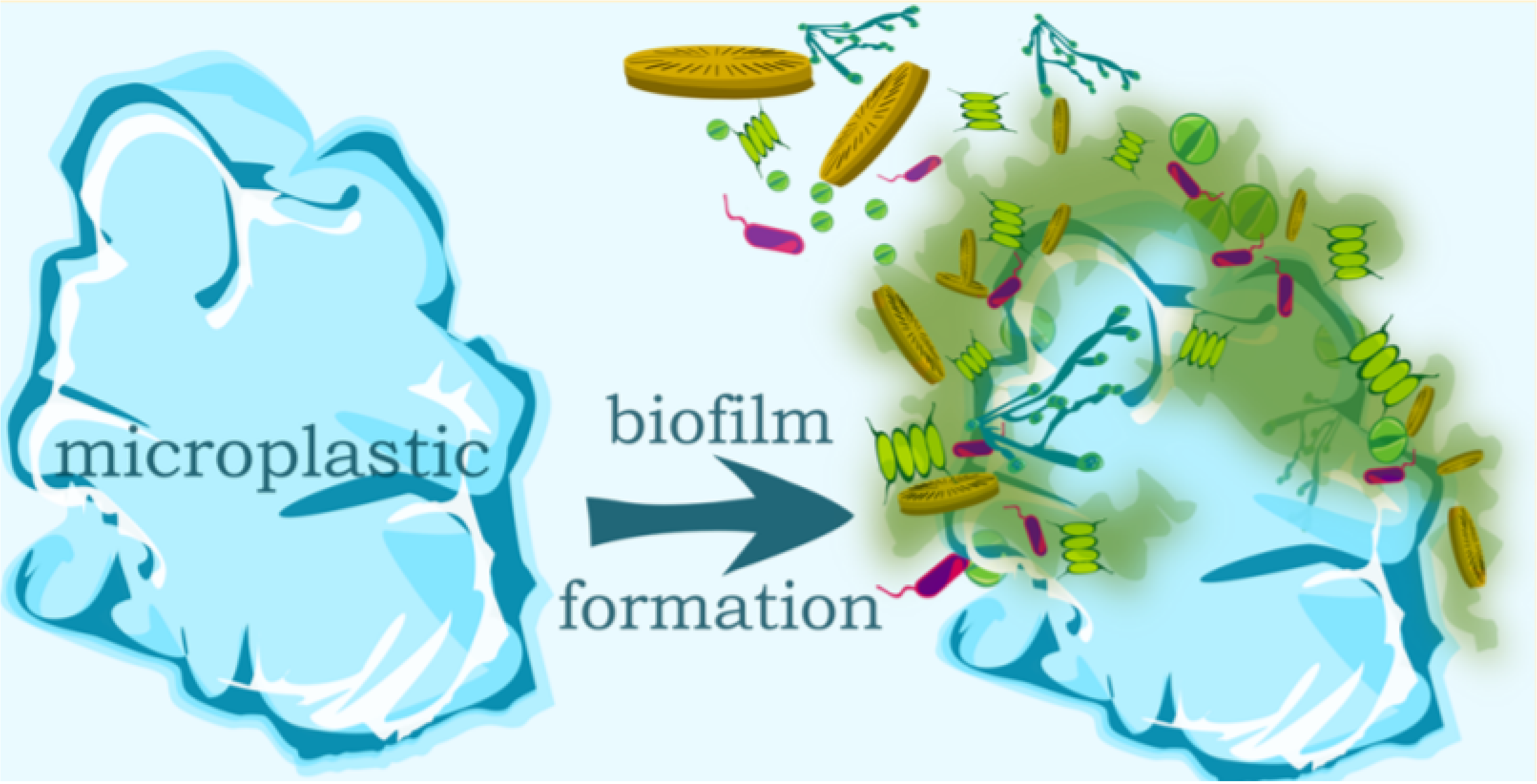
Lu *et al*., Nature, 2022

Enzyme engineering for improved PET recycling and upcycling



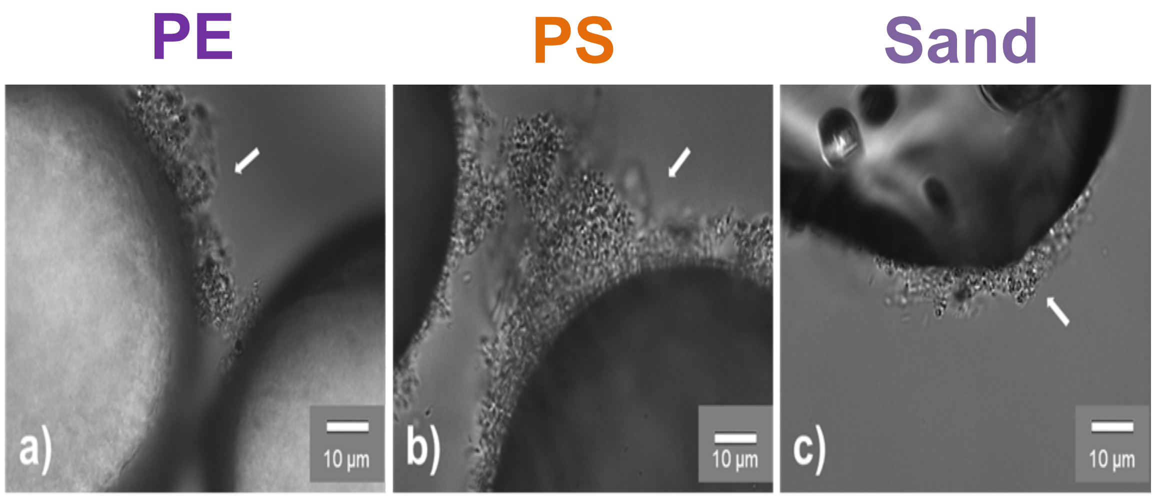
Li *et al.*, Nature Communications, 2023

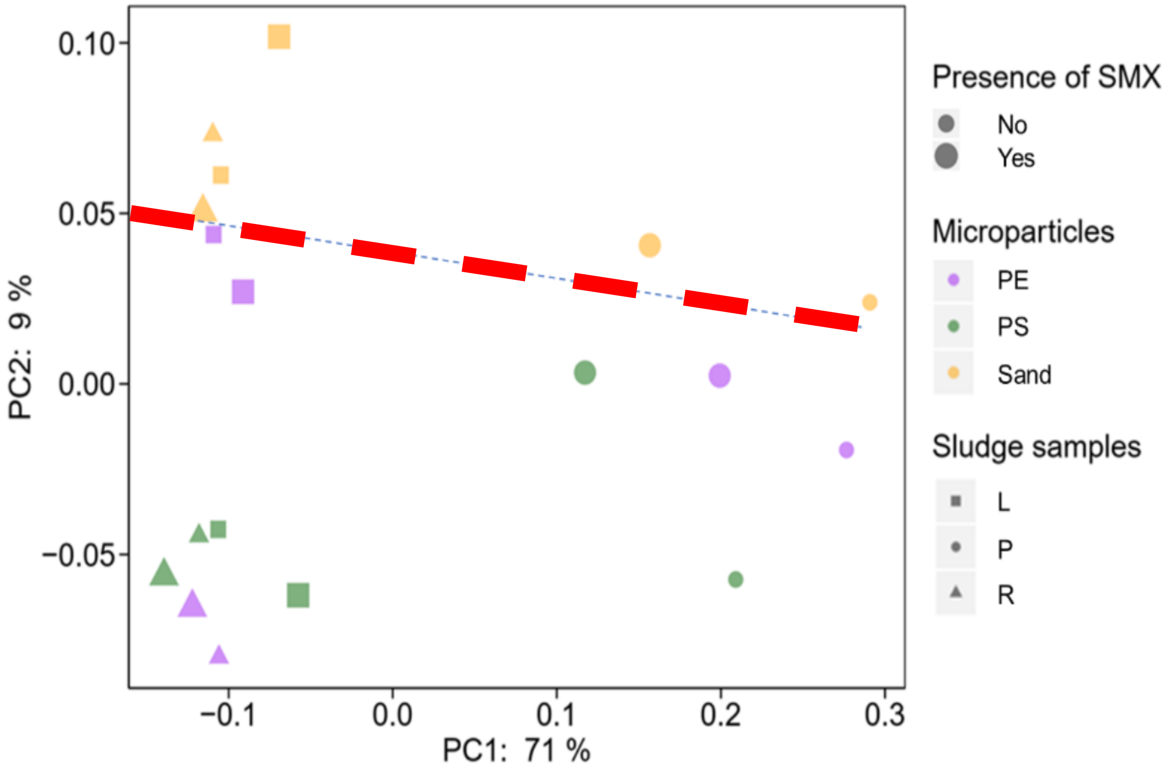
Importance of Plastisphere



Rummel *et al.*, ES&T, 2017

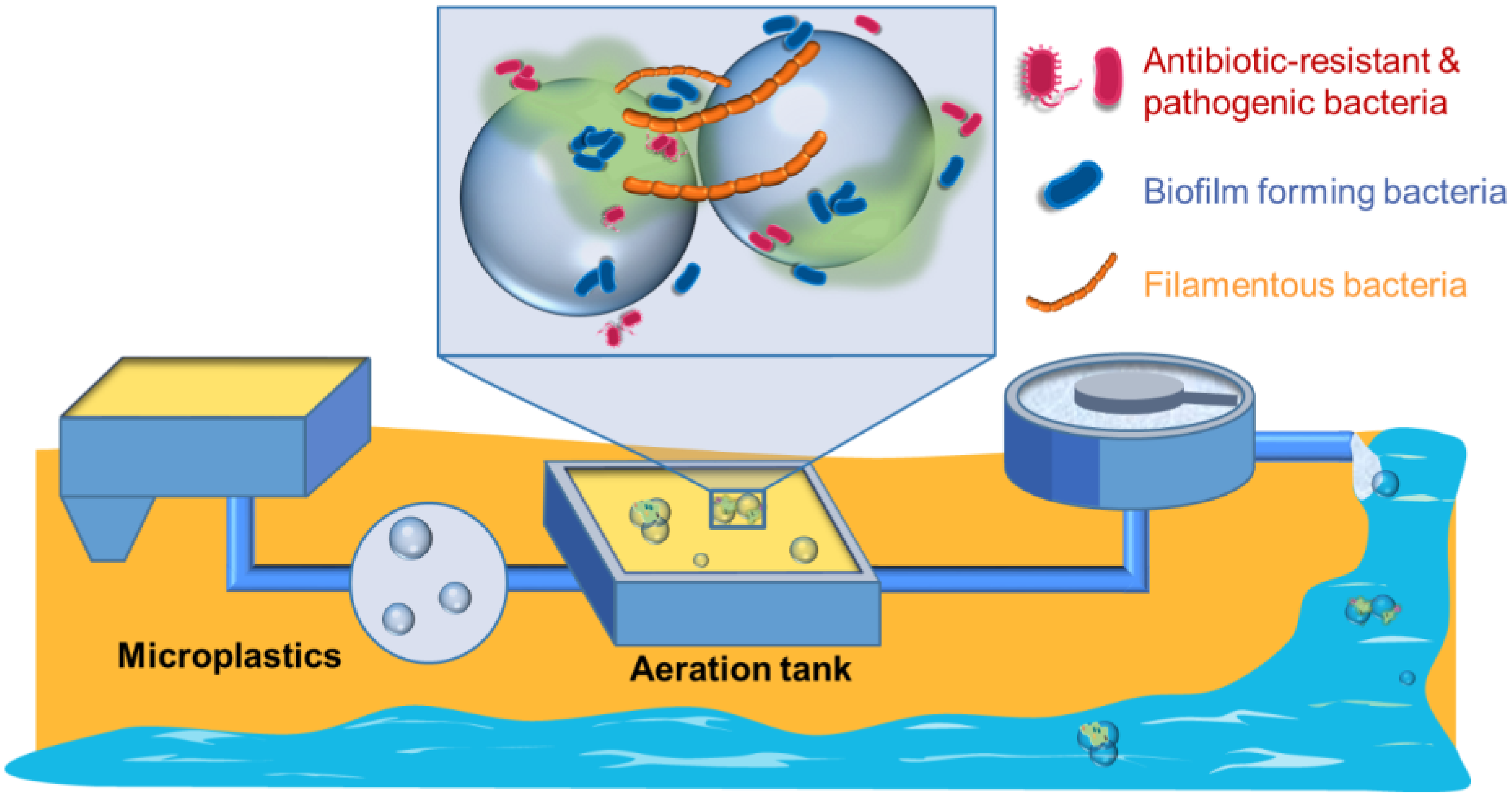
Distinct Microbial Communities in Biofilms Attached to Microplastics versus Sand

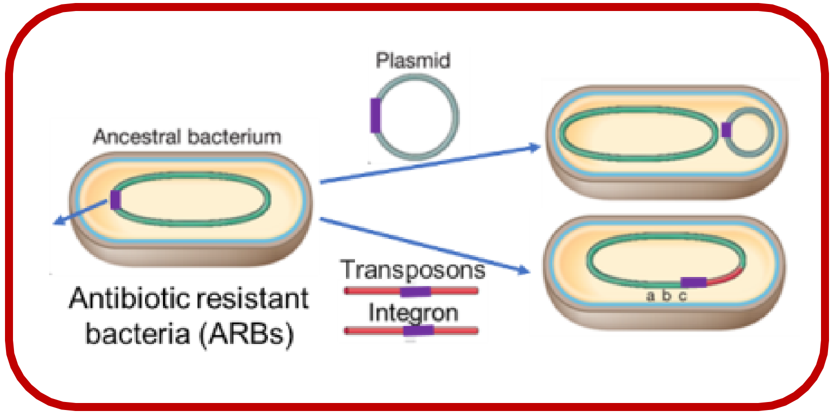


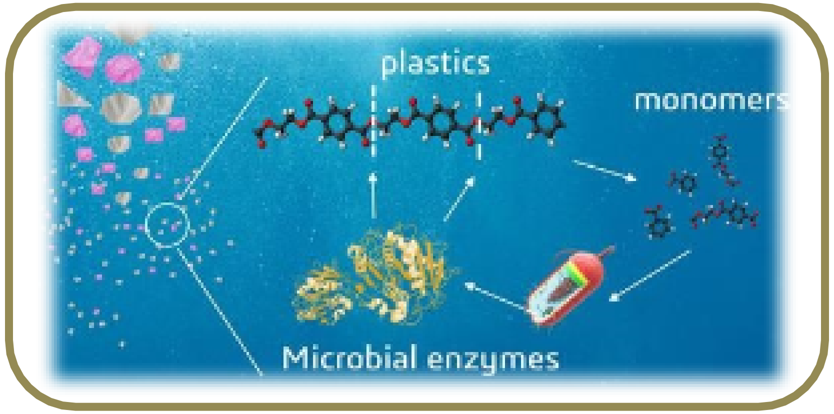


Pham *et al.*, JHM Letters, 2021

Microplastics are hubs of bacteria with antibiotic resistance and plastic biodeterioration potentials

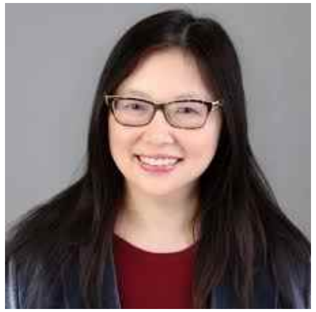






Pham *et al.*, JHM Letters, 2021; Pham *et al.*, in preparation; Zhang, Tech. Networks, 2021

This Panel



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What do all these things have in common?

EU PRIORITY: Plastics monitoRIng detectiOn RemedIaTion recoverY

WG1 – Impacts and risks on human health and environment related to N/MPs

WG1 aims to assess impacts and risks on human health and environment related to N/MPs, as well as to identify, develop and increase the European and global standardization of methods for testing the hazards of N/MPs.

WG2 – Monitoring and sampling Microplastics

WG2 aims to help European and developing countries to assess and develop harmonized monitoring methods and sampling procedures for different environmental matrices.

WG3 – Instrumentation, modelling, data evaluation, software, and analytical procedures

The objectives of WG3 are to (1) understand the potential of the tools available for the analysis, (2) to help European and developing countries to

https://ca-priority.eu/

EU PRIORITY: Plastics monitoRIng detectiOn RemedIaTion recoverY

WG4 – Nanoplastics

WG4 aims to identify suitable and validated analytical methods for detection and quantification of NPs based on the experiences of the Action participants.

WG5 – Remediation, recovery and development of sustainable alternative to plastic materials

WG5 – Remediation, recovery and development of sustainable alternative

WG6 – Metrology and standardization

The main objectives of this WG are the validation of existing protocols for sample preparation and measurements (shape, size, abundance, and composition) in the range of N/MPs, through organization and the participation of PRIORITY laboratories

WG7 – Develop new strategies to increase the synergies with society and education

This WG plans to encourage scientists to participate in science communication activities to increase awareness in society and education regarding the environmental issues

https://ca-priority.eu/

Research History on Microplastic Biofilms

Marine and Freshwater Environments

Wastewater Treatment Plants

From 2006
Microplastic contamination

From 2011
Plastisphere

From 2018
antibiotic resistance & microplastics

From 2019
antibiotic resistance & microplastics in wastewater effluent

Up to present
few study on microplastics & antibiotic resistance in activated sludge units

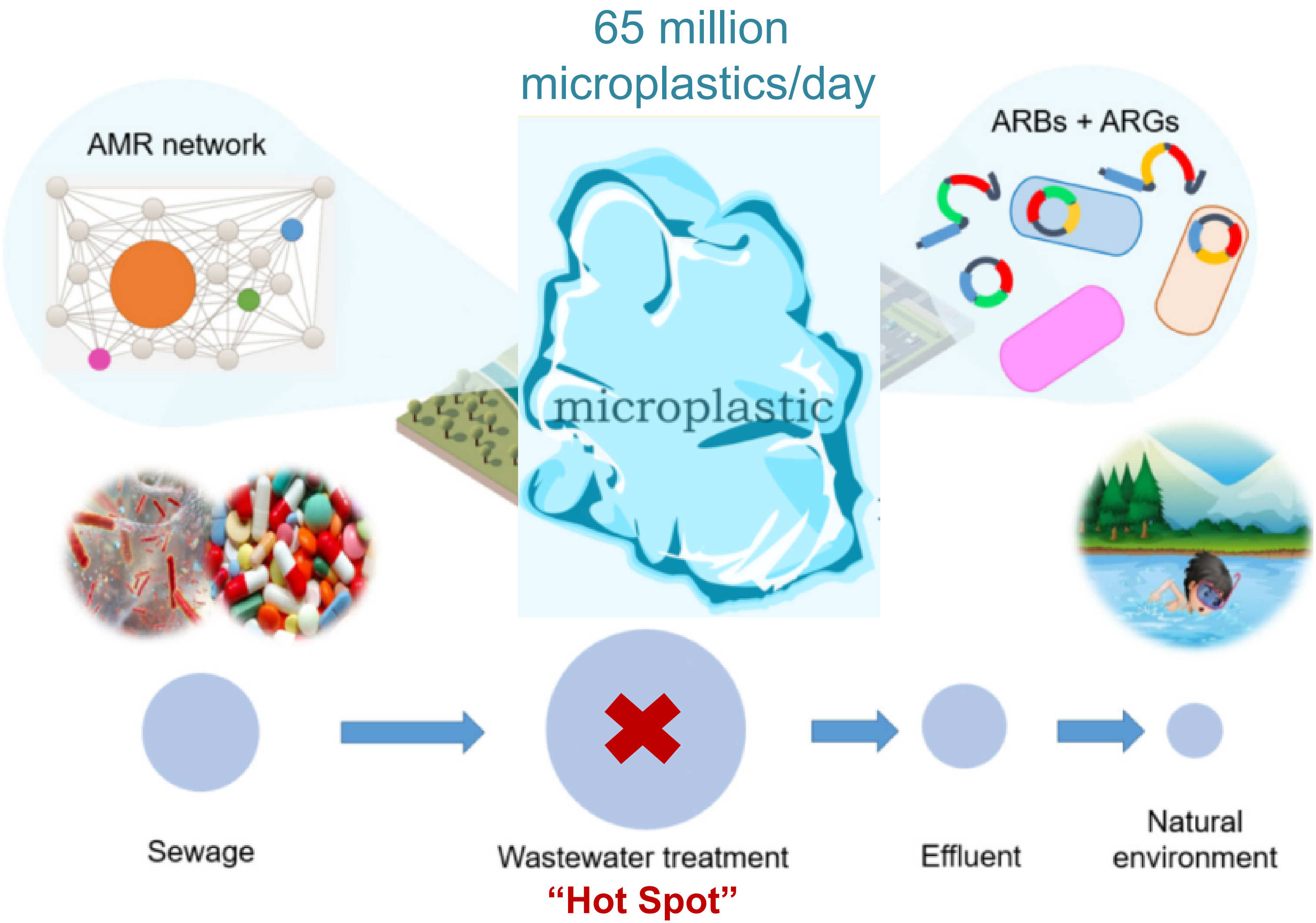
Primary microplastics - a major source of pollution

Microplastics are plastics < 5mm

5,000~100,000 microbeads released in a **single** use! The global release: **1.5 Mtons/year** (15-30%)

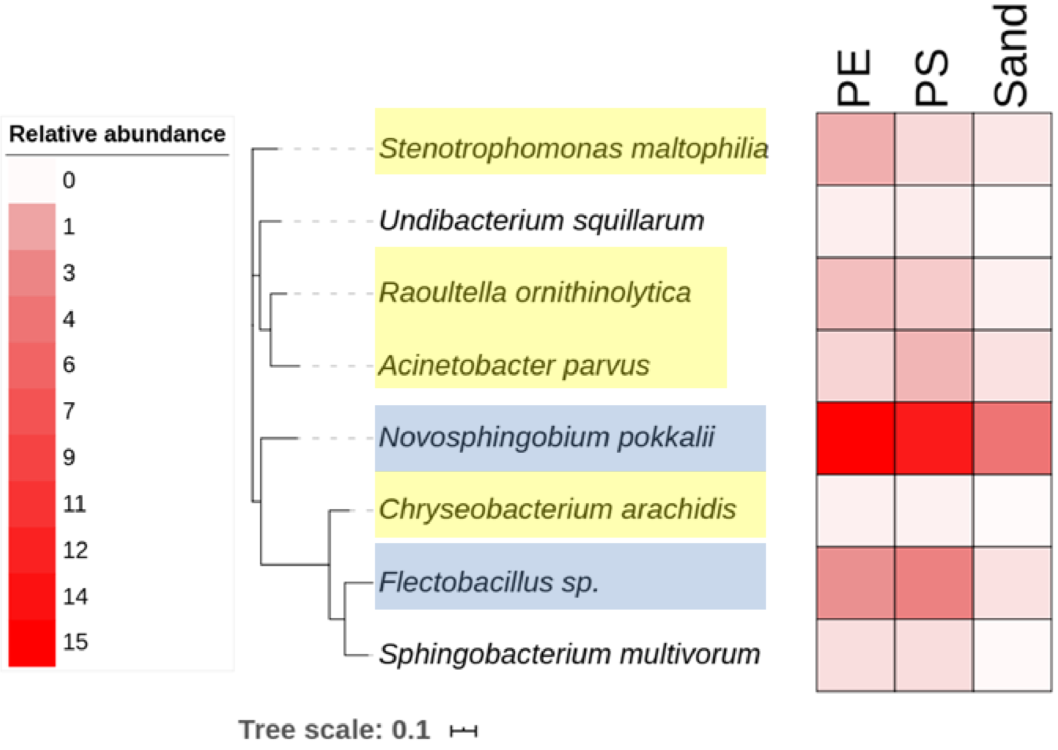
Boucher, J. and Friot D. *et al*., IUCN. (2017)

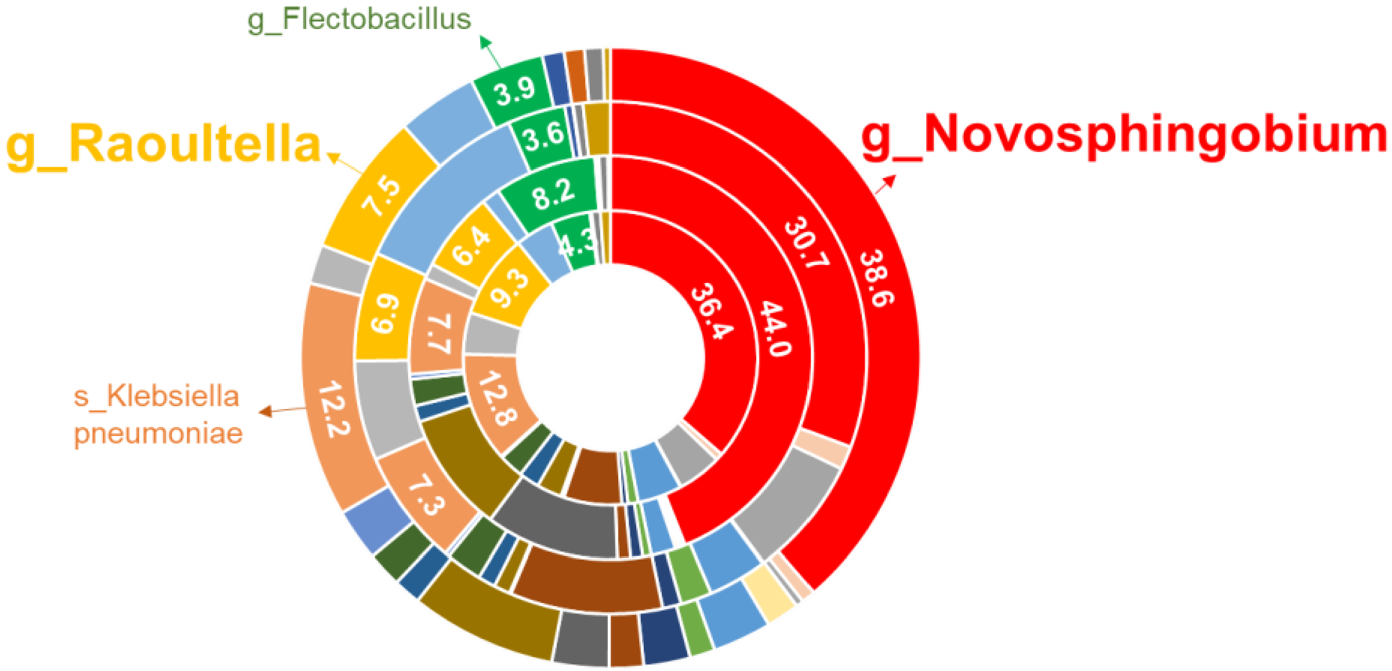
Activated Sludge Tanks as “Hot Spots” where Microplastics, Bacteria, and Contaminants Commingle



Adapted from O’neill *et al*., Rev. Antimicrob. Resist., 2014; Nguyen *et al*., STOTEN, 2021

Metagenome-Assembled Genomes (MAGs)



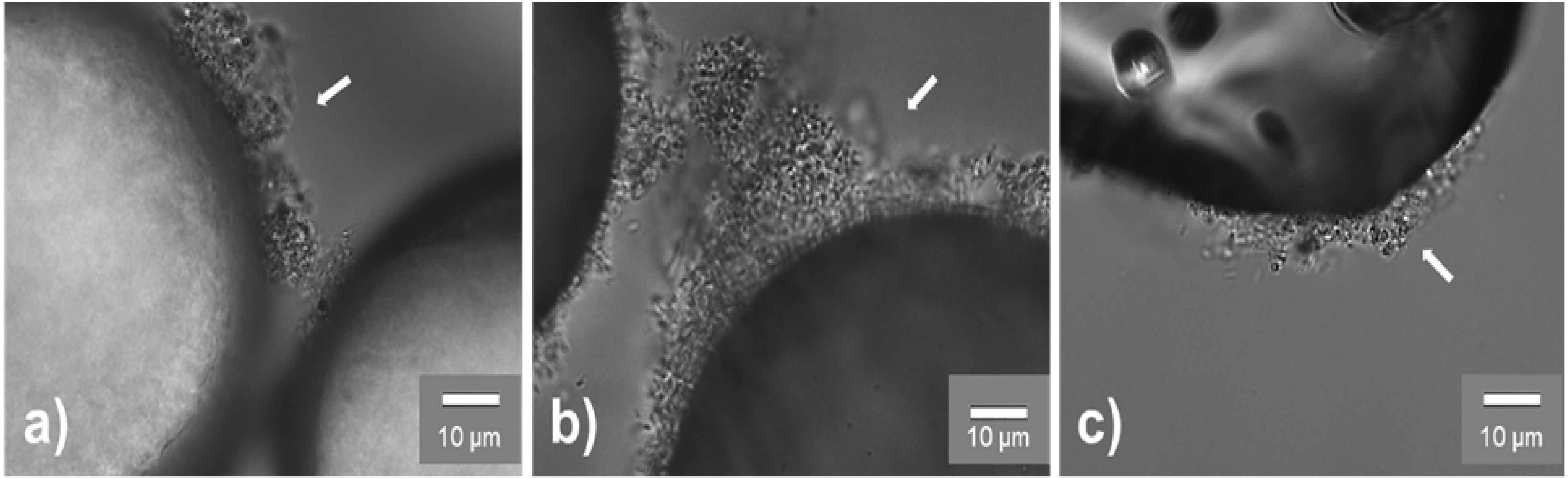


Nanopore MinION

Pham *et al*., JHM Letters, 2021; Pham *et al*., in preparation

Biofilm Formation on Microplastics versus Sand

PE **PS** **Sand**



Pham *et al*., JHM Letters, 2021

Experimental Design

Homogenized activated sludge samples (**L, R, & P sludge**)

10 μm

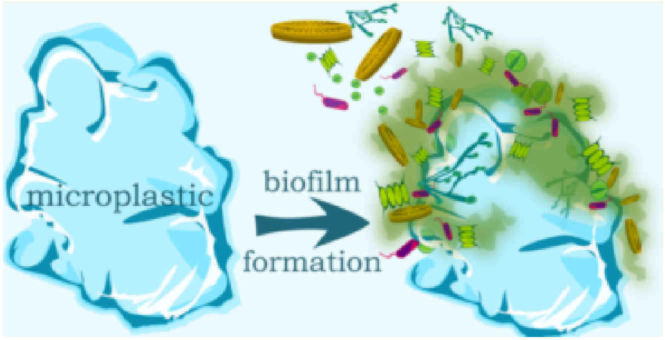
resuspended in synthetic wastewater

inoculated

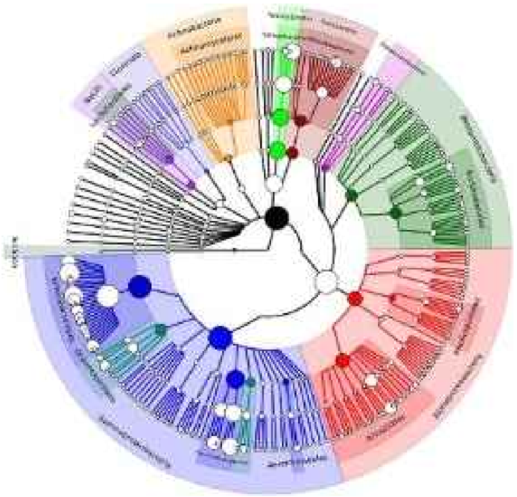
PE/PS/sand (80-105 μm)

0.1 mg/L SMX

3 days of incubation



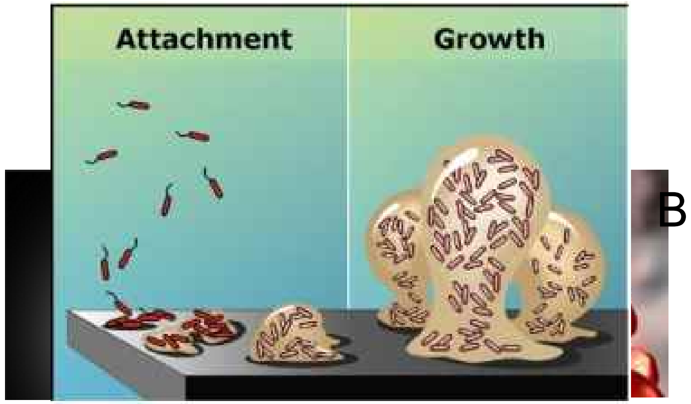
Microparticle **biofilms** were collected for DNA extraction



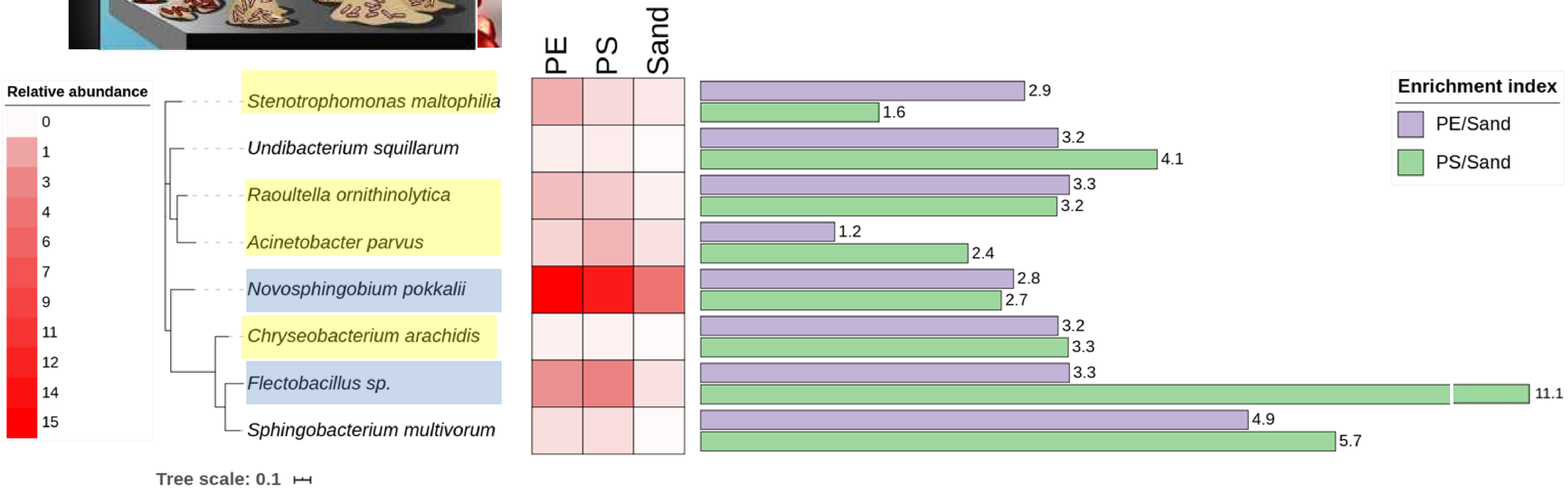
Metagenomics Analysis

Microplastics Enriched Eight Bacterial Species

Enrichment index defines how many times higher that species presented on PE or PS than on sand.

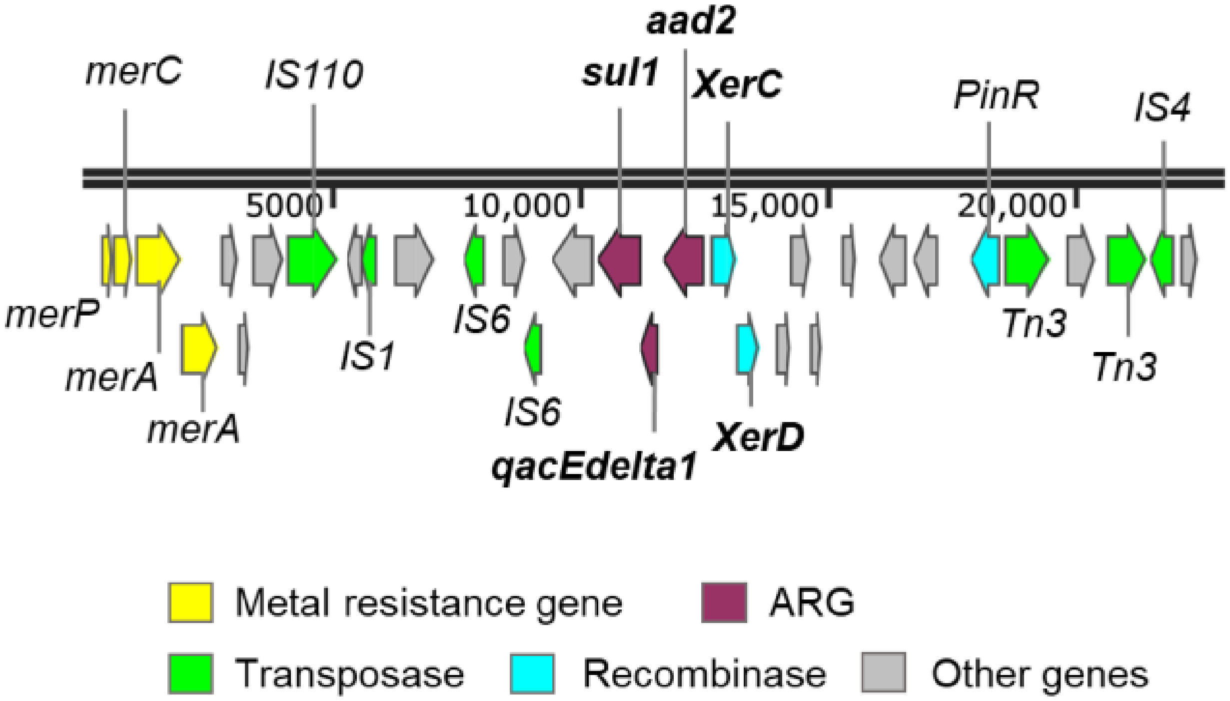


Biofilm formation



A *Raoultella* Genome Carries 26 ARGs and Neighboring Genes to Mobilize Them

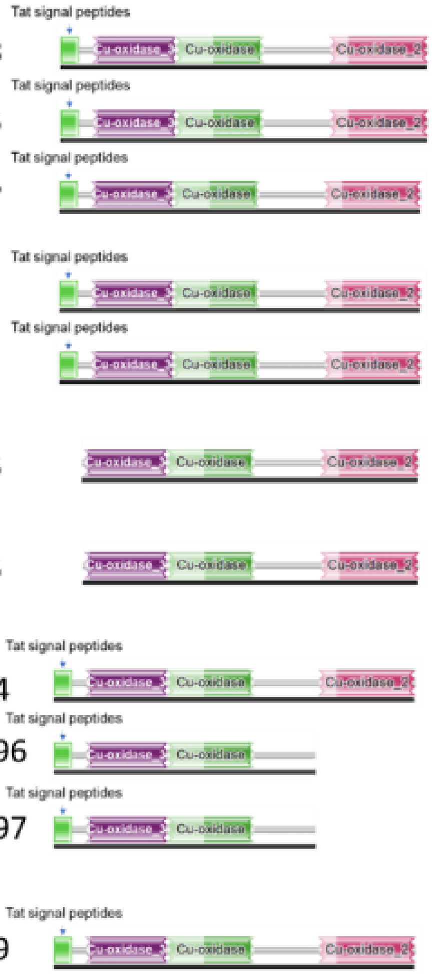
Antibiotic	ARG subtype	Number
Aminoglycoside	*kdpE, aad2*	2
Aminocoumarin	*mdtC, mdtG*	2
Beta-lactam	*OmpA, blaPLA OKP-B-7*	3
Fluoroquinolone	*mdtK*	1
Fosfomycin	*FosA6, mdtH*	2
Peptide	*bacA , yojI*	2
Phenicol	*cmlA*	1
Sulfonamide	*sul1*	1
Multidrug	*acrA, acrB, acrF, baeR, KpnE, KpnF, LptD, marA, qacEdelta1, ramA, rsmA, tolC*	12



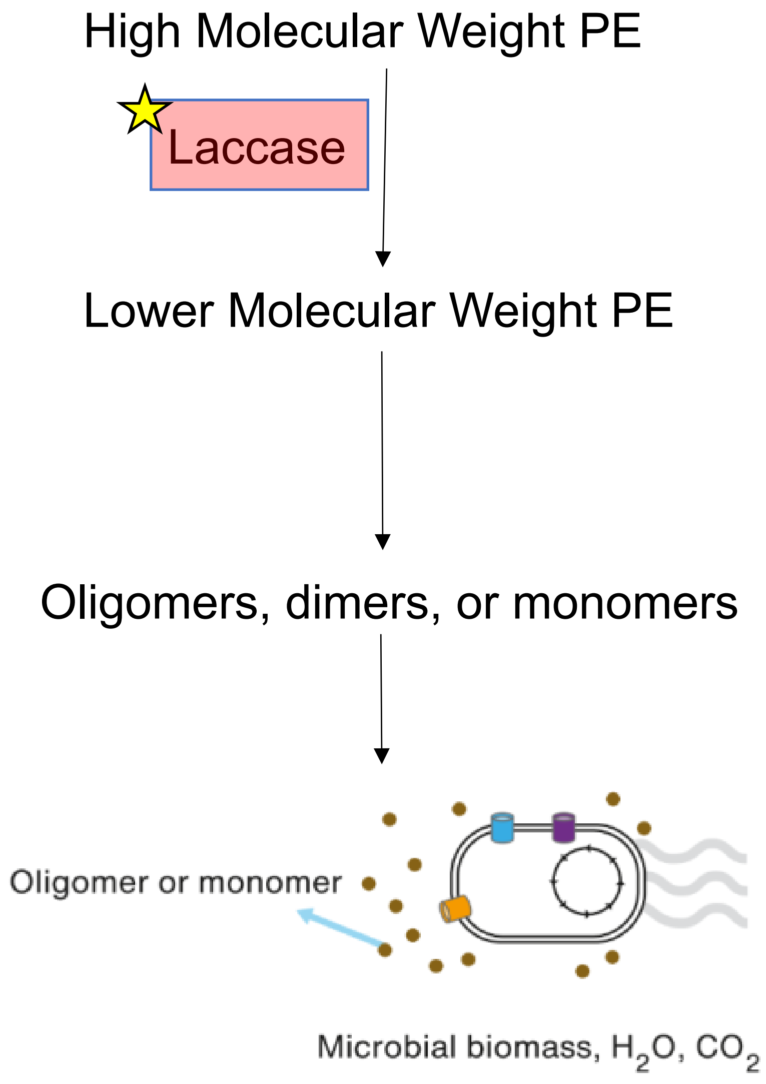
an example of a resistance island

Pham *et al.*, in preparation

All *Novosphingobium* Genomes Contain Putative Laccase Genes with Plastic Biodeterioration



		Identity to gene_241689	Length of protein (bp)
Bin1	Gene_241698	100%	602
	Gene_282975	59%	641
	Gene_357237	59%	568
Bin19	Gene_21100	59%	628
	Gene_67166	58%	571
Bin2	Gene_352615	74%	589
Bin22	Gene_352615	57%	448
Bin40	Gene_95004	45%	563
	Gene_430096	60%	264
	Gene_430097	59%	379
Bin64	Gene_14939	68%	576



Pham *et al.*, in preparation

Plastic Pollution - a Global Issue

Global plastic production: **348 Mtons/year**

Plastic waste entering the ocean: **4.8 to 12.7 Mtons/year**

Boucher, J. and Friot D. *et al.*, IUCN. (2017)

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