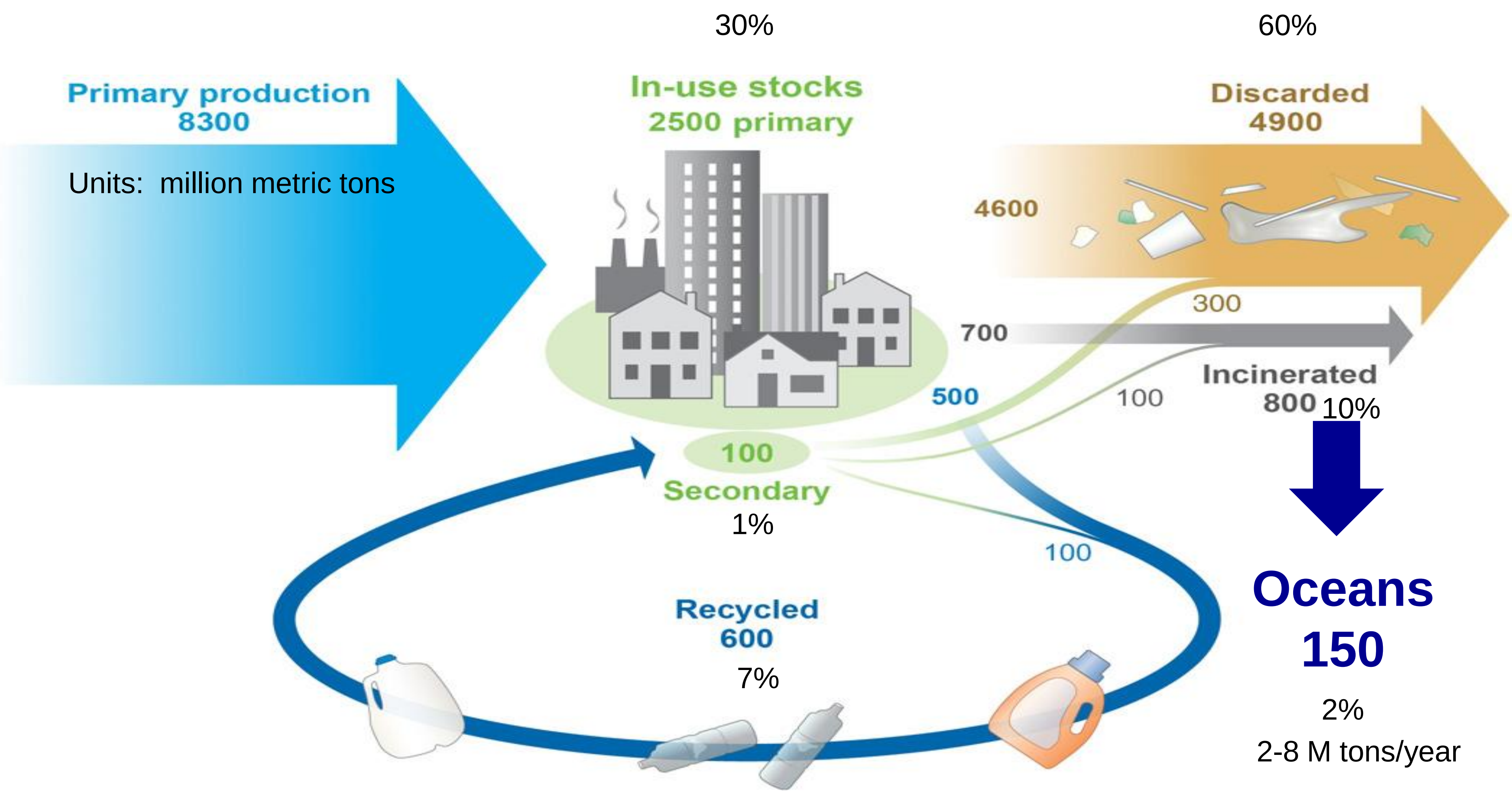
Microplastics in the Ocean: Emergency or an Exaggeration

Scott Gallager, Woods Hole Oceanographic Institution
Chair- WHOI Microplastics Initiative

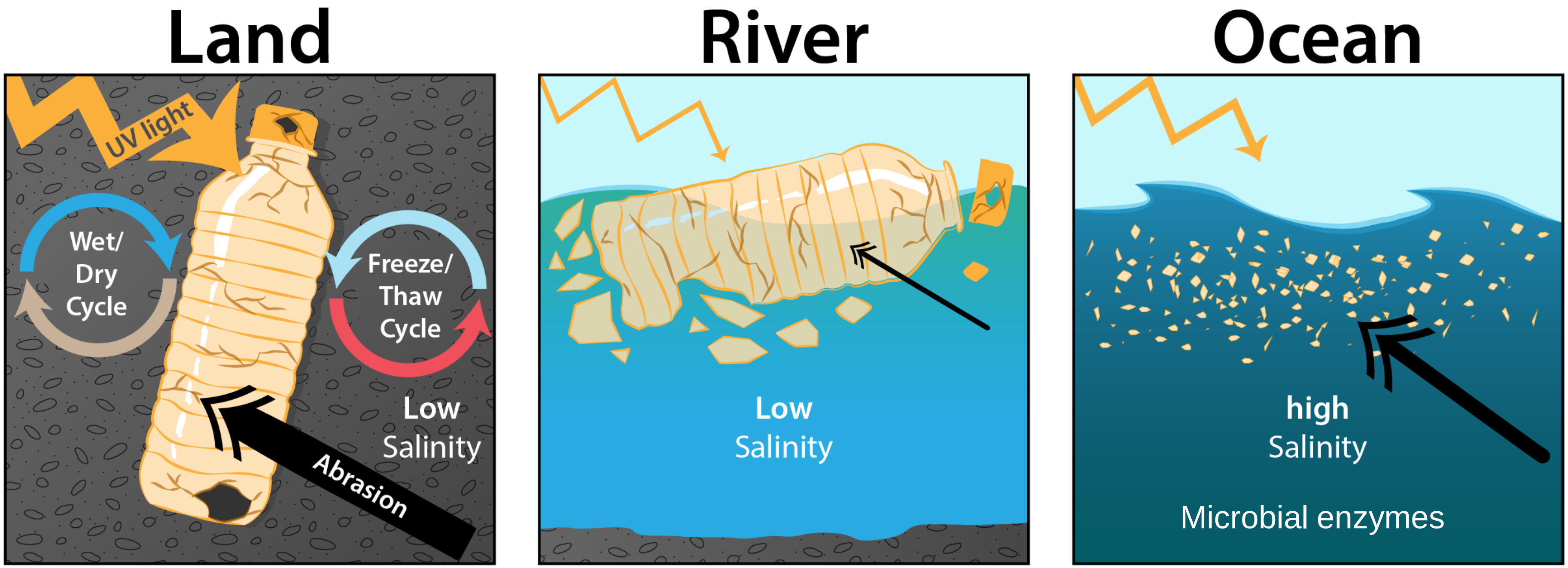
NESSA-April-10-2019

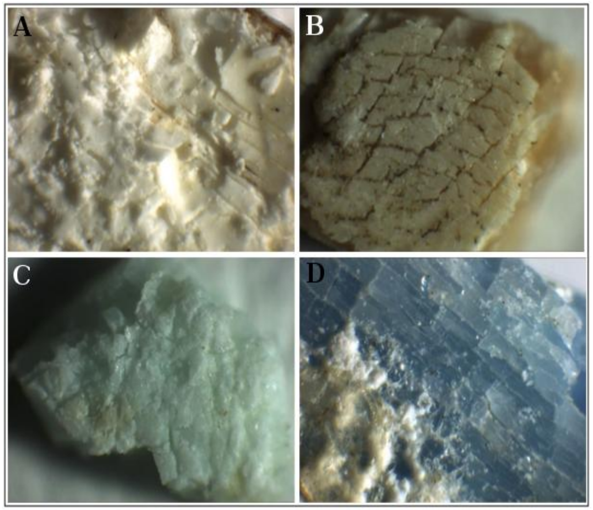
Global production, use, and disposal of plastics (1950-2015, 65 years)

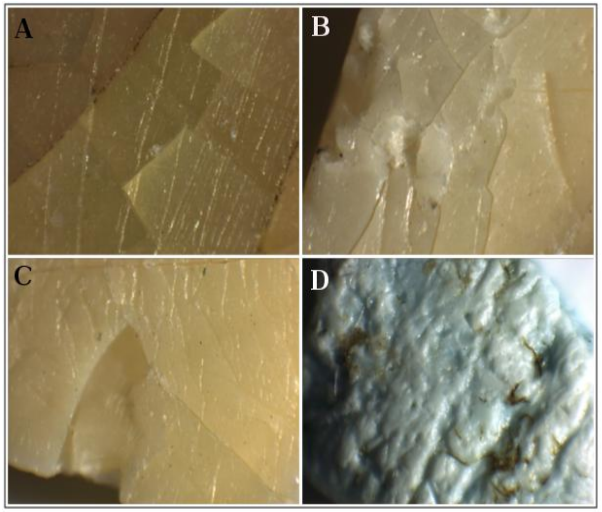


Roland Geyer et al. Sci Adv 2017;3:e1700782

Weathering of Plastics in the Ocean





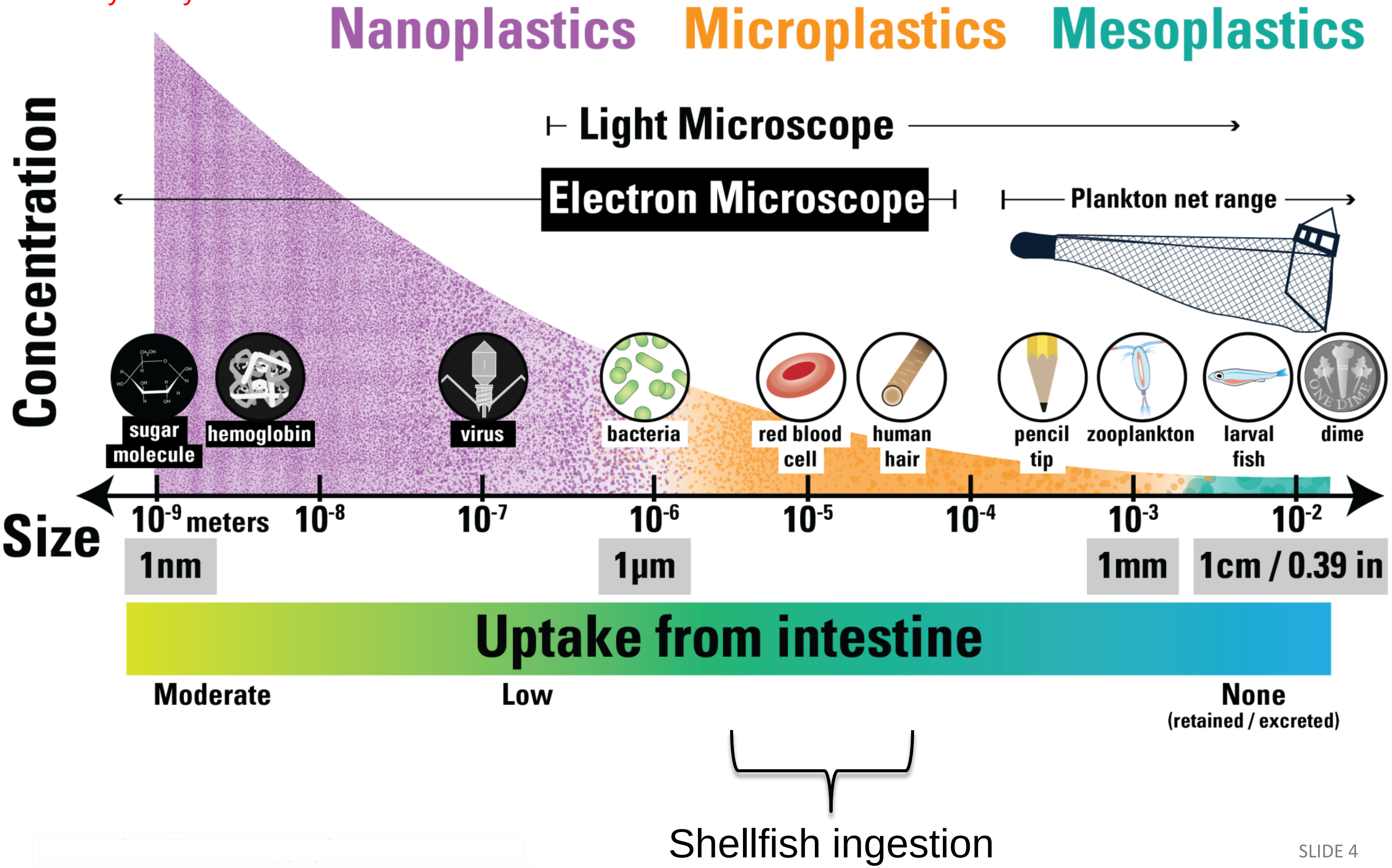


Cracks, fissures, chips-

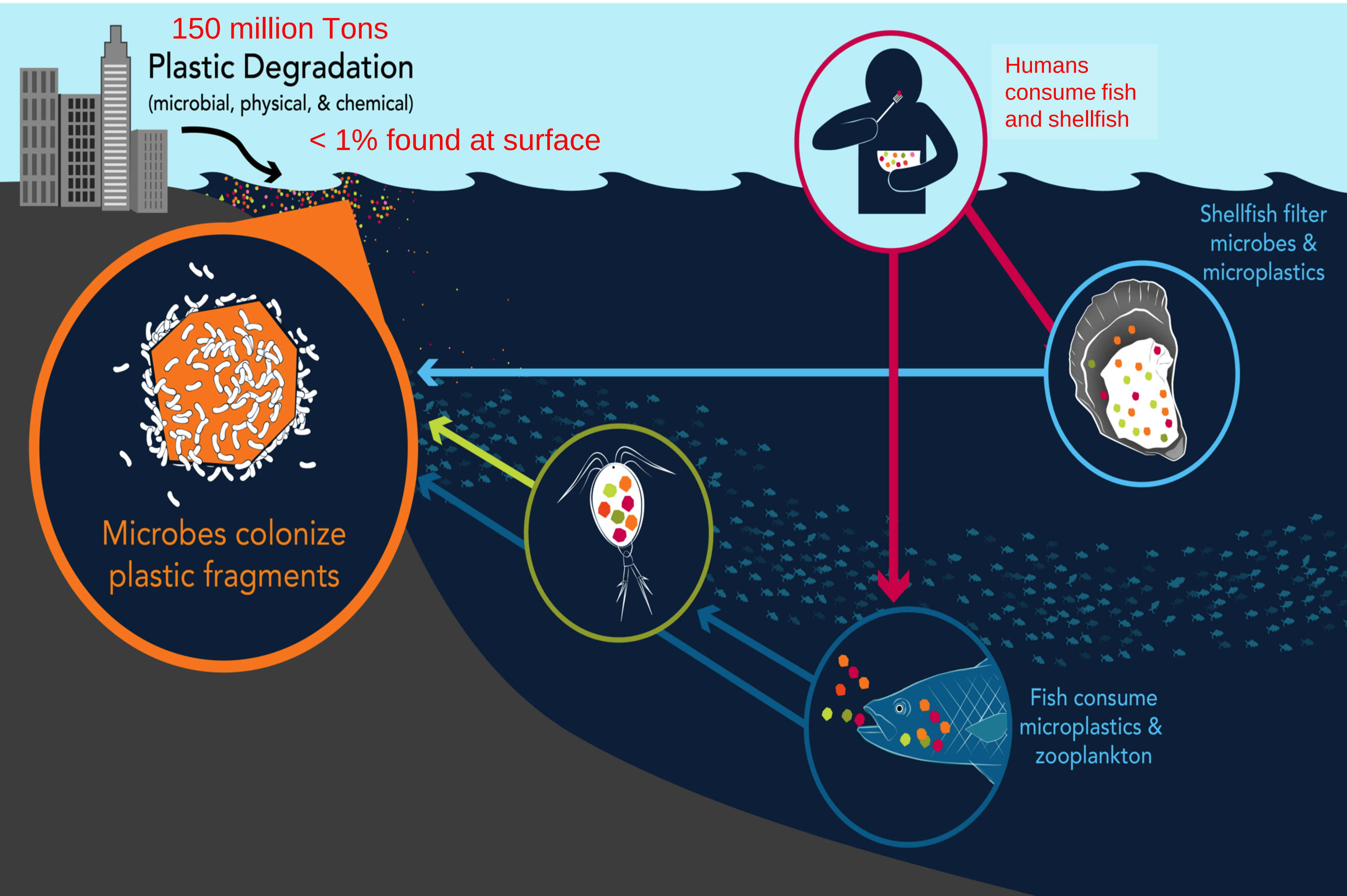
Open more surface area available for microbial attack

Microplastics: A 10,000,000-fold size range

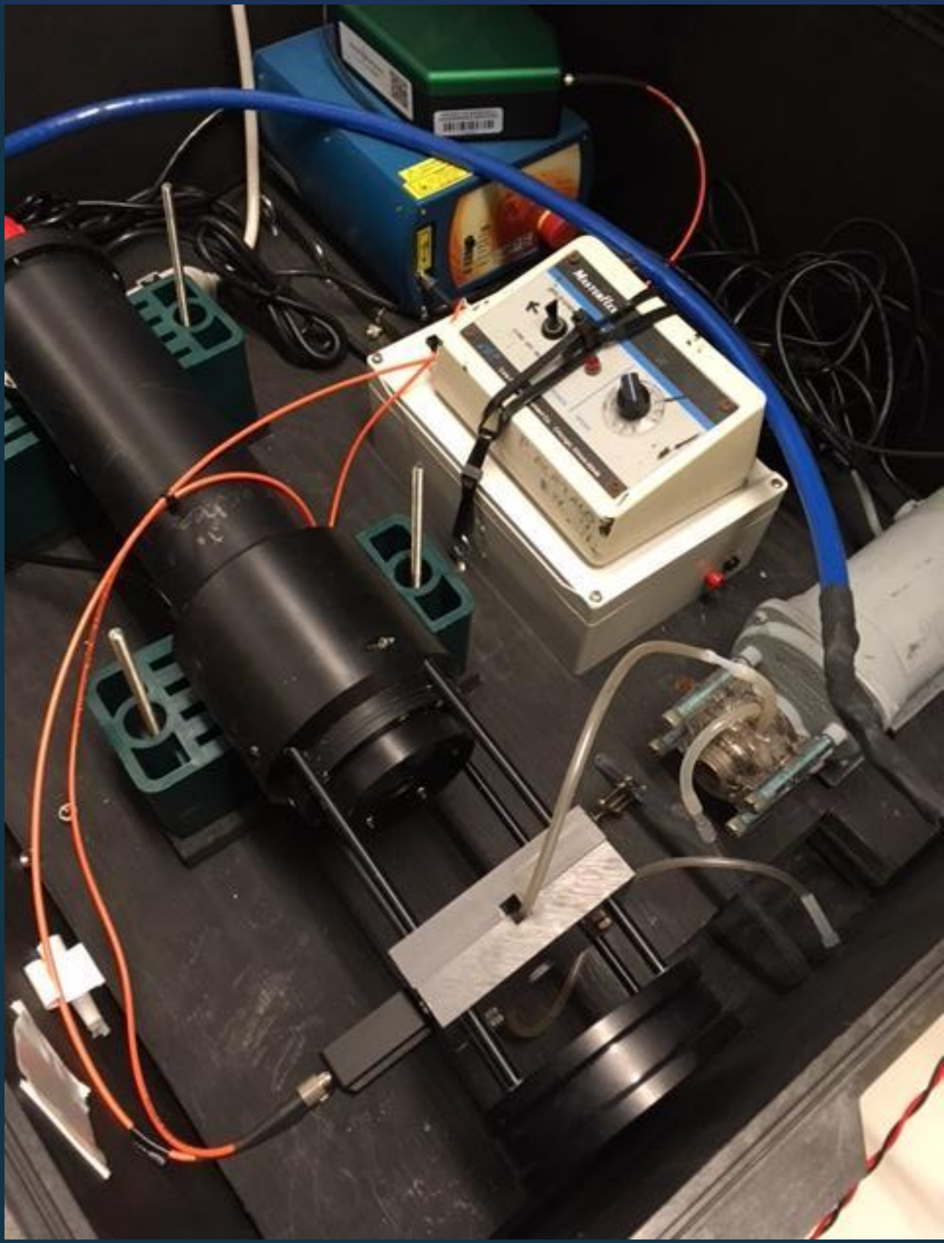
1 PET water bottle = 10^{27} 1 nm MP
But do they really form?



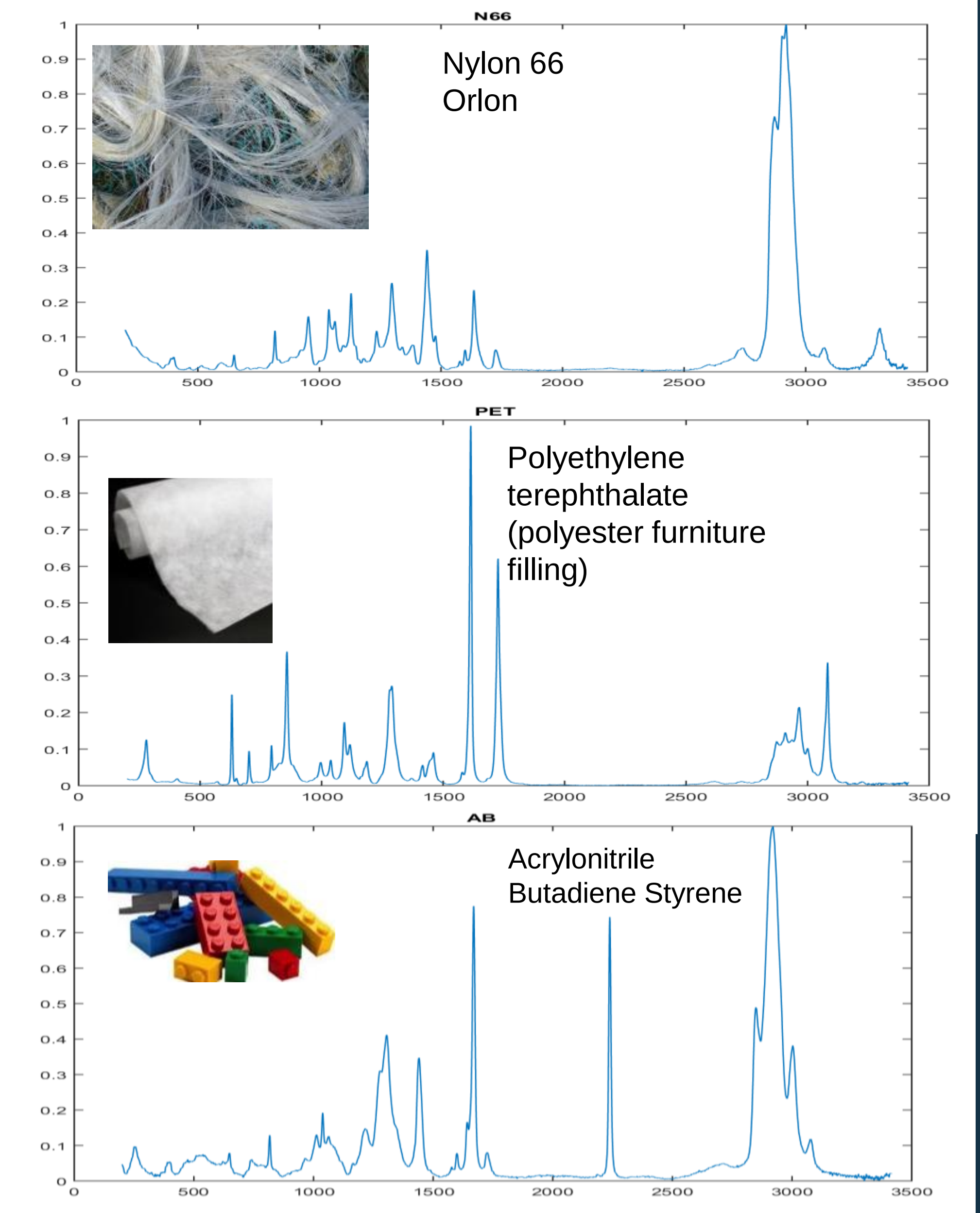
Microplastics in the food chain

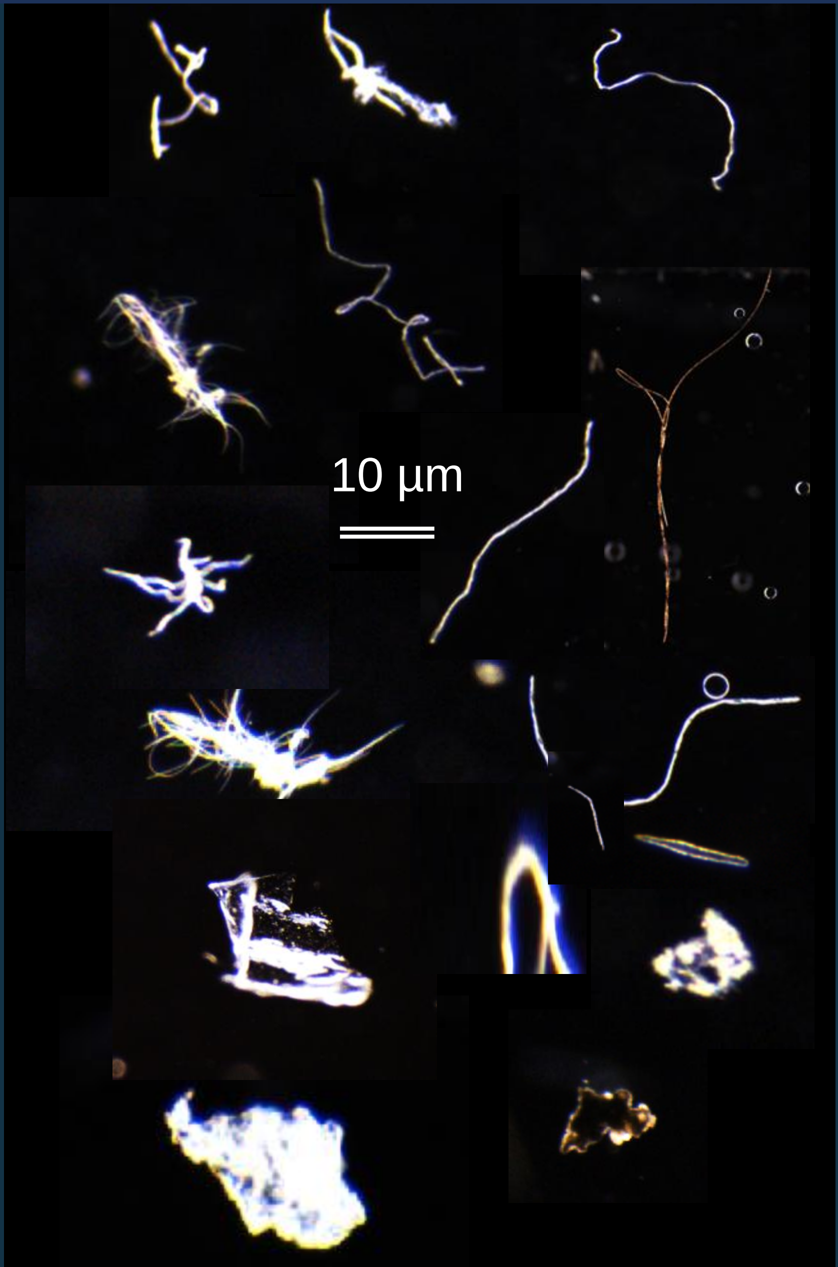


Raman Spectroscopy: Microplastics in the Hudson River



Microplastics in the Hudson River dominated by fibers





Concentration of Microplastics in the Hudson River

Abv.	Polymer	mean #/L	Total	den g/cc	Location
AB	Acrylonitrile Butadiene	872	1,577	1.080	L
ABS	Poly(Acrylonitrile Butadiene Styrene)	109	197	1.058	L
EVA	Ethylene Vinyl Acetate Copolymer	4	8	0.951	U
HDPE	High Density Polyethylene	Na	1	0.970	U
LDPE	Low Density Polyethylene	Na	2	0.940	U
NY	Nylon 66	2,753	4,977	1.150	L
PAN	Polyacrylonitrile fibers Creslan, Orlon	9,825	17,756	1.184	UL
PB	Polybutene-1	48	87	0.910	L
PBTE	Polybutylene Terephthalate	70	127	1.316	L
PC	Polycarbonate	149	271	1.223	L
PES	Polyethersulfone	42	76	1.376	L
PET	Polyethylene terephthalate	22	41	1.386	L
PEO	Polyethylene oxide			1.211	UL
PMMA	Polymethylmethacrylate (acrylic, plexiglass)	87	159	1.183	L
PP	Polypropylene	813	1,471	0.855	L
PS	Polystyrene	1	3	1.040	L
PTFE	Polytetrafluoroethylene (Teflon)	35	65	2.211	L
PVAL	Poly(Vinyl Alcohol)	4	9	1.192	L
PVC	Polyvinyl Chloride	1,121	2,027	1.452	L

Lower river: L
Upper river : U
Both: UL

Microplastics Risk Assessment

Hazard Assessment
- Effects
- Mechanisms
- Dose-response relationships

Exposure Assessment
- Sources & Routes
- Amounts
- Types & Sizes

Shellfish Risk Assessment
Ecological Risk Assessment
Human Health Risk Assessment

What is the impact of microplastics and nanoplastics on human health?

What is known about uptake by shellfish and fish?

Microplastics found common in shellfish

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Microplastics in bivalves cultured for human consumption

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Ingestion
Human food chain

ABSTRACT
Microplastics are present throughout the marine environment and ingestion of these plastic particles (<1 mm) has been demonstrated in a laboratory setting for a wide array of marine organisms. Here, we investigate the presence of microplastics in two species of commercially grown bivalves: *Mytilus edulis* and *Crassostrea gigas*. Microplastics were recovered from the soft tissues of both species. At time of human consumption, *M. edulis* contains on average 0.36 ± 0.07 particles g^{-1} (wet weight), while a plastic load of 0.47 ± 0.16 particles g^{-1} ww was detected in *C. gigas*. As a result, the annual dietary exposure for European shellfish consumers can amount to 11,000 microplastics per year. The presence of marine microplastics in seafood could pose a threat to food safety, however, due to the complexity of estimating microplastic toxicity, estimations of the potential risks for human health posed by microplastics in food stuffs is not (yet) possible.

Mytilus edulis, Crassostrea gigas
0.36 – 0.47 MP /g WW

PNAS
CrossMark

Oyster reproduction is affected by exposure to polystyrene microplastics

Rossana Sussarellu[a,1], Marc Suquet[a], Yoann Thomas[a], Christophe Lambert[a], Caroline Fabioux[a], Marie Eve Julie Pernet[a], Nelly Le Goïc[a], Virgile Quillien[a], Christian Mingant[a], Yanouk Epelboin[a], Charlotte Corporeau[a], Julien Guyomarch[b], Johan Robbens[c], Ika Paul-Pont[a], Philippe Soudant[a], and Arnaud Huvet[a,2]

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Edited by Marguerite A. Xenopoulos, Trent University, Durham, ON, Canada, and accepted by the Editorial Board December 22, 2015 (received for review September 25, 2015)

Plastics are persistent synthetic polymers that accumulate as waste in the marine environment. Microplastic (MP) particles are derived from the breakdown of larger debris or can enter the environment as microscopic fragments. Because filter-feeder organisms ingest MP while feeding, they are likely to be impacted by MP pollution. To assess the impact of polystyrene microspheres (micro-PS) on the physiology of the Pacific oyster, adult oysters were experimentally exposed to virgin micro-PS (2 and 6 μm in diameter; 0.023 mg·L^{-1}) for 2 mo during a reproductive cycle. Effects were investigated on ecophysiological parameters; cellular, transcriptomic, and proteomic responses; fecundity; and offspring development. Oysters preferentially ingested the 6-μm micro-PS over the 2-μm-diameter particles. Consumption of microalgae and absorption efficiency were significantly higher in exposed oysters, suggesting compensatory and physical effects on both digestive parameters. After 2 mo, exposed oysters had significant decreases in oocyte number (−38%), diameter (−5%), and sperm velocity (−23%). The D-larval yield and larval development of offspring derived from exposed parents decreased by 41% and 18%, respectively, compared with control offspring. Dynamic energy budget modeling, supported by transcriptomic profiles suggested a significant shift of energy allocation from repro-

and fecundity in copepods (20, 22) and reproductive disruption in *Daphnia* (21). At cellular and molecular levels, alterations of immunological responses, neurotoxic effects, and the onset of genotoxicity have been observed in mussels exposed to polycyclic aromatic hydrocarbon-contaminated polystyrene particles (17). Additional impacts may arise from harmful plastic additives and persistent organic pollutants adsorbed on MP, which are known to be taken up and accumulated by living organisms (23).

In this study, the effects of MP exposure were assessed on reproductively active *Crassostrea gigas* adults and their offspring. The Pacific oyster was chosen because of its world-wide production, economic importance as seafood, and important role in estuarine and coastal habitats (24). A 2-mo exposure of adult oysters to microsized polystyrene spheres (micro-PS, 2 and 6 μm, 0.023 mg·L^{-1}) was performed under controlled conditions suitable for germ-cell maturation. Polystyrene is one of the most commonly used plastic polymers worldwide, often found in microplastics sampled at sea (25, 26). In our study, toxic endpoints were investigated through an integrative approach, covering data from molecular and cellular parameters to ecophysiological behavior and energy budget modeling. Our results show that experimental

MPs reduced energy uptake and allocation, reproduction, and offspring performance.

Environmental Science & Technology
Article
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Ingestion of Nanoplastics and Microplastics by Pacific Oyster Larvae

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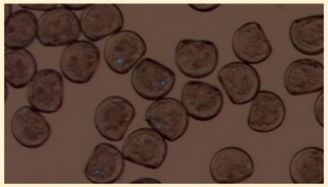
Supporting Information



ABSTRACT: Plastic debris is a prolific contaminant effecting freshwater and marine ecosystems across the globe. Of growing environmental concern are "microplastics" and "nanoplastics" encompassing tiny particles of plastic derived from manufacturing and macroplastic fragmentation. Pelagic zooplankton are susceptible to consuming microplastics, however the threat posed to larvae of commercially important bivalves is currently unknown. We exposed Pacific oyster (*Crassostrea gigas*) larvae (3−24 d.p.f.) to polystyrene particles spanning 70 nm-20 μm in size, including plastics with differing surface properties, and tested the impact of microplastics on larval feeding and growth. The frequency and magnitude of plastic ingestion over 24 h varied by larval age and size of polystyrene particle (ANOVA, $P < 0.01$), and surface properties of the plastic, with aminated particles ingested and retained more frequently (ANOVA, $P < 0.01$). A strong, significant correlation between propensity for plastic consumption and plastic load per organism was identified (Spearmans, $r = 0.95$, $P < 0.01$). Exposure to 1 and 10 μm PS for up to 8 days had no significant effect on *C. gigas* feeding or growth at <100 microplastics mL^{-1}. In conclusion, whil micro- and nanoplastics were readily ingested by oyster larvae, exposure to plastic concentrations exceeding those observed in the marine environment resulted in no measurable effects on the development or feeding capacity of the larvae over the duration of the study.

Larvae of *C gigas* ingest large numbers of MPs
No impact on growth up to 100 MP/mL
160 nm MPs readily ingested

MP concentrations used in experimental exposures

PNAS

Oyster reproduction is affected by exposure to polystyrene microplastics

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de Recherche
and [c]Instituu

Edited by Ma
September 2

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PNAS

LETTER

Microplastic exposure studies should be environmentally realistic

Robin Lenz[a,1], Kristina Enders[a], and Torkel Gissel Nielsen[a]

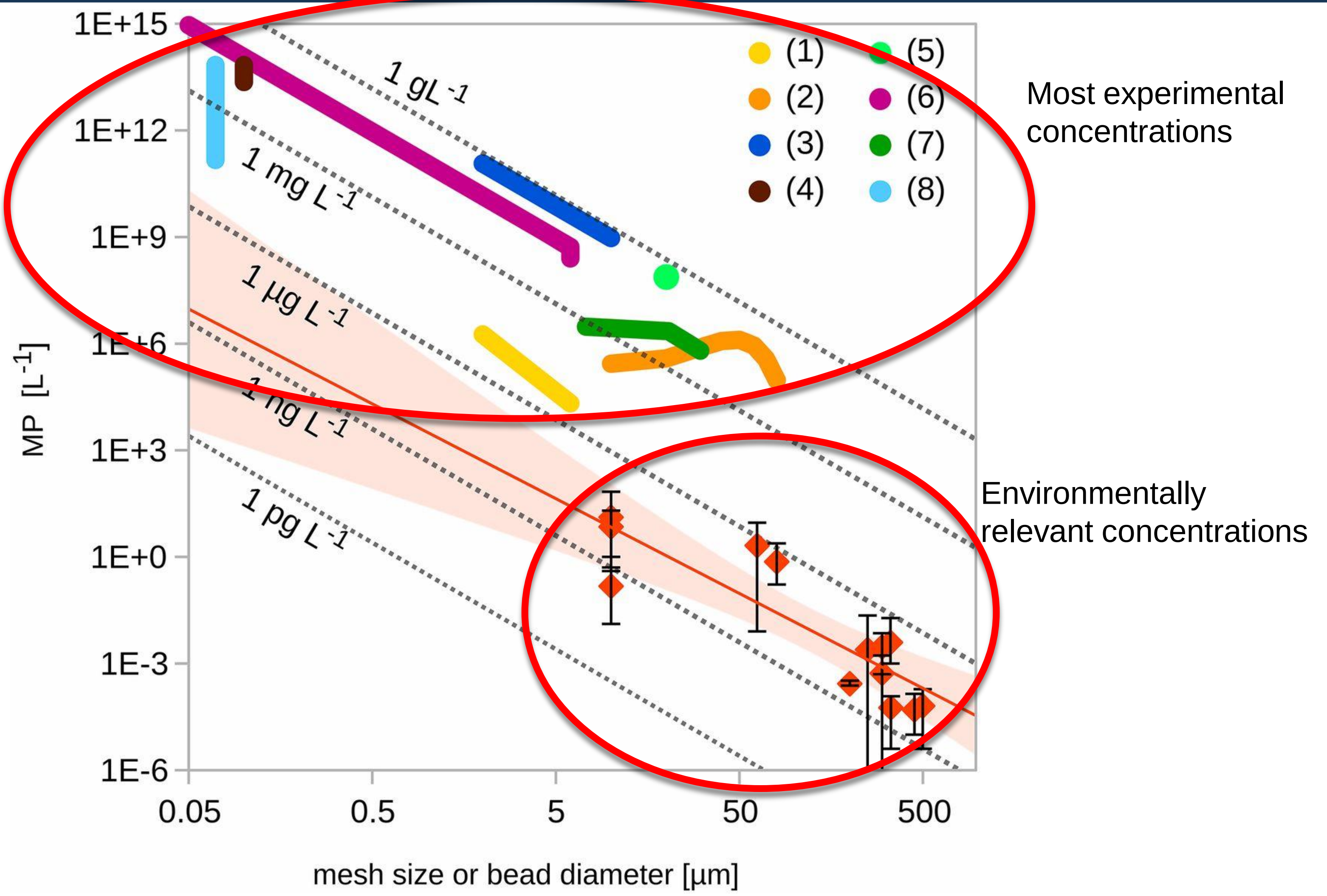
To understand the impact of microplastic (MP) pollution to aquatic ecosystems, it is important to identify the mechanisms of interaction with organisms. Exposure experiments, like the study of Sussarellu et al. (1) recently published in PNAS, may provide such insights. However, the results of dose–response experiments must always be interpreted in light of environmental concentrations, and the experimental concentrations examined by Sussarellu et al. (1) and several others (2–8) are orders-of-magnitude higher than those reported from field studies (Fig. 1).

Experimental studies on effects of MP on mussels (2, 3), lugworms (4), copepods (5–7), and oysters (1)

tation process, where numbers of particles will scale inversely with the particle radius to the power of 3. In contrast, the environmental concentrations documented in studies appear to follow a slightly lower exponent (2.67) (Fig. 1), possibly caused by size-dependent removal processes, lower dimensional breakdown (i.e., of flakes, sheets, and fibers), or considerable influence of new MP input of larger sizes. Additionally, decreased detection accuracy of applied sampling methods in their respective lower size ranges might play a role.

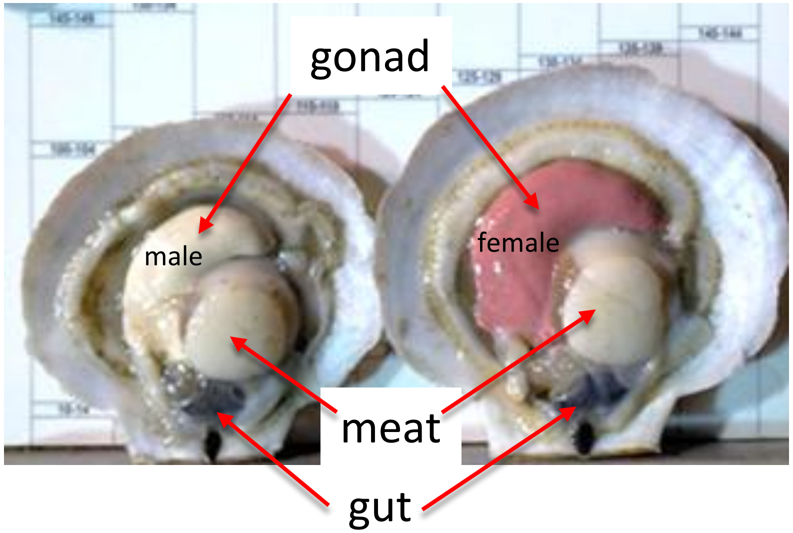
Experimental exposure concentrations tend to be between two to seven orders-of-magnitude higher than environmental levels. The most recent study (1)

Mismatch between MP concentrations used in exposure studies and observed environmental levels

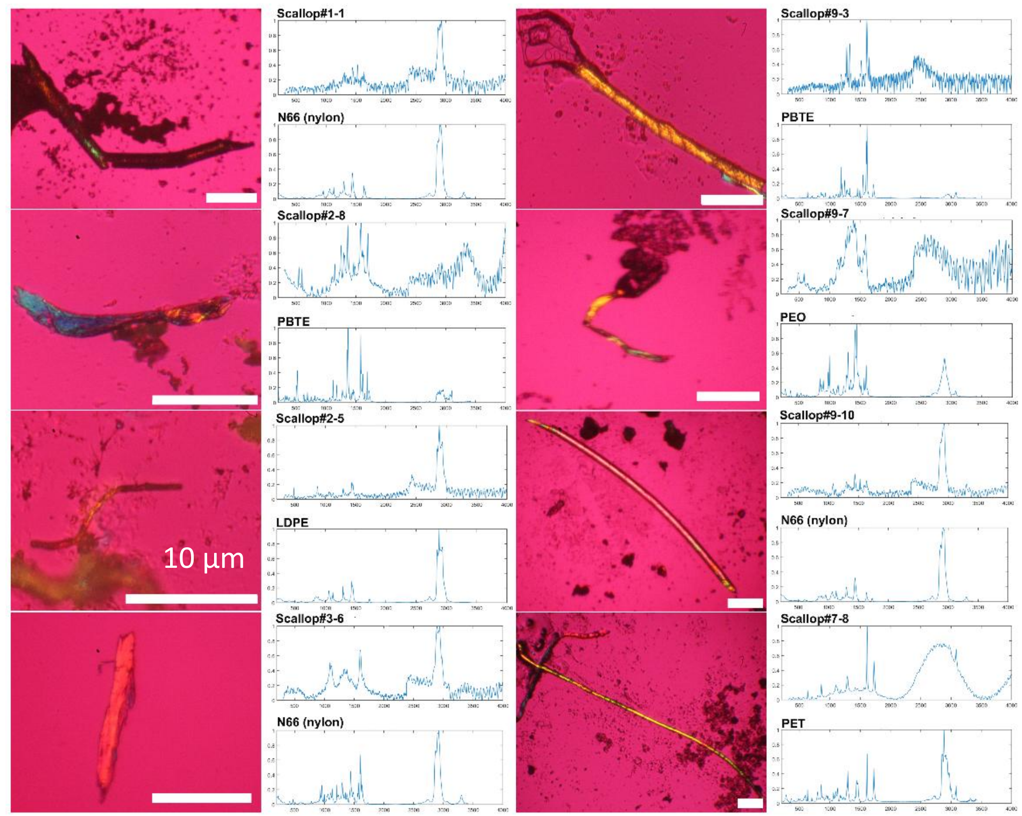


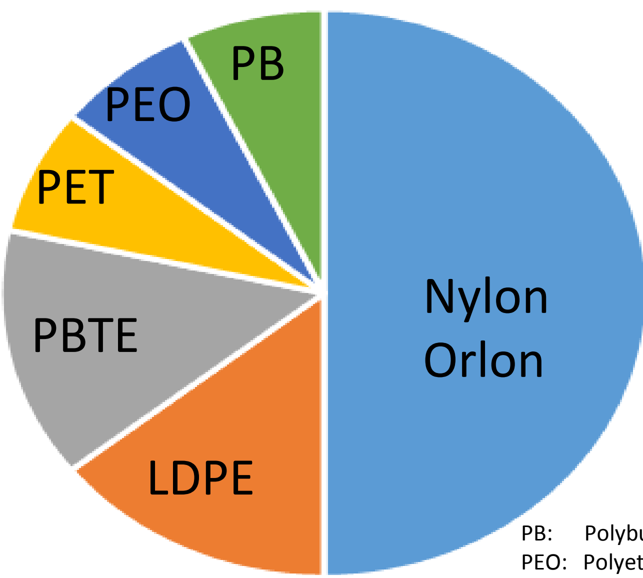
Lenz (2016) “Microplastic exposure studies should be environmentally realistic” PNAS

Microplastics in Sea Scallops from Georges Bank



Microplastics under polarized light microscopy and their Raman spectra from scallop gut





PB: Polybutene-1
PEO: Polyethylene oxide
PBTE: Polybutylene terephthalate
LDPE: Low Density Polyethylene
Nylon: Nylon 66, Orlon

- 455 scallops collected on Northeast Continental Shelf.
- 443 had MPs in their gut (97%)
- > 40% had more than 20 MPs
- 22% had more than 100 MPs
- Abundance: Nylon > LDPE > PBTE > PET > PEO > PB
- No other tissues had MPs

Gallager (unpublished)

Exposure in context: Seafood vs. other MP sources

Environmental Pollution 237 (2018) 675–684

Contents lists available at ScienceDirect

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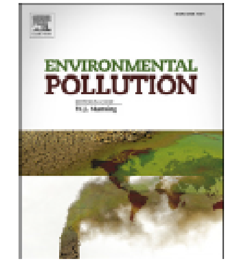

Low levels of microplastics (MP) in wild mussels indicate that MP ingestion by humans is minimal compared to exposure via household fibres fallout during a meal☆

Ana I. Catarino [a,*], Valeria Macchia [b], William G. Sanderson [a,c], Richard C. Thompson [d], Theodore B. Henry [a,e]

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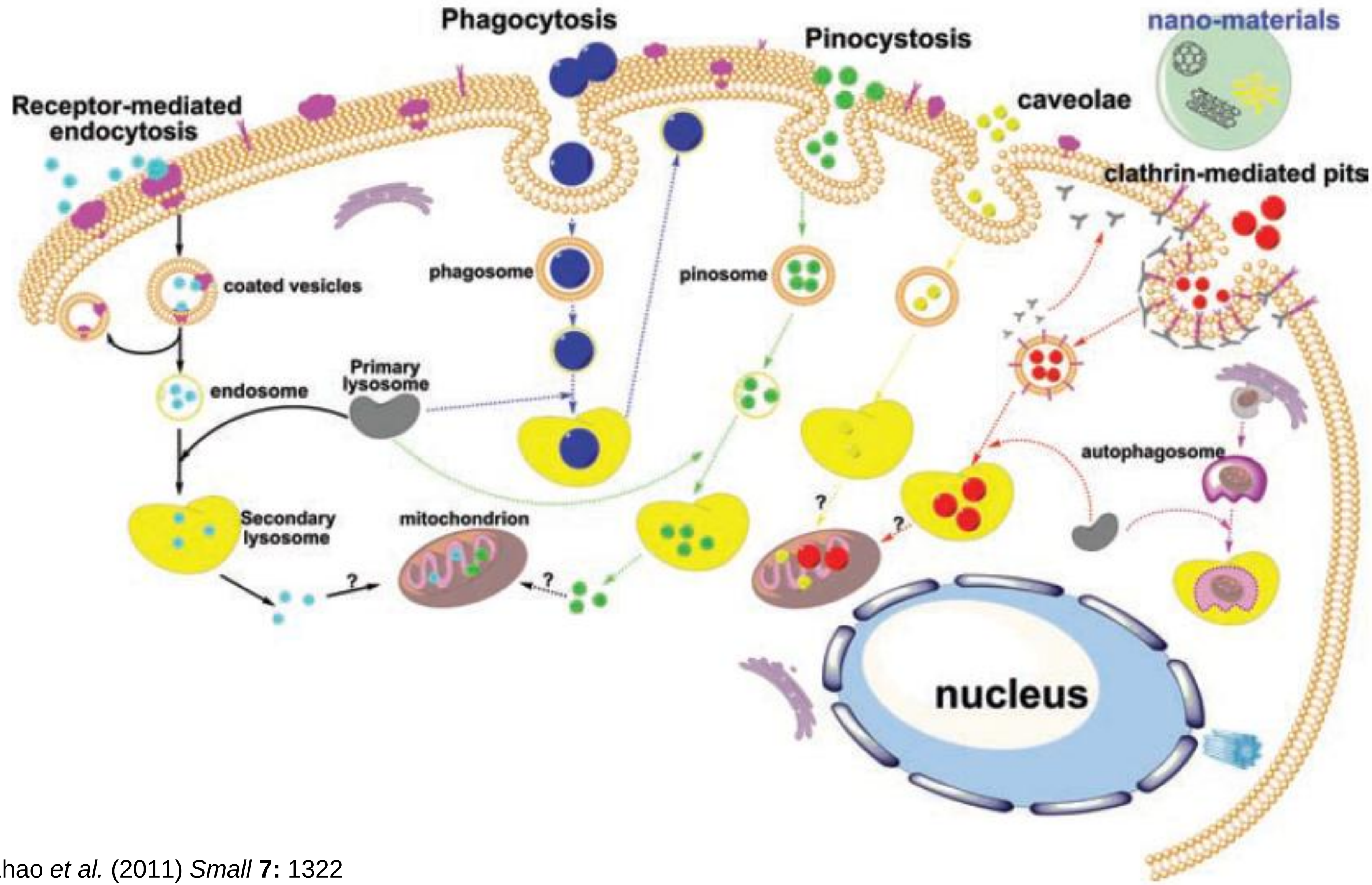
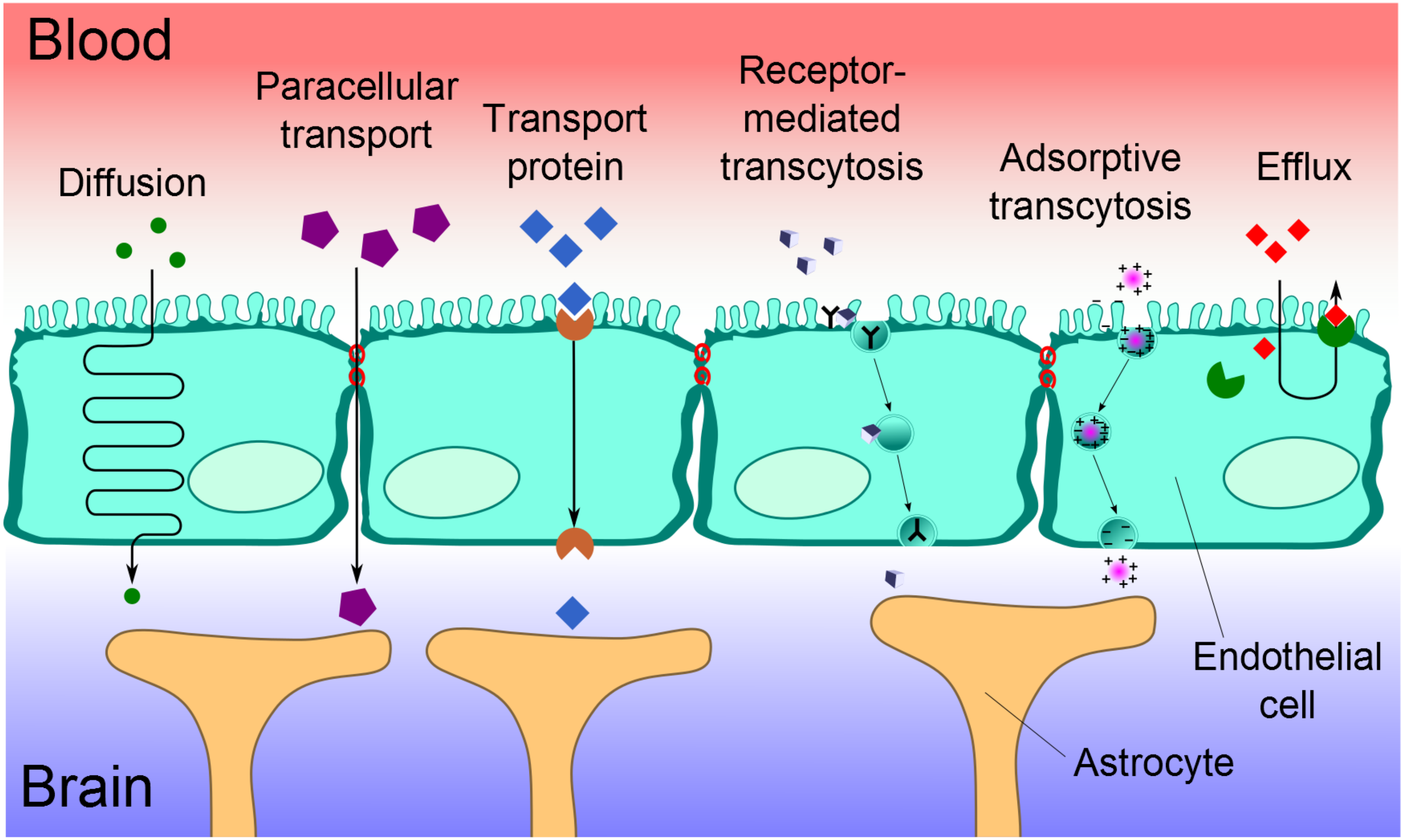
mussels:	123 MP / year
plastic dust:	>13,731 MP / year

Routes of intracellular uptake of nanoparticles



Zhao *et al.* (2011) *Small* **7:** 1322

MPs < 100nm cross the blood-brain barrier



Armin Kübelbeck, https://commons.wikimedia.org/w/index.php?curid=17334124

What is the impact on human health?

What we know:

- Microplastics occur in seafood (fish, shellfish)
- Microplastics can carry toxic chemicals (contaminants, additives)
- Microplastic-adsorbed chemicals can be transferred to animals- biomagnification

What we **DON'T** know:

- How much microplastics are humans exposed to?
- Relative contribution of seafood vs other MP exposures?
- Are consumed microplastics transported in humans?
- Fate of absorbed MPs in humans?
- Are MPs a significant source of toxic chemicals?
- Adverse effects in humans from consuming microplastics?

WHOI Marine Microplastics Initiative

How much microplastic is in the ocean?

- New sensors on autonomous vehicles, ships, & buoys
- Make measurements from surface to sediment

What is the fate of plastics in the ocean?

- Models of transport
- Impacts of weathering
- Marine microbes

What are the impacts of microplastics on human health and ecosystems?

- Identify what organisms take up plastics- use shellfish as model systems
- How do microplastics pass through the food chain
- What microplastics and additives are most toxic?

Conclusions

Microplastics are:

- Everywhere
- Consumed by shellfish
- Transferred to humans

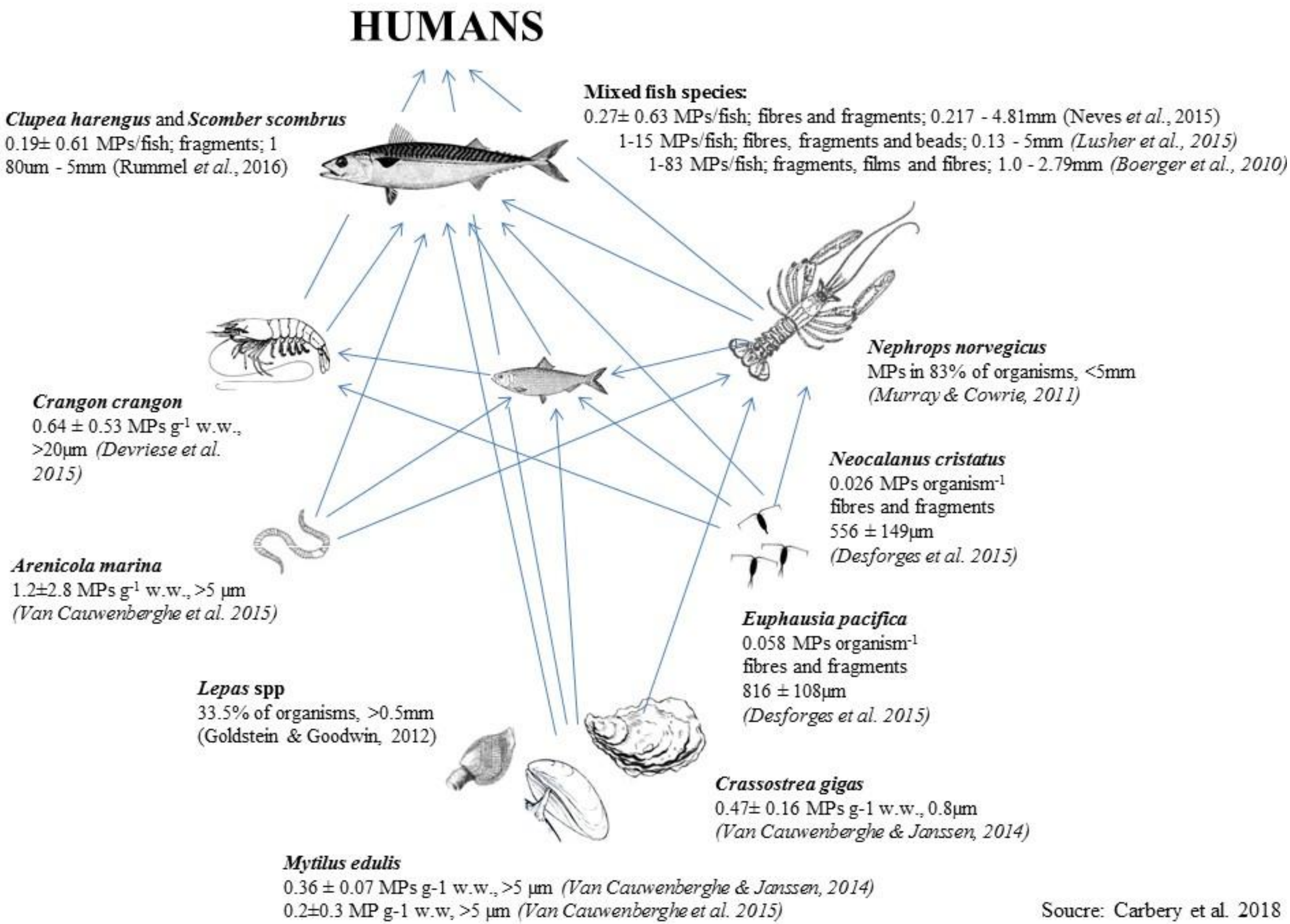
What are the impacts?

- Unknown

Is it an emergency?

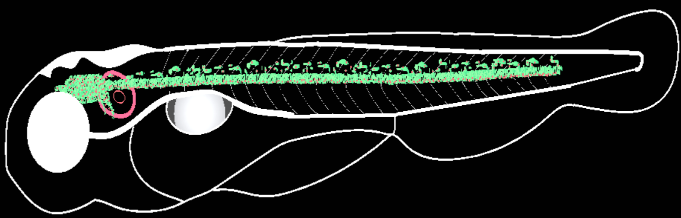
- Jury will be out until much more research is done

Human Exposure through Marine Food Webs



Soucre: Carbery et al. 2018

Time lapse image of myelination after exposure of 2 dpf zebrafish embryos to domoic acid



Tg(nkx2.2a:mEGFP) x Tg(sox10:RFP)

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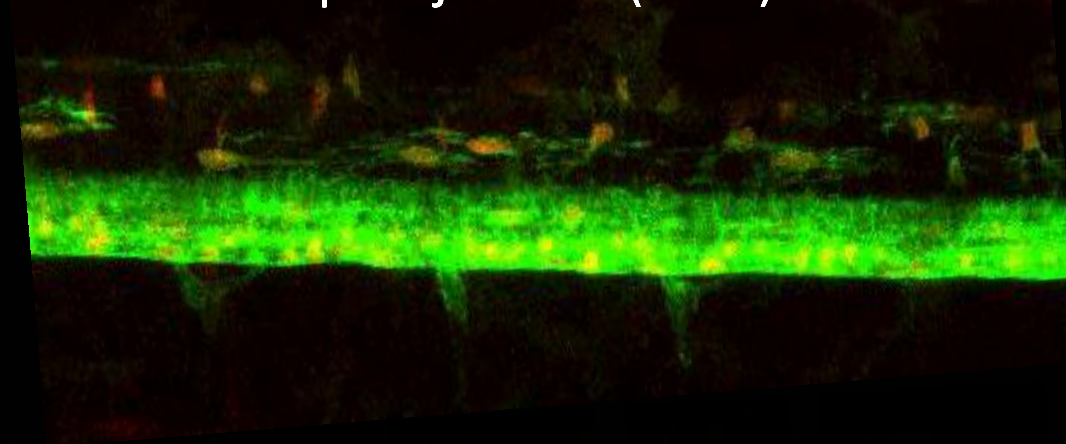
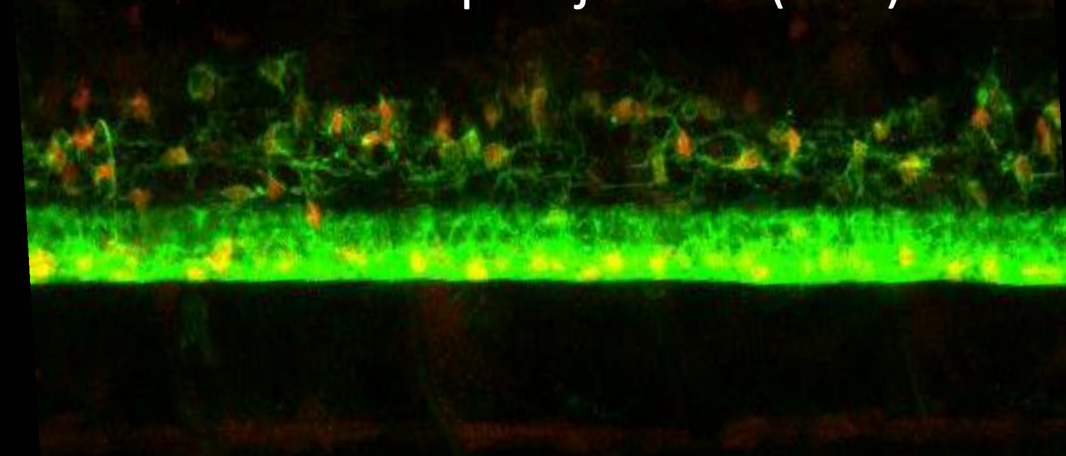
Water 2 dpf injection (n= 5)



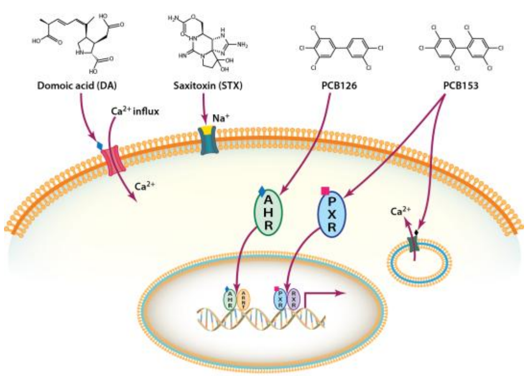
Domoic acid 2 dpf injection (n=6)

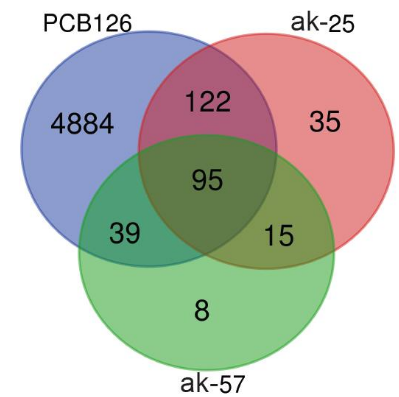


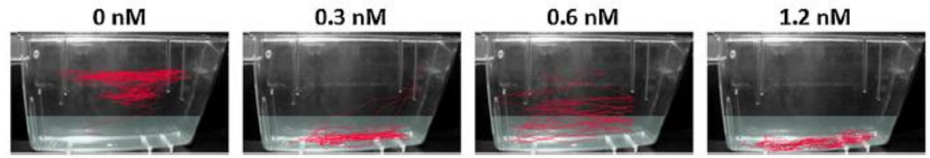
Jenny Panlilio
MIT-WHOI Joint Program

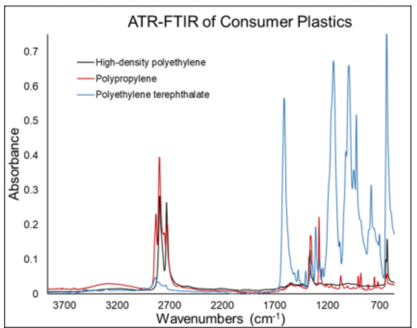
WHOI Toxicology

- **Shellfish as models**
  - Marine and freshwater
  - Developmental toxicology
  - Transgenic and CRISPR-Cas9
- **Molecular mechanisms**
  - Transcription factors
  - Gene expression
  - Epigenetics and genomics
- **Microscopy**
  - Epifluorescence, confocal
- **Behavioral assays**
- **Access to analytical capabilities**
  - Raman (Gallager)
  - ATR-FTIR (Michel)
  - MS (Ward, Reddy)



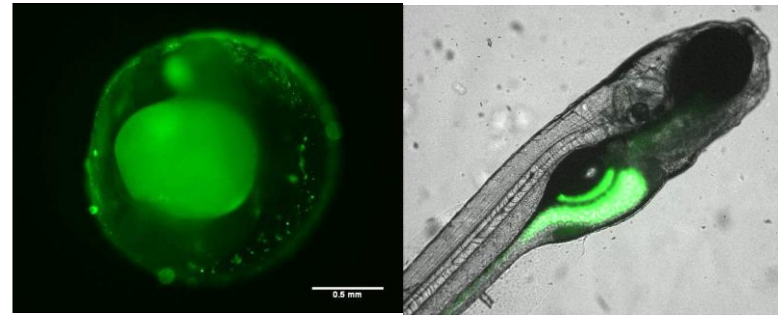




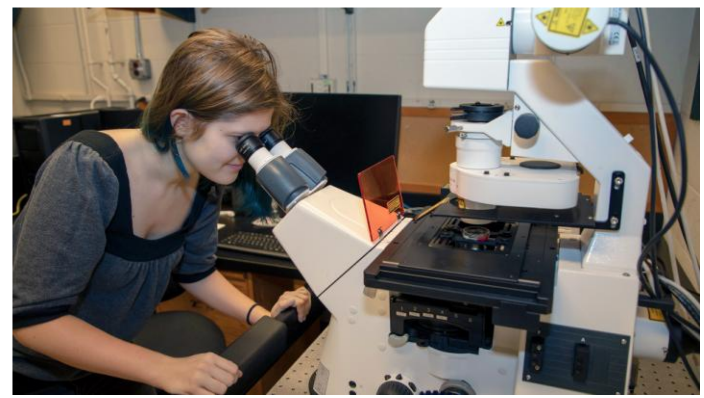


Research Directions

- **MP & NP in Seafood**
  - analytical advances (Gallager, Michel)
- **Uptake from intestine**
  - size-dependence (systematic)
- **Biological effects**
  - Early life susceptibility?
  - RNA-sequencing
  - Epigenetics
- **Effects of transformation products**
  - collaboration with Ward
- **Multiple stressor effects**
  - temperature, pH



Pitt et al. (2018) *Aquatic Toxicology*



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