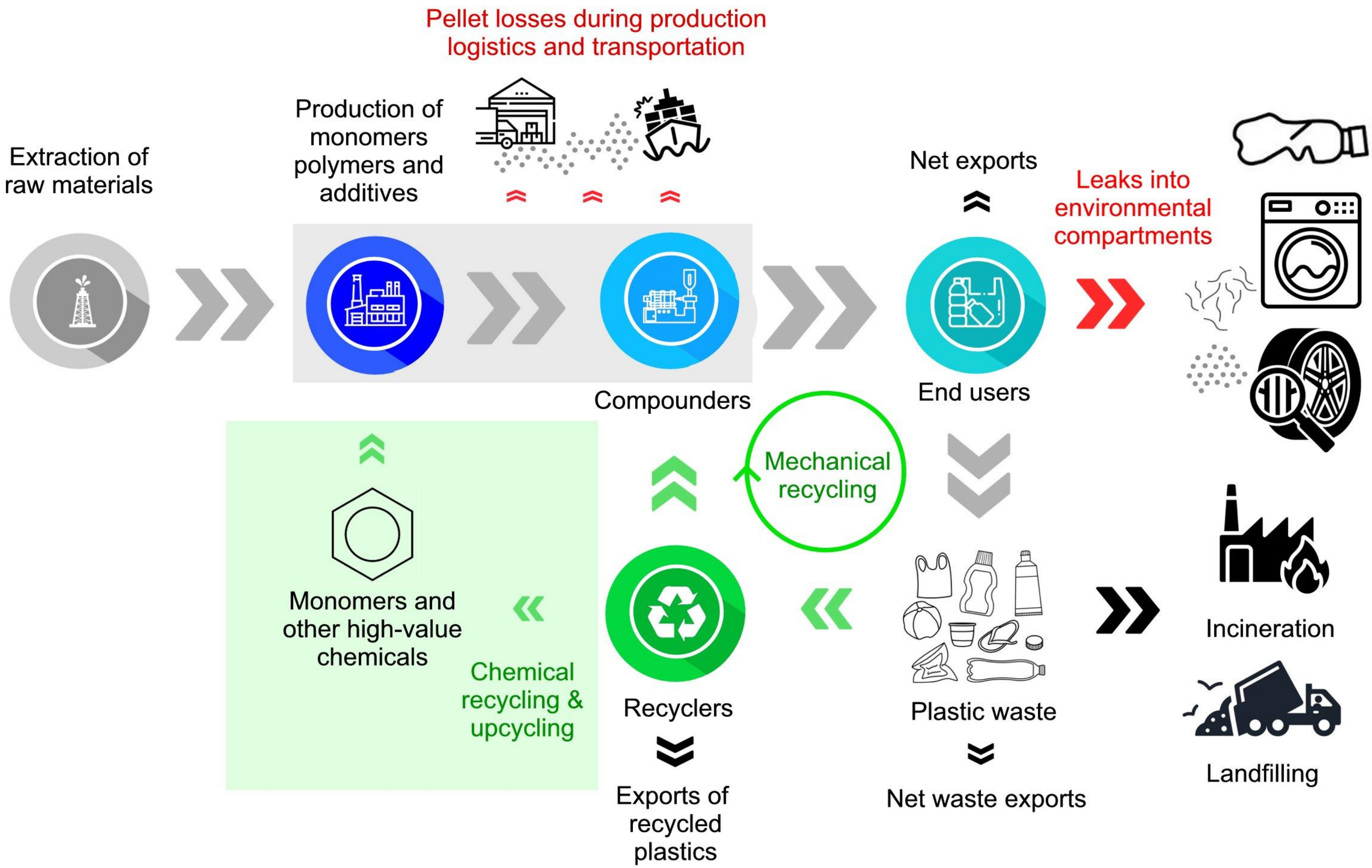
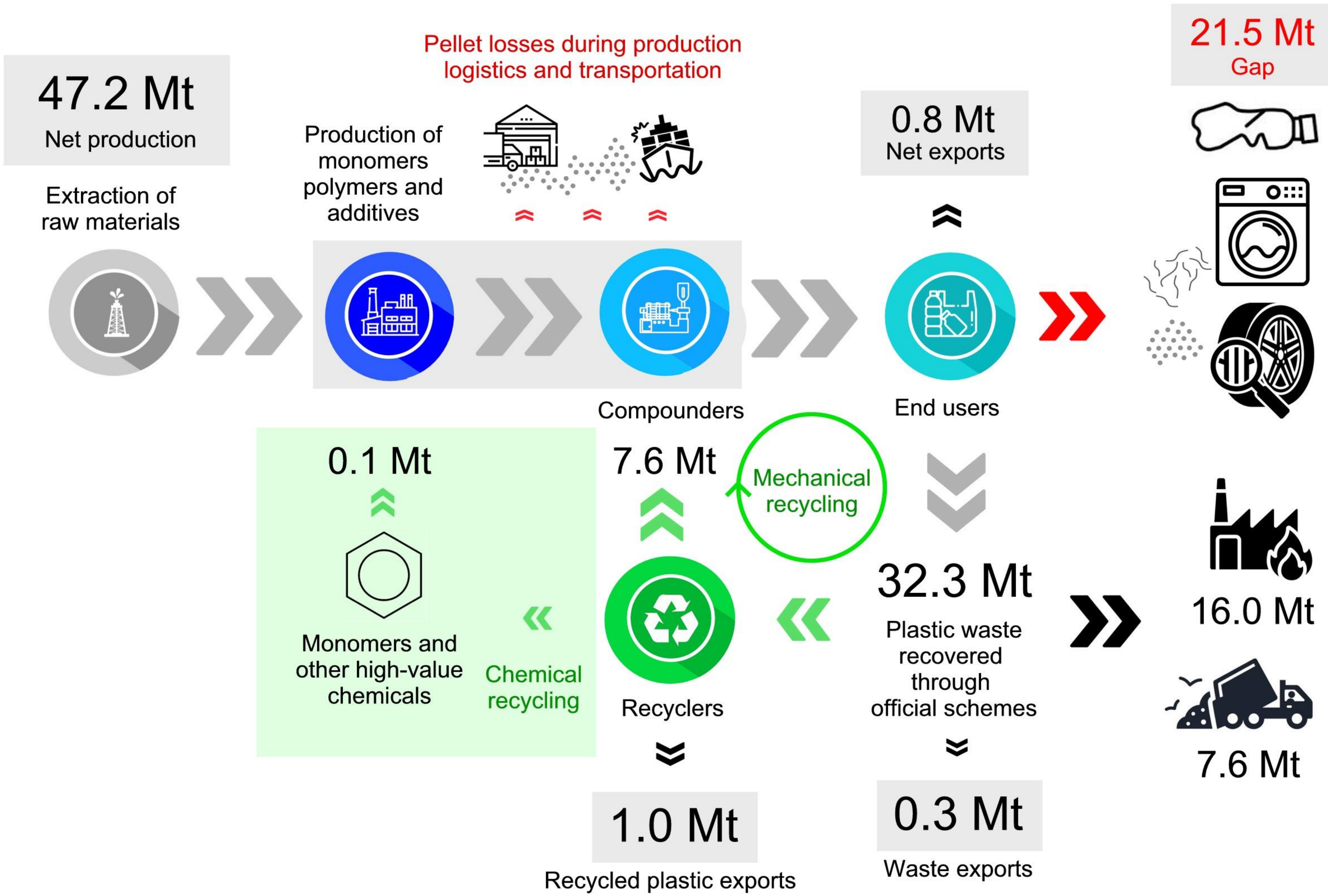
marii
Summit on Microplastics

Challenges in plastic risk assessment: Exposure and hazard of particles and additives

Roberto Rosal
Professor of Chemical Engineering
University of Alcalá
roberto.rosal@uah.es
https://rosal.web.uah.es

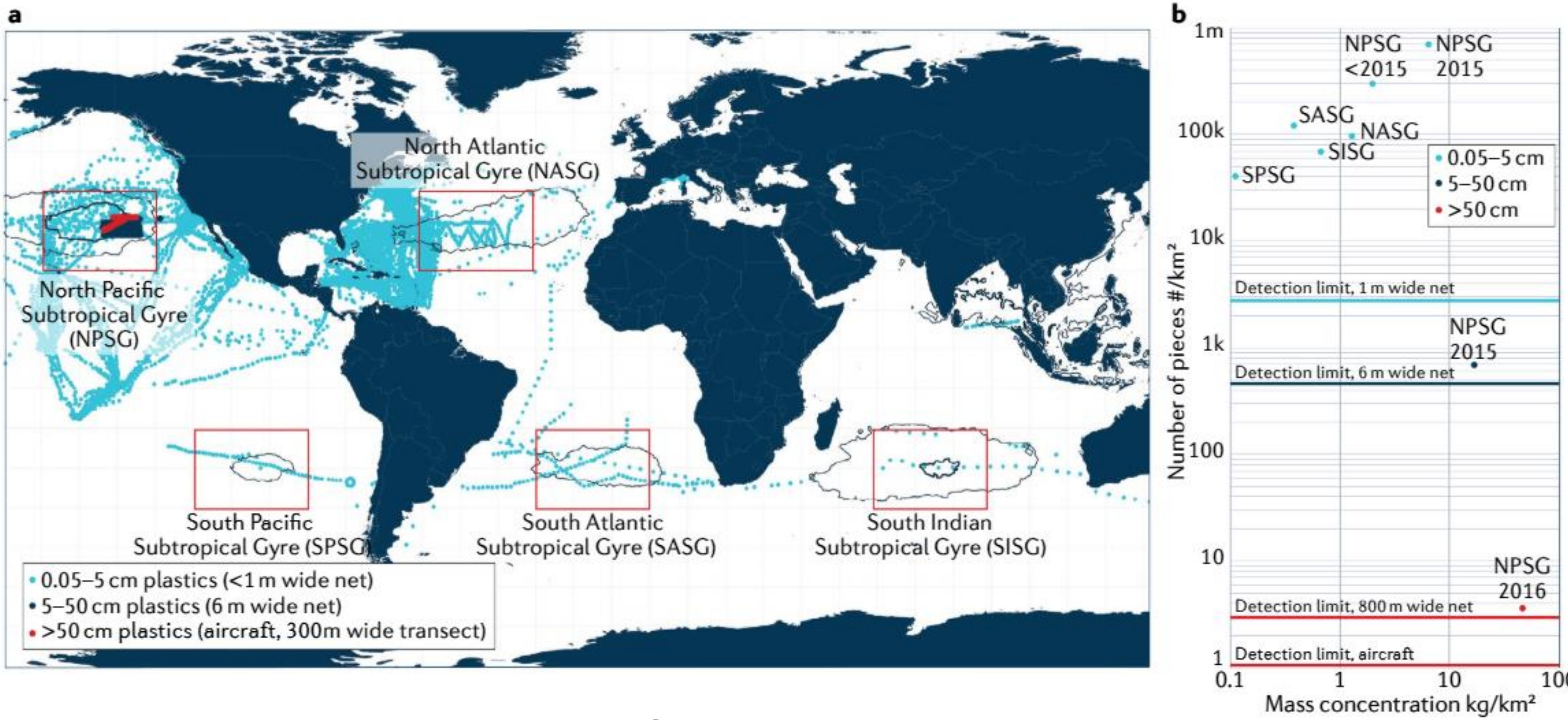

Pellet losses during production logistics and transportation
Extraction of raw materials
Production of monomers polymers and additives
Compounders
Net exports
Leaks into environmental compartments
End users
Mechanical recycling
Monomers and other high-value chemicals
Chemical recycling & upcycling
Recyclers
Exports of recycled plastics
Plastic waste
Net waste exports
Incineration
Landfilling



47.2 Mt
Net production
Extraction of raw materials
Pellet losses during production logistics and transportation
Production of monomers polymers and additives
0.8 Mt
Net exports
21.5 Mt
Gap
Compounders
End users
0.1 Mt
7.6 Mt
Mechanical recycling
32.3 Mt
Plastic waste recovered through official schemes
16.0 Mt
Monomers and other high-value chemicals
Chemical recycling
Recyclers
7.6 Mt
1.0 Mt
Recycled plastic exports
0.3 Mt
Waste exports

Estimated global abundance of plastic in oceans

Eriksen et al. 2023 — 17 (8–36) × 10^{13} particles weighing 1.1 – 4.9 Mt
van Sebille et al. 2015 — 1.5-5.1 × 10^{13} particles weighing 93-236 kt



Estimated concentration of plastic in oceans

Plastic in gyres peaks of < 1 items/m^2 (NASG) and 10 items/m^2 (NPSG)
Mass equivalence: 1-10 kg/km^2 ~ 1-20 µg/L (0.5-1 m water column thickness)
Beiras and Schönemann 2020 (27 studies) — 0.7 µg/L (median); 19 µg/L (av.)

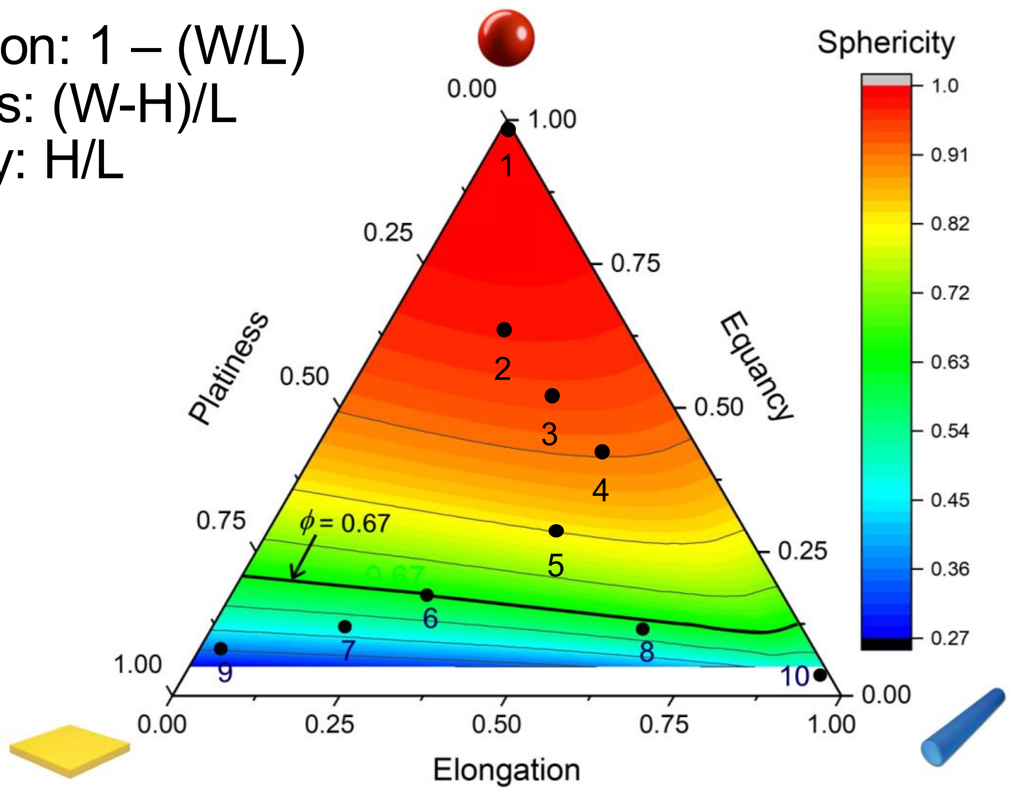
Plastic particles display a wide variety of shapes

Fragments, Granules, Flakes, Foams, Styrofoam, Films, Sheets, Filaments, Lines, Fibres, Strands, Pellets, Beads, Mermaid’s Tears... (GESAMP, 2019)

Shape determines the interconversion of weight and number concentration

Three main orthogonal dimensions: L ≥ W ≥ H

Elongation: 1 – (W/L)
Platiness: (W-H)/L
Equancy: H/L

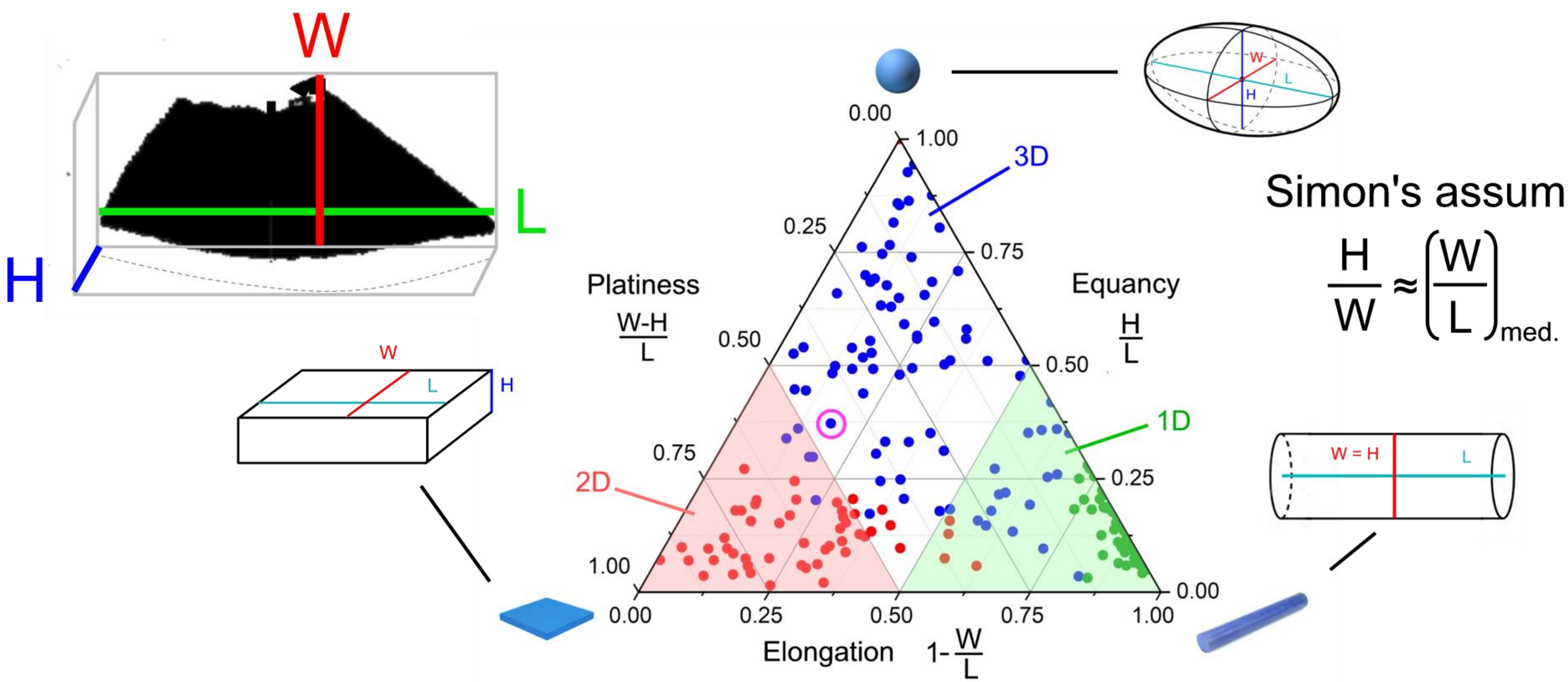


Mar. Pollut. Bull. 171, 112716, 2021

Mass of plastic from two-dimensional images

Risk Assessment requires mass concentration: Exposure verification – Adverse Outcomes (hazard) – Estimated/Acceptable Rate Intakes

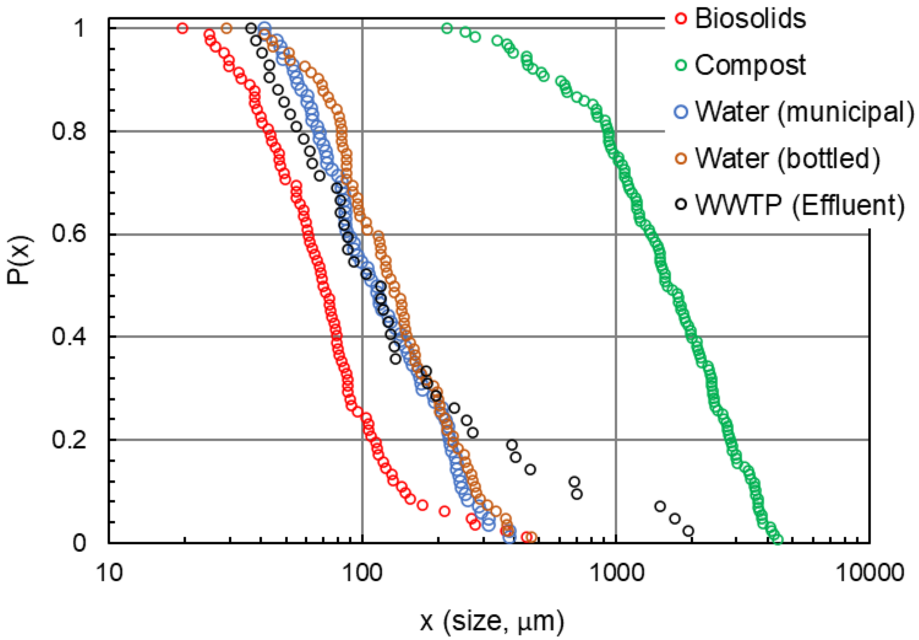
Projected (2D) images + Shape models = Particle volume
Particle volume + Density + Void fraction (if needed) = Mass of individual particle
Mass of individual particle + Subsample estimations = Total mass in a sample
Total mass in sample/subsample + Sample volume/mass = **Mass concentration**



$$\frac{H}{W} \approx \left(\frac{W}{L}\right)_{med.}$$

Exposure estimation from images

Particle counts and number concentration versus mass concentration



WWTP Effluent:

A2O WWTP: 10.7 MPs/L ~ **15 µg/L**

300 Million MPs/day = 430 g/day

Biosolids:

Dry sludge 183 MPs/g

Dry pellets 165 MPs/g

In mass units 165 MPs/g ~ **135 µg MP/g**

MP input to agricultural lands in Europe:

2-3 Mt x 135 µg MP/g = 270-400 t/year

(other estimations 50 000 and 175 000 tonnes/year)

Compost from OFMSW:

5-20 MPs/g (separate collection of biowaste) 15-60 mg MPs/g **~30 mg MPs/g**

OFMSW (per year) 100 Mt; dry compost 32 Mt; x 30 mg MPs/g = **0.5-1.9 Mt/year** (only MPs)

Drinking water:

Municipal: 12.5 (8.3-21.7) MPs/m^3, **18 ng/L**, EDI: 0.5-2.2 ng kg^{-1} day^{-1} (2 L/day)

Bottled (PET): 0.73 (0.64-1.58) MPs/L, **1.61 (1.1-2.9) µg/L**, EDI (65 L/year): 4-18 ng kg^{-1} day^{-1}

1 mg in 10 years (bottled, 65 L/year) and 75 years (municipal 2 L/day)

Georg Dierkes*, Tim Lauschke, Peter Schweyen, Thomas A. Ternes
Bundesanstalt für Gewässerkunde, Koblenz, Deutschland
*Kontakt: dierkes@bafg.de

Polyethylen überall!

Wirklich?

nature medicine

Brief Communication https://doi.org/10.1038/s41591-024-03453-1

Bioaccumulation of microplastics in decedent human brains

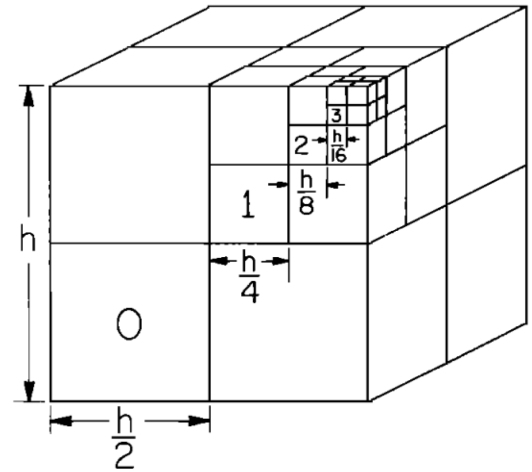
Environmental Science & Technology

pubs.acs.org/est Article

Assessing the Efficacy of Pyrolysis−Gas Chromatography−Mass Spectrometry for Nanoplastic and Microplastic Analysis in Human Blood

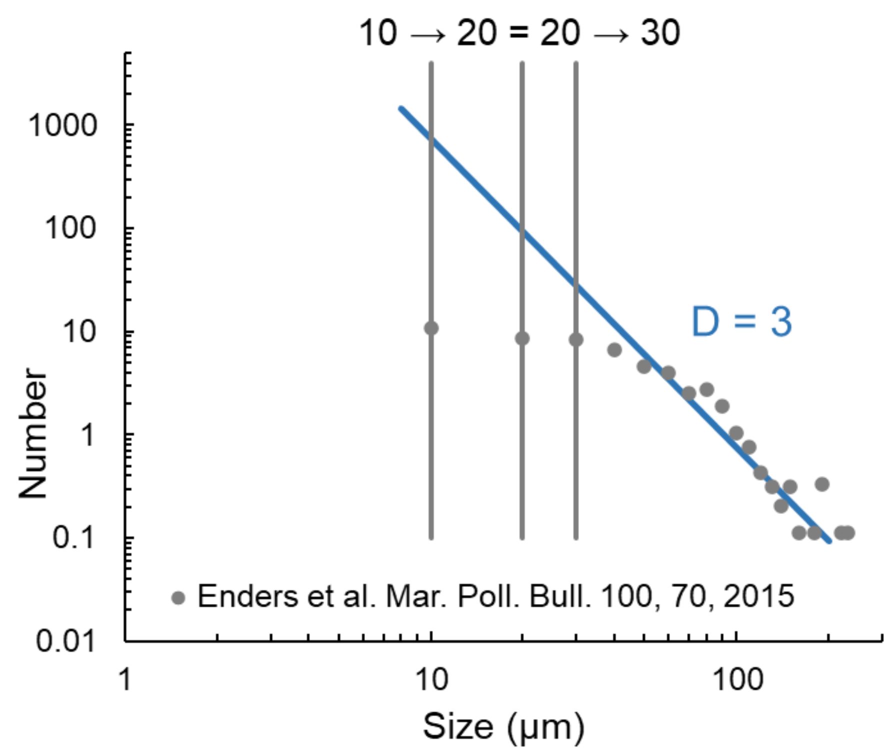
Exposure estimation from fragmentation patterns

Fractal fragmentation (meaning scale invariance) allows rational estimations of mass concentration for sizes too small to be accurately measured. Fragmentation depends on the probability «p» of crushing with crushing ratio «b» [b = 2 →]



The number of fragments N_i with size x_i is given by (**power law**):

$$N_i = C\, x_i^{-D} \text{ with } D = 3 + \frac{\ln p}{\ln b} \rightarrow 3\,(p \rightarrow 1)$$



D is the dimension of the fragmentation process – If D = 3 fragmentation is mass conserving: **same Δ (size) corresponds to same mass:**

$$M_i = \int \rho \frac{\pi}{6} x_i^3 \left(C\, x_i^{-3}\right) dx = \rho \frac{\pi}{6} C\, \Delta x_i$$

Exposure to nanoplastics

Drinking water: Microplastics → Nanoplastics

Gálvez-Blanca et al. 2024: **1.61 µg/L** (29-294 µm) → **6.1 ng/L**

Oßmann et al. 2018 (0.4-10 µm):

Single use: **23 ng/L** → **2.4 ng/L,** Reusable bottles: **171 ng/L** → **18 ng/L**

Schymanski et al., 2018 (5-100 µm):

Single use: **260 ng/L** → **2.7 ng/L**, Returnable: **650 ng/L** (5-100 µm) → **6.8 ng/L**

Drinking water: Nanoplastics

Qian et al. 2024: Hyperspectral stimulated Raman scattering (200 nm, Anodisc filters): → **10 ng/L < 1 µm**

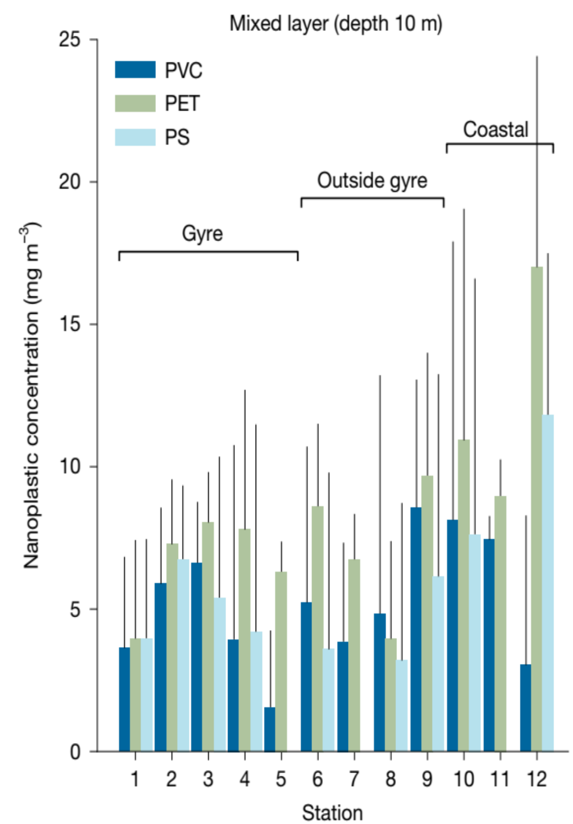
Seawater: Nanoplastics

ten Hietbrink et al. 2025: **1.5–32.0 µg/L** NPs (PET, PS and PVC), PVC Niskin bottles, < 1 µm filters, TD-PTR-MS)

Seawater: Microplastics → Nanoplastics

Beiras and Schönemann, 2020: concentration in marine samples (< 5 mm, 27 studies):

0.71 µg/L (median), 19 µg/L (average) → 0.2-3.9 ng/L

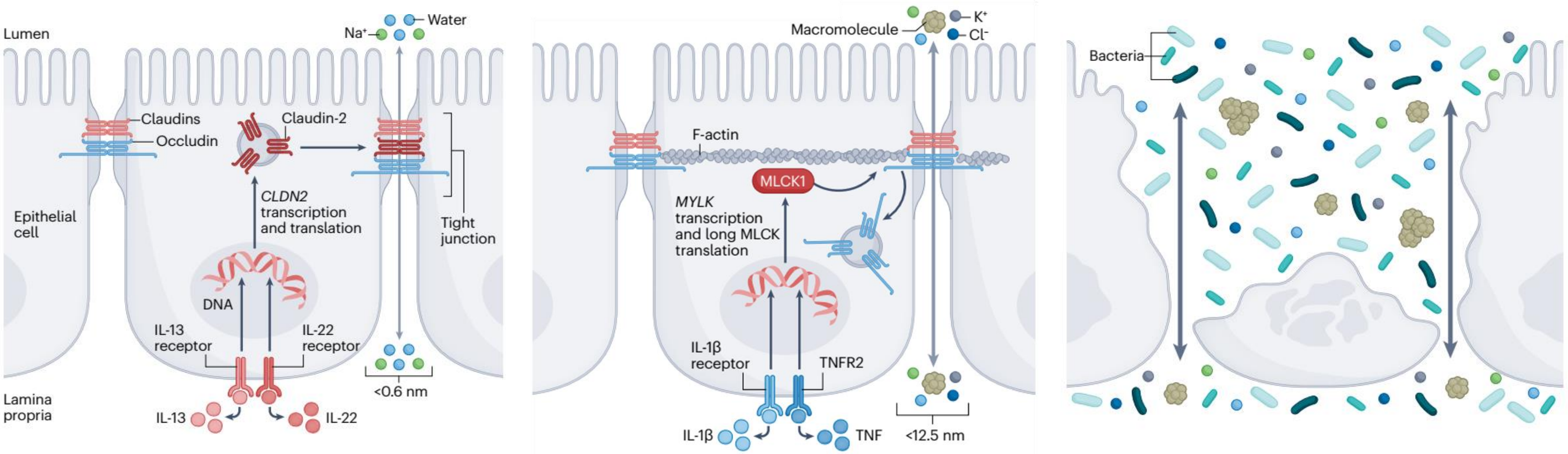


Particle toxicity only expected for the smallest sizes

Transcellular (endocytic) route: active transport used by small hydrophilic and lipophilic compounds: 200-300 nm.

Paracellular transport across tight junctions: passive transport of water, ions and small molecules mostly < 10 nm

Unrestricted pathway due to pathologic situations involving damage of dead of epithelial cells (large molecules and even bacteria)



Exposure to MPs may alter the expression of Tight Junctions/ZO proteins, induce oxidative stress or apoptosis, but the available data are very limited.

Plastic-related chemicals

NIAS: Monomers (not polymerized), oligomers and other NIAS (solvents, impurities)

Additives. Bring functionality (average 4% wt.) [**Plasticizers, flame retardants**, fillers, colorants, antioxidants, heat and light stabilizers, lubricants, biocides, antistatic agents, and many more] and intentionally added substances (catalysts)

Gaps in exposure and hazard assessment:

(i) Limited information on the identity of the chemicals used in each plastic on the market because of industrial secrecy

(ii) Exposure and toxicity profile is difficult because most additives are highly hydrophobic

(iii) Difficulty to perform exposure and risk assessments (environmental and physiological degradation, sublethal effects, realistic particles multiple stressors)

Current knowledge gaps

1. Accurate exposure information is needed in mass units, especially for small microplastics and nanoplastics and for human exposure trough food products
2. Detailed information on internalization mechanisms: findings of nanoplastics must be accompanied by an explanation of how they reached that location
3. Hazard information needed about additives, NIAS and new products such as bioplastics even if highly hydrophobic
4. There is insufficient exposure-effect information for Bayesian risk assessment including sublethal chronic effects and the combination of stressors


Microplastics?
COOPER