Microplastics—An Emerging Global Issue

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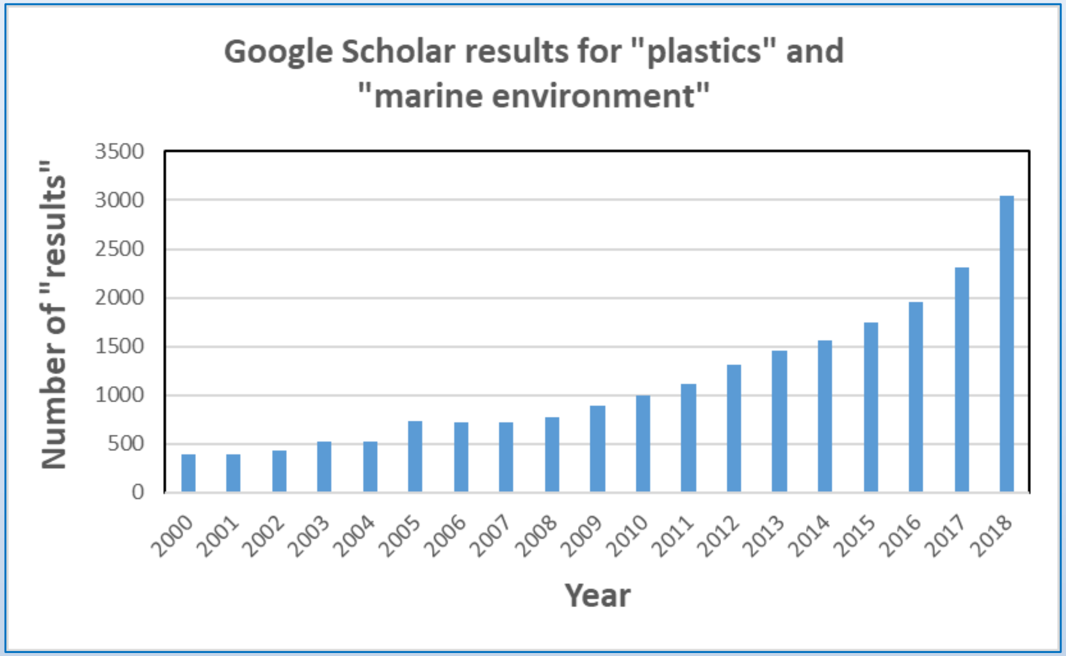
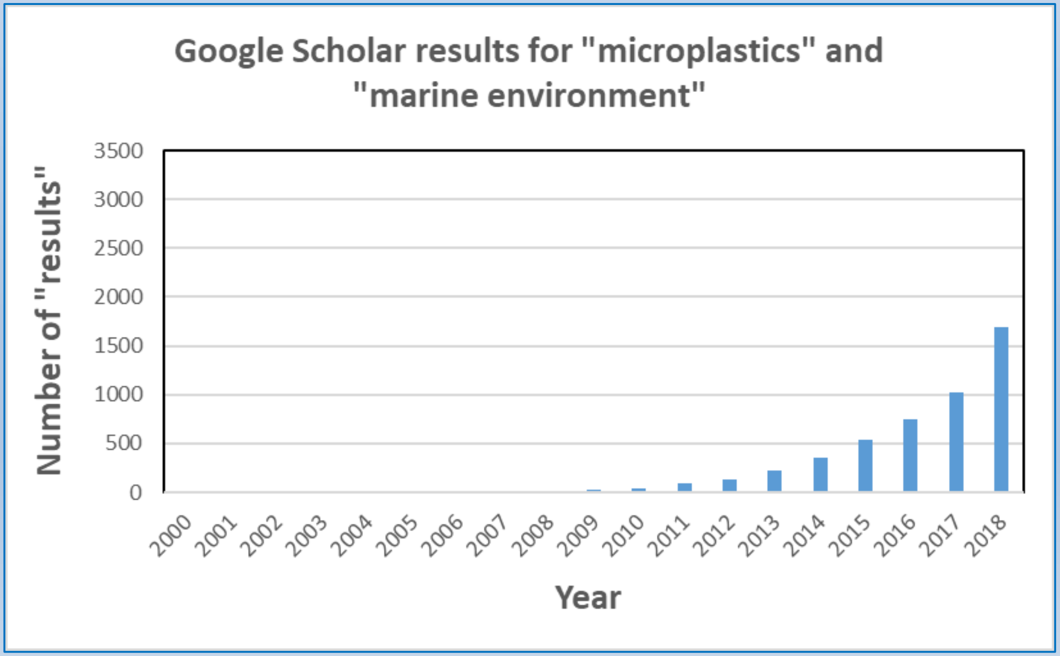
CBP STAC Workshop
Microplastics in the Chesapeake Bay and its Watershed
24-25 April 2019

Plastics in the Scholarly Literature

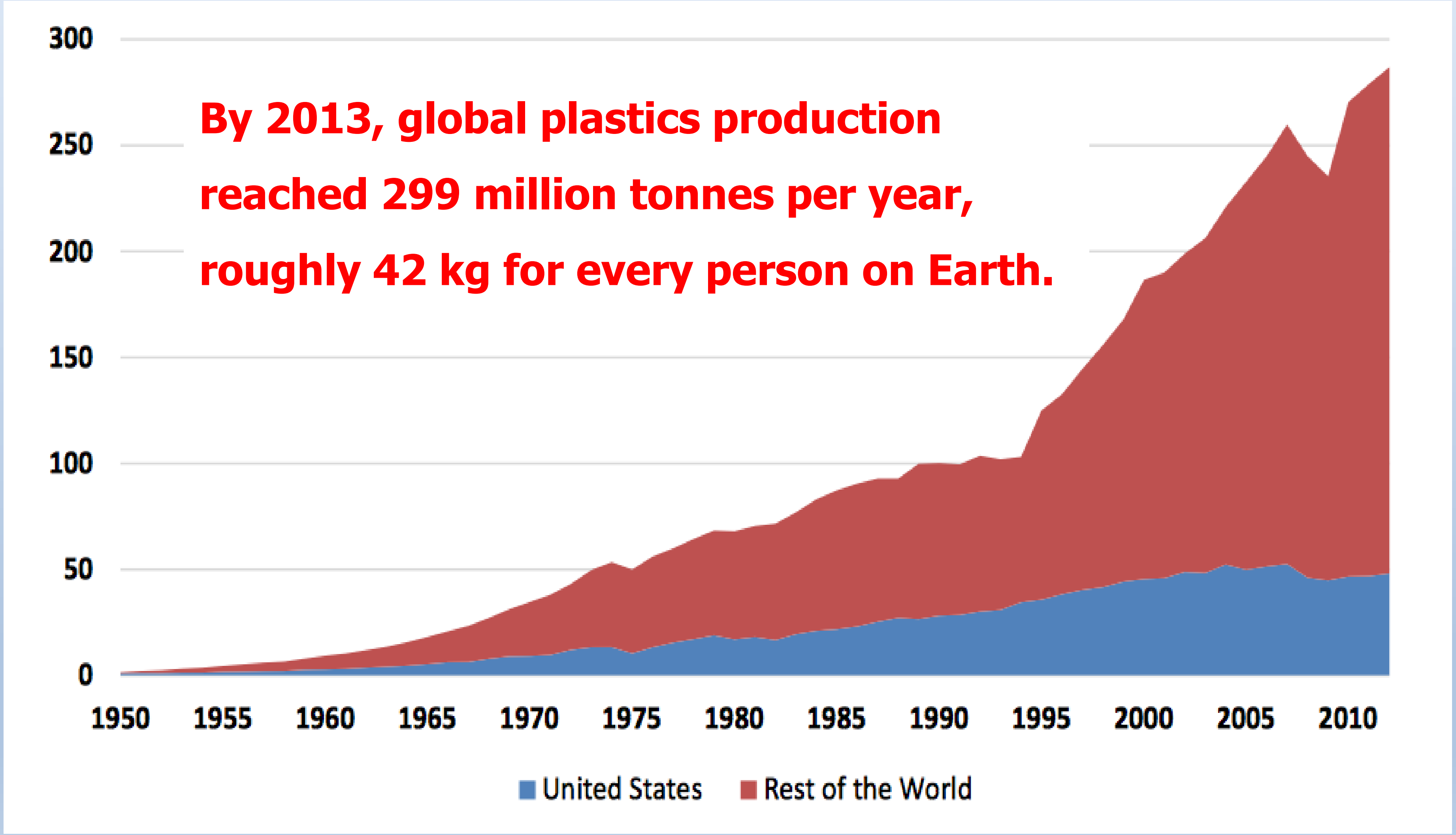




The Nature of the Problem

- In less than a century, plastic has gone from invention to ubiquity
- Significant growth as an industry began during WWII
- This rapid expansion of the plastics industry has continued more-or-less unabated to the present time

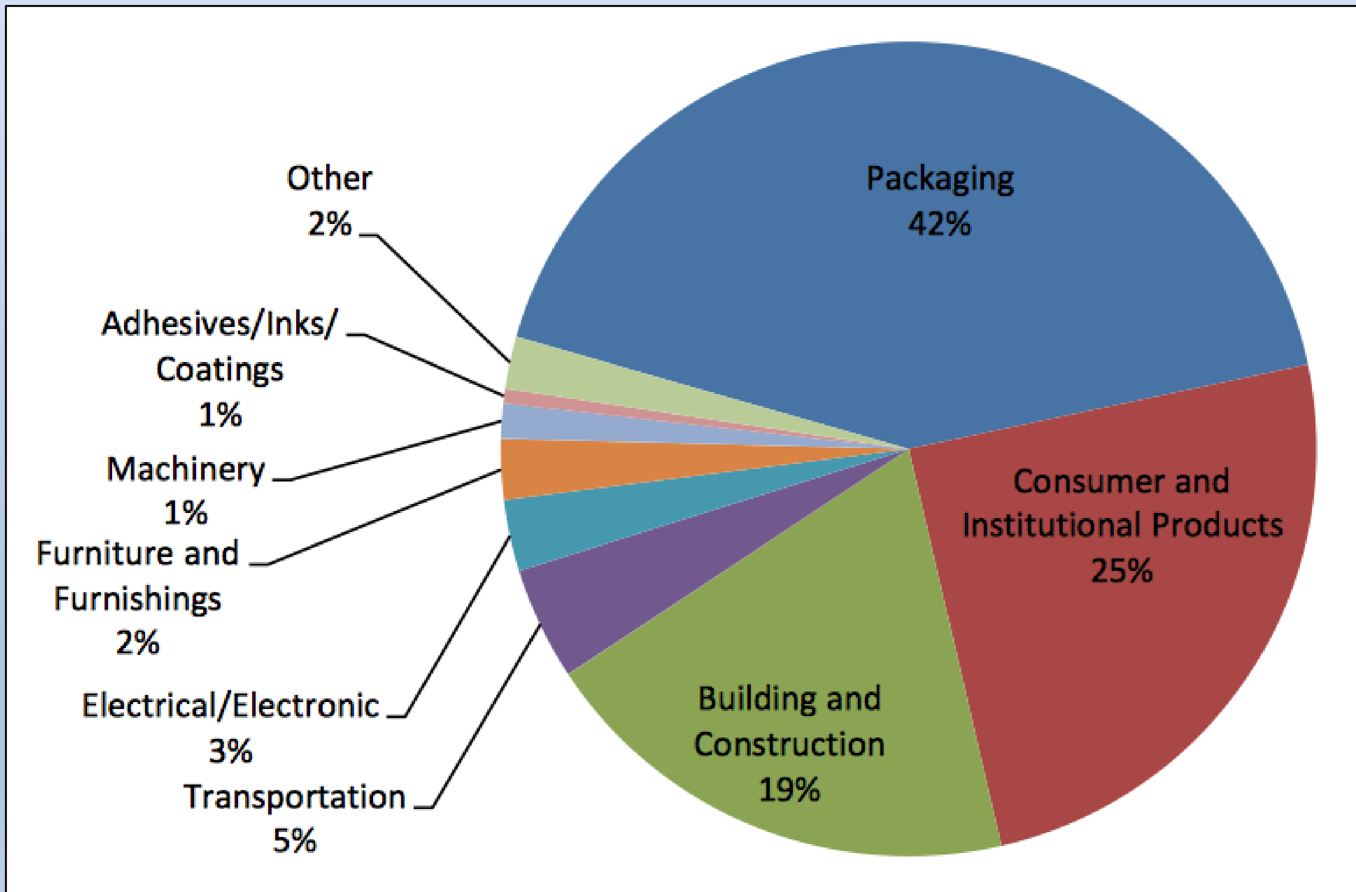
The Nature of the Problem



[American Chemistry Council - Plastic Resins in the US.pdf]

Key End Use Markets for US Thermoplastic Resins (2012)

Plastic product manufacturers take plastic resins (raw materials) and transform them into a wide variety of shapes and sizes for use by other industries and ultimately, final consumers.



Note: Excludes exports

[American Chemistry Council - Plastic Resins in the US.pdf]

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Every day in the US, we use 500 million straws.

What is the volume occupied by that many straws?

1 box of 40 straws from Harris Teeter: 3.6 cm X 8.0 cm X 20 cm = 576 cm^3

$$\frac{40 \text{ straws}}{576 \text{ cm}^3} = \frac{500 \times 10^6 \text{ straws/day}}{\text{volume } x}$$

Cross-multiply, solve for *x*, and convert cm^3 to m^3

$x = 7.2 \times 10^9 \text{ cm}^3$

$(1 \text{ m}^3/10^6 \text{ cm}^3) = 7.2 \times 10^3 \text{ m}^3$

A bit more than 7,000 m^3 per day!

Compare that volume with the volume of this room.

Production, use, and fate of all plastics ever made

Roland Geyer,[1]* Jenna R. Jambeck,[2] Kara Lavender Law[3]

Plastics have outgrown most man-made materials and have long been under environmental scrutiny. However, robust global information, particularly about their end-of-life fate, is lacking. By identifying and synthesizing dispersed data on production, use, and end-of-life management of polymer resins, synthetic fibers, and additives, we present the first global analysis of all mass-produced plastics ever manufactured. We estimate that 8300 million metric tons (Mt) as of virgin plastics have been produced to date. As of 2015, approximately 6300 Mt of plastic waste had been generated, around 9% of which had been recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment. If current production and waste management trends continue, roughly 12,000 Mt of plastic waste will be in landfills or in the natural environment by 2050.

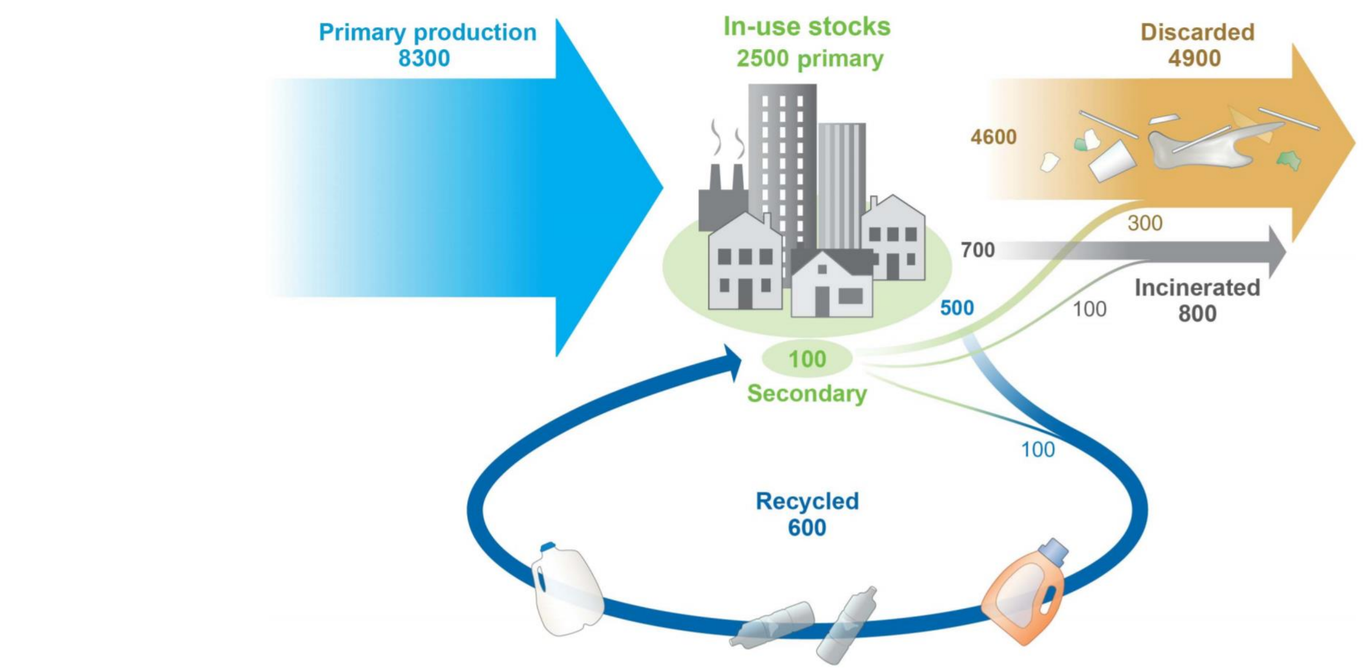


Fig. 2. Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons).

Geyer et al. (2017) Science Advances

Mismanaged Plastic Waste (estimated 8 M mt/yr enters the ocean)

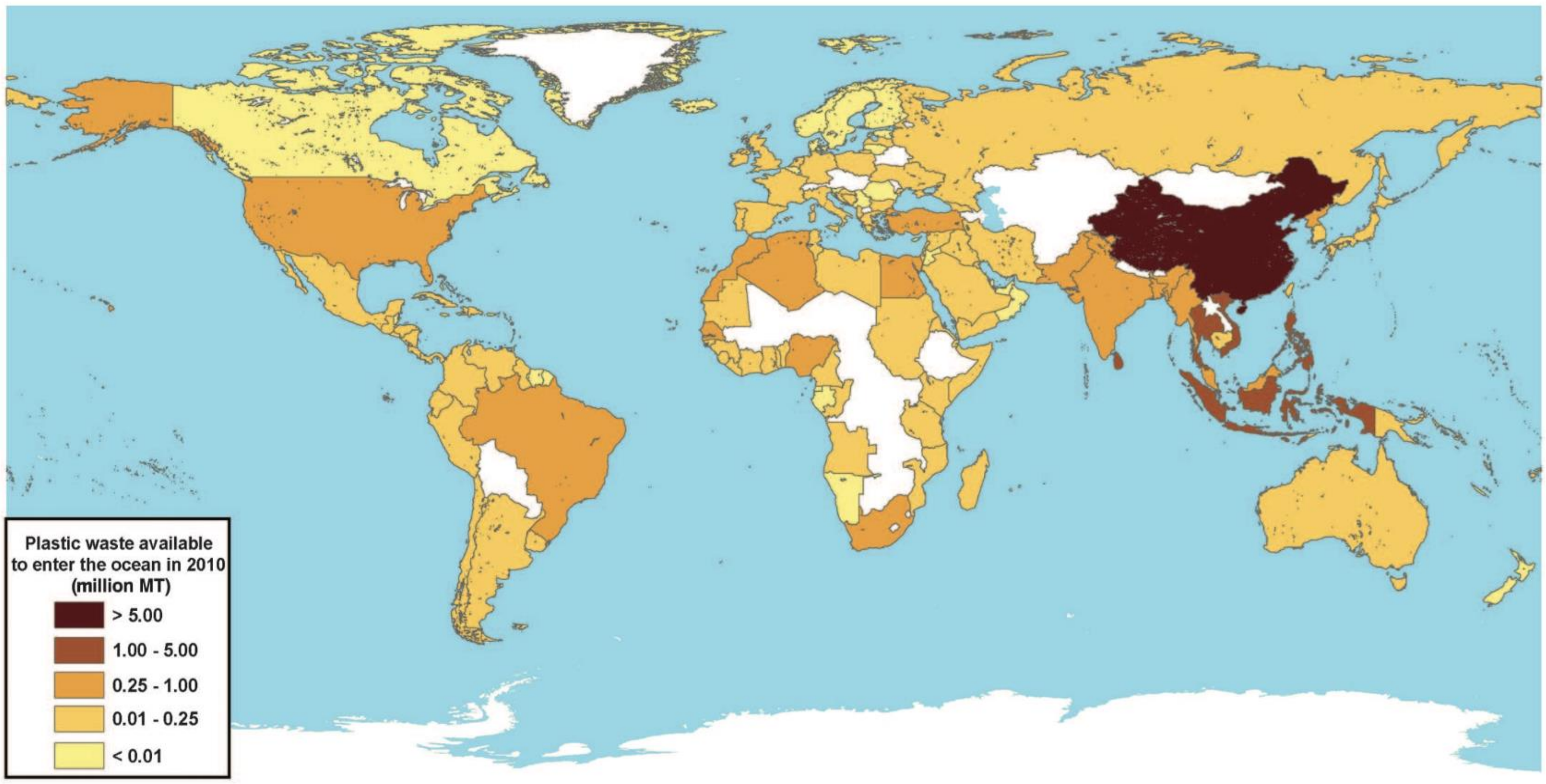


Fig. 1. Global map with each country shaded according to the estimated mass of mismanaged plastic waste [millions of metric tons (MT)] generated in 2010 by populations living within 50 km of the coast. We considered 192 countries. Countries not included in the study are shaded white.

Jambeck et al. 2015

Waste Problem

- The magnitude of plastics production and their use has created a significant solid waste disposal problem.

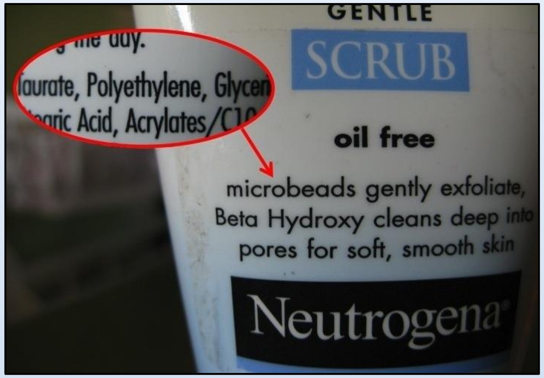
- Until recently virtually all plastic products were nonbiodegradable; nearly all products continue to be so.

- They persist; plastics discarded in the aquatic environment may remain in largely unaltered form for years if not decades (centuries?).

- (Especially for microplastics) They can serve as adsorptive surfaces for persistent organic pollutants and as settlement sites for macro- and microorganisms.

http://www.huffingtonpost.com/2011/10/26/plastic-ocean-pacific-conservation_n_1032897.html

Microplastics



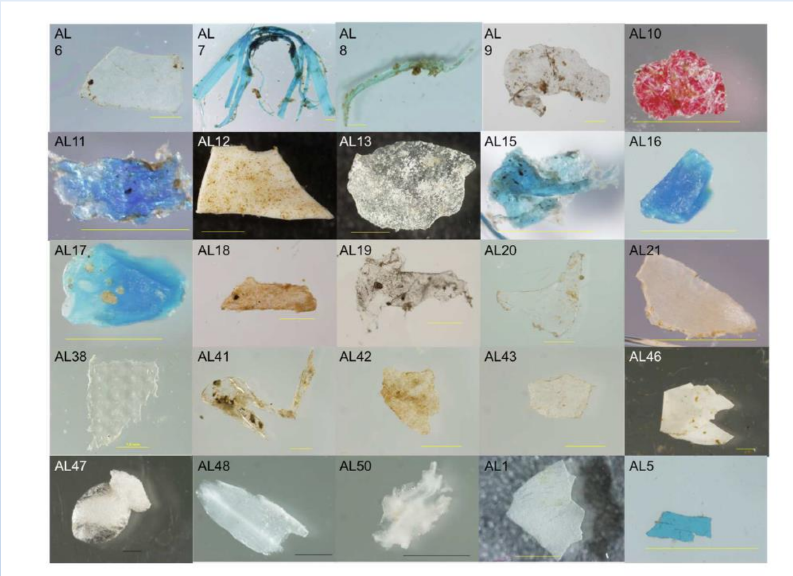
http://theboatgalley.com/instead-of-microbeads/

Small plastic fragments, fibers, and granules

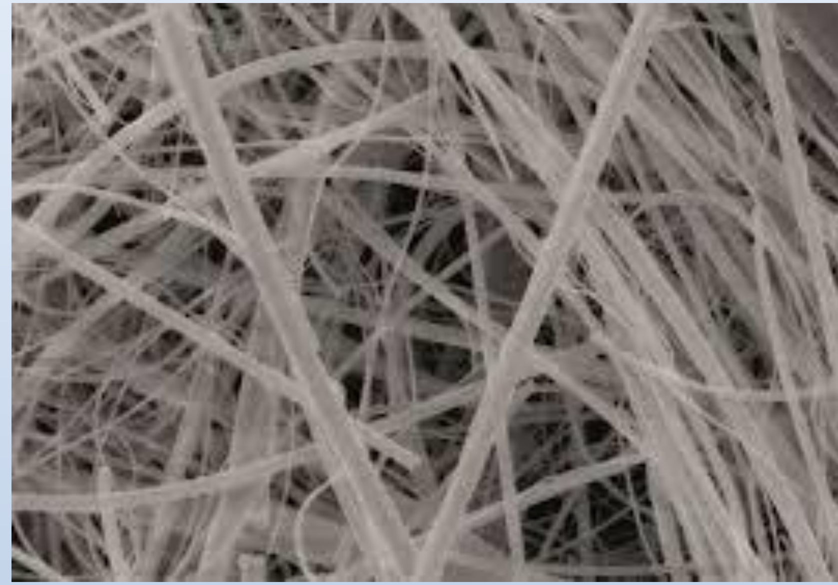
How small? Usage of the term in the literature varies from 0.1 µm to 10 mm--a size range of 5 orders of magnitude!

- **Primary Microplastics--**manufactured products used in:
  - Facial cleansers and cosmetics - microbeads
  - As vectors for drugs
  - As air-blasting media for removing rust – often contaminated with heavy metals (e.g., cadmium, chromium, lead)
  - Virgin plastic production **pellets** - Pellets are convenient to ship and are eventually melted down and molded into manufactured products
- **Secondary Microplastics--**pieces that have broken off larger plastic objects, through physical, biological, or chemical processes

Laverty (2018) MS Thesis, OEAS, ODU



http://www.purewatergazette.net/synthetic-fibers-from-clothing-are-becoming-serious-pollutants-january-11-2014/



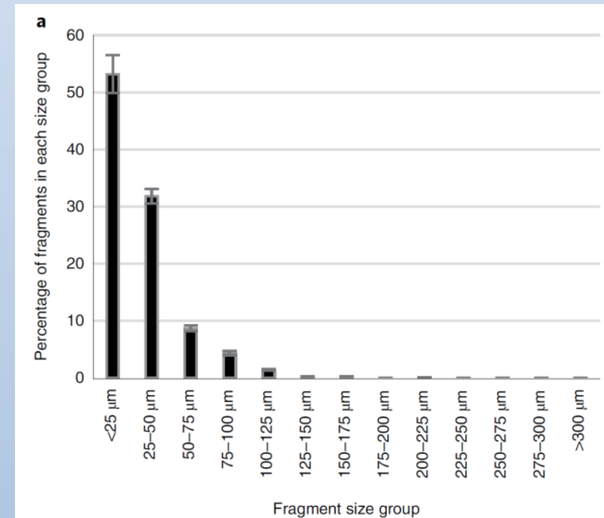
https://www.upi.com/Health_News/2014/09/17/Crest-agrees-to-stop-putting-plastic-microbeads-in-your-toothpaste/8681410993062/

https://www.greenbiz.com/article/solving-recycled-plastics-puzzle

Plastics on the Sargasso Sea Surface

Abstract. *Plastic particles, in concentrations averaging 3500 pieces and 290 grams per square kilometer, are widespread in the western Sargasso Sea. Pieces are brittle, apparently due to the weathering of the plasticizers, and many are in a pellet shape about 0.25 to 0.5 centimeters in diameter. The particles are surfaces for the attachment of diatoms and hydroids. Increasing production of plastics, combined with present waste-disposal practices, will undoubtedly lead to increases in the concentration of these particles. Plastics could be a source of some of the polychlorinated biphenyls recently observed in oceanic organisms.*

Carpenter et al. 1972. Science



Human footprint in the abyss: 30 year records of deep-sea plastic debris

Chiba et al. 2018. Marine Policy

Atmospheric transport and deposition of microplastics in a remote mountain catchment

Allen et al. 2019. Nature Geoscience

Ingestion of Microplastics

Nearly 60% of **seabird** species in the world have ingested plastic, especially pellets, and by 2050 that percentage will rise to 99% (Wilcox et al. 2015)

https://en.wikipedia.org/wiki/Plastic_particle_water_pollution

Fish eat plastic too - juvenile flounder have been reported to contain as many as thirty 2–5 cm diameter plastic pellets in their intestines (Kartar et al. 1976; Kartar et al. 1973)

The ingestion rate of plastic debris by **mesopelagic fish** (200—800 m depth) in the North Pacific estimated to be 12,000 to 24,000 tons per year (Davison et al. 2011)

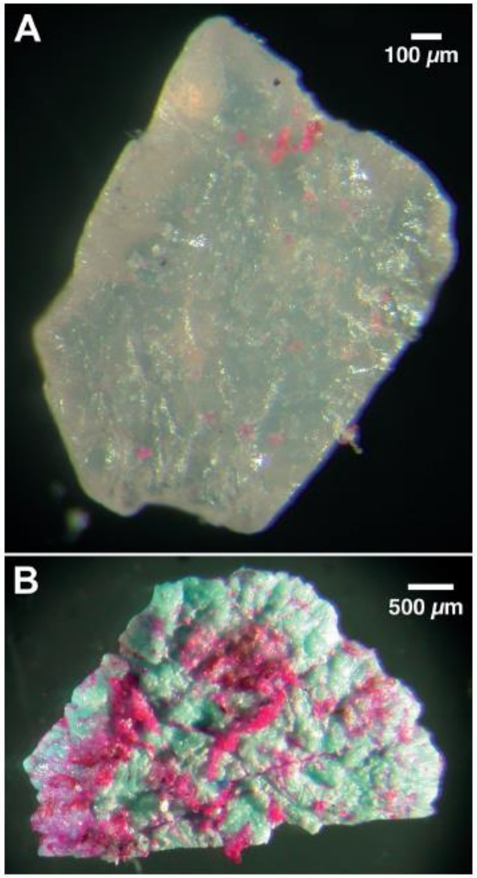
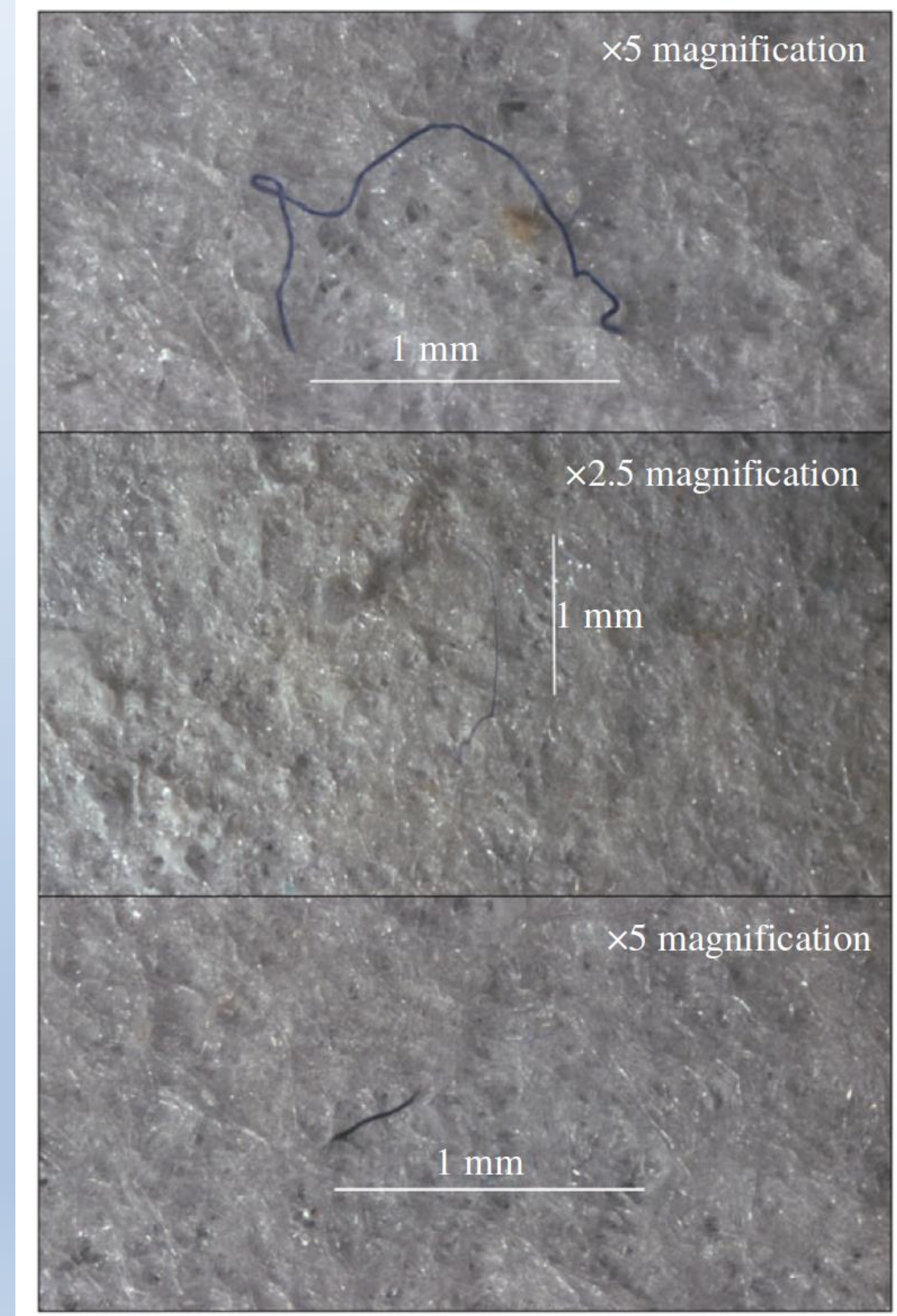


Fig. 2. (A) White plastic particle (longest dimension of 1.5 mm) recovered from the stomach of a *Myctophum nitidulum*. (B) Blue–green plastic particle (longest dimension of 4.4 mm) recovered from the stomach of a *Sternoptyx pseudobscura*. Pink areas are organic material stained with rose bengal

Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine ecosystems on Earth



Jamieson et al. 2019. Roy. Soc. Open Sci.

Microplastics' resemblance to fish eggs has been partly responsible for their ingestion by larger animals

Smaller animals (e.g., plankton) ingest plastic also (video)

Plastic pellets have been reported in concentrations as high as 3,500 and 34,000 km^{-2} in surface waters of the Atlantic and Pacific Oceans (O'Hara et al. 1988)

[Five Films]

Five Films captured this video under a microscope at the Plymouth Marine Laboratory in the UK (July 2015). Fluorescent polystyrene beads are 7 to 30 µm in diameter.

http://ecowatch.com/2015/07/09/plankton-eat-ocean-plastic/

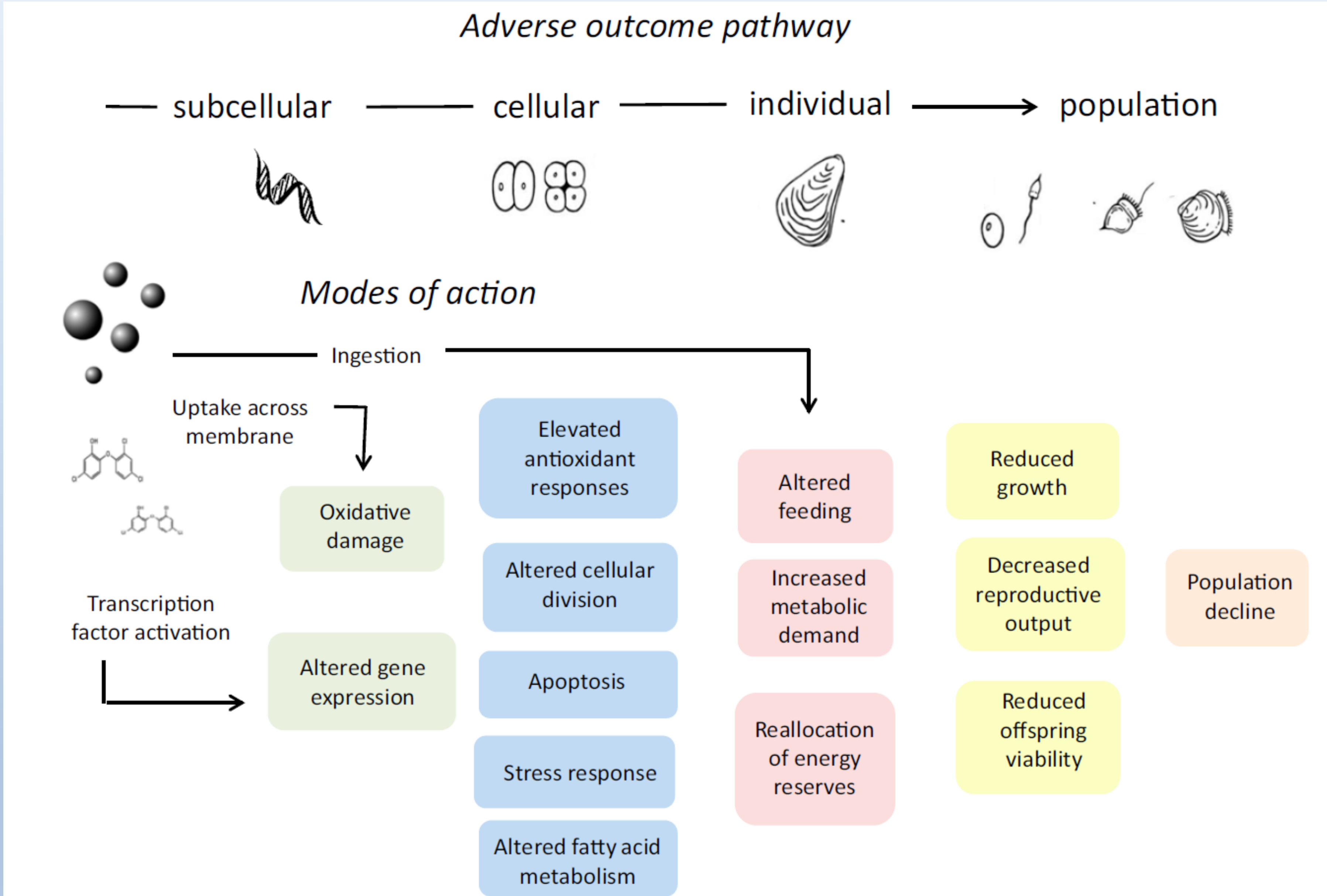


Fig. 1. Tentative AOP scheme for microplastics exposure of aquatic species showing potential pathways linking ingestion, uptake across membranes, and chemical release with adverse outcomes of growth inhibition and reproductive decline.

Galloway & Lewis (2016) PNAS 113:2331-2333

Microplastics in Chesapeake Bay

Environmental Science & Technology
Article
pubs.acs.org/est
2014 ES&T 48:14195-14202

Microplastics in Four Estuarine Rivers in the Chesapeake Bay, U.S.A.

Lance T. Yonkos,*,†,‡ Elizabeth A. Friedel,‡ Ana C. Perez-Reyes,† Sutapa Ghosal,§ and Courtney D. Arthur∥,⊥,∇

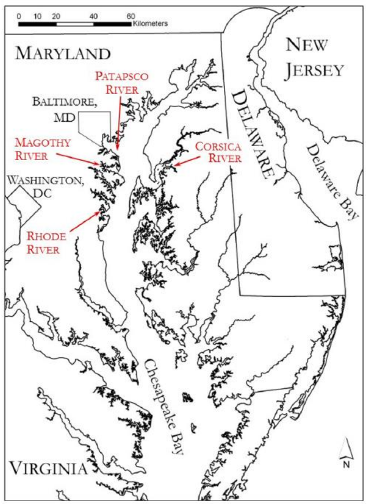


Figure 1. Locations of estuarine sites within the Chesapeake Bay sampled for microplastics between July and December 2011.

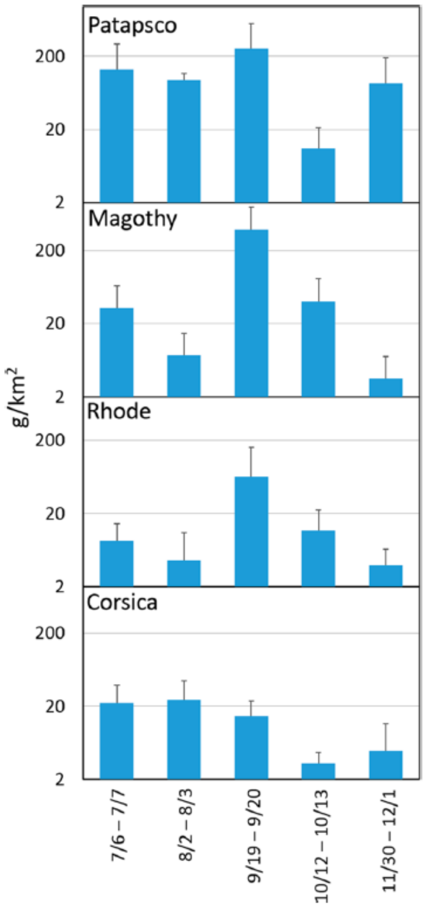


Figure 4. Concentrations of microplastics in surface water collections from four Chesapeake Bay tributaries on five occasions between July and December 2011; mean (log scale; $n = 3$) and standard deviation (error bars).

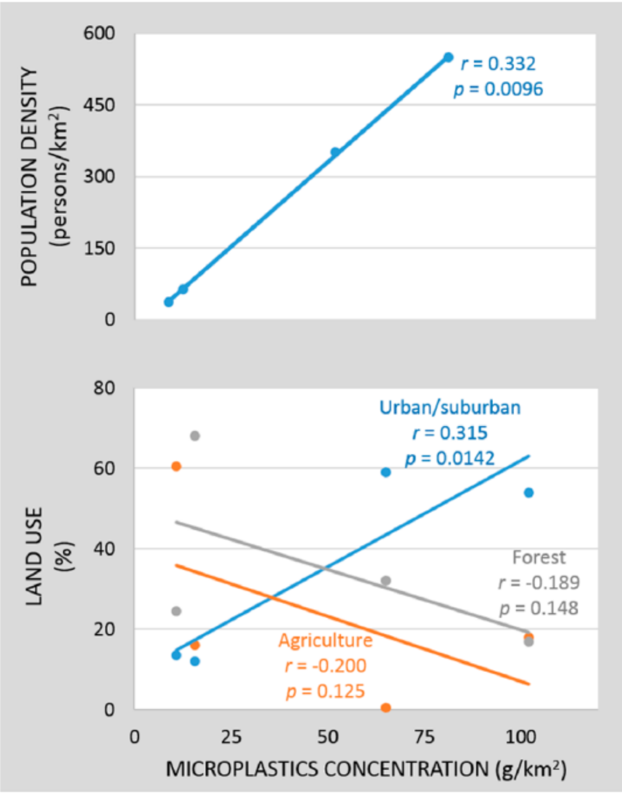


Figure 6. Associations between watershed characteristics and microplastics concentrations in Chesapeake Bay surface waters: population density (top); land use patterns (bottom); positive correlation coefficients (r) indicate variables that tend to increase together while negative correlation coefficients indicate that one variable tends to decrease while the other increases; only variable pairs with p-values below 0.050 (e.g., population density, urban/suburban land use) are statistically significant.

Screen size of 300 µm

Are We Underestimating Microplastic Contamination in Aquatic Environments?

Jeremy L. Conkle[1] · Christian D. Báez Del Valle[2] · Jeffrey W. Turner[3]

- **Reviewed 50 environmental surveys of microplastic**
- **Most (~80%) account only for plastics ≥ 300 µm**

- **Their particular work with personal care products showed > 95% of particles were <300 µm minimum diameter**

By mass

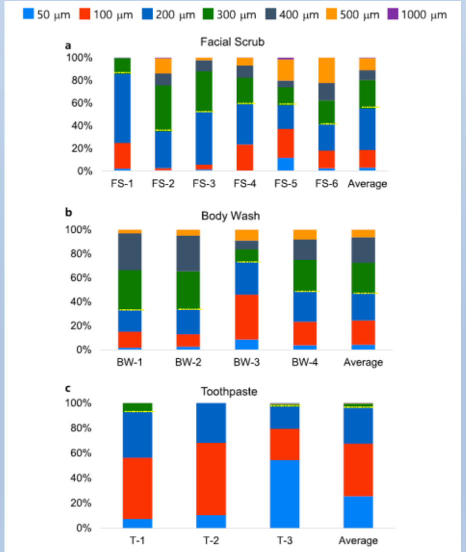


Fig. 1 Polyethylene microplastic mass size distribution by for **a** facial scrub, **b** body wash and **c** toothpaste. Dotted yellow lines indicate the division between smaller (<300 µm) and larger (>300 µm) size classes

By count

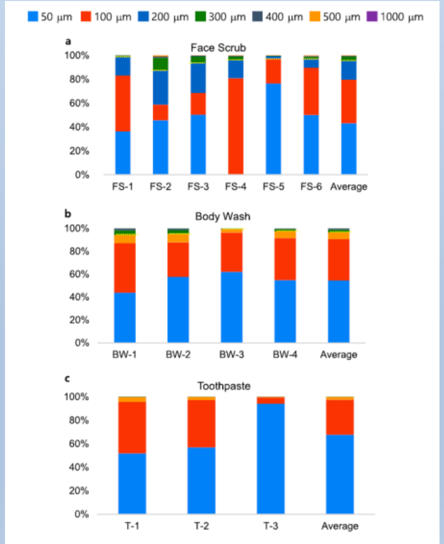


Fig. 2 Polyethylene microplastic count size distribution for **a** facial scrubs, **b** body washes and **c** toothpastes. Dotted yellow lines indicate the division between smaller (<300 µm) and larger (>300 µm) size classes

Conkle et al. (2018) Environmental Management

Plastics and Microplastics as vectors for bacteria and human pathogens

Amanda L. Laverty, M.S. 2018.
Dept. OEAS
Old Dominion University
Norfolk, VA

"The objective of this study was to examine marine plastic pollution as a substrate for bacteria, with particular focus on *Vibrio* spp. known to be human pathogens."

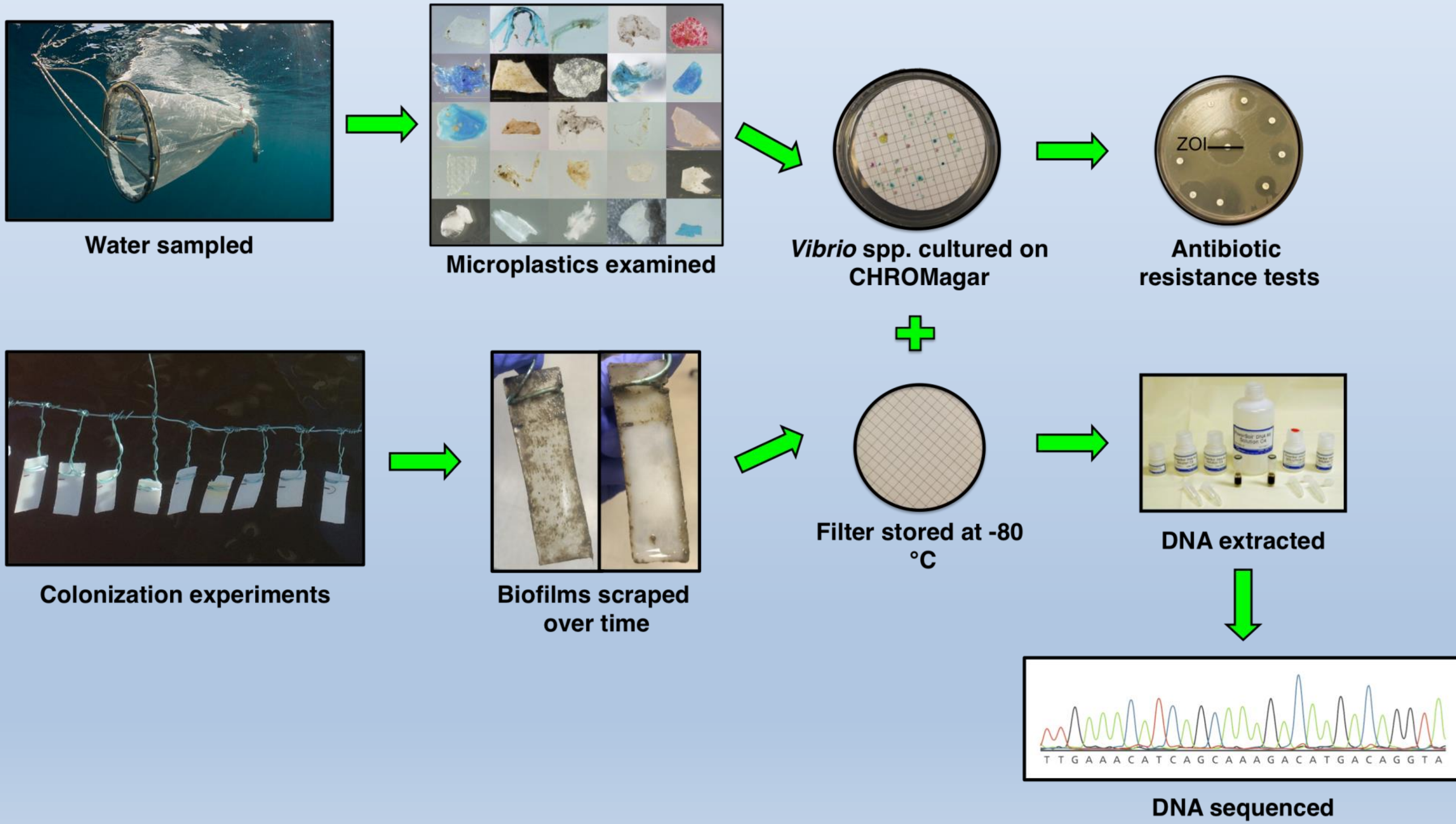
Her thesis in a nutshell:

Collect microplastics

Analyze the bacterial biofilms on microplastics for:

- antibiotic resistance
- antibiotic-resistance genes
- community composition
- *Vibrio* spp. (bacteria)

Methods


Water sampled
Microplastics examined
Vibrio spp. cultured on CHROMagar
ZOI
Antibiotic resistance tests
Colonization experiments
Biofilms scraped over time
Filter stored at -80 °C
DNA extracted
T T G A A A C A T C A G C A A A G A C A T G A C A G G T A
DNA sequenced

Conclusions

- Biofilms on plastics serve as a habitat for bacteria and human pathogens, particularly *V. vulnificus, V. parahaemolyticus, and V. cholerae*

  This is the first study to isolate all three potentially pathogenic species from marine plastics

- These findings support the initial report of vibrios on microplastics and extend the observation from the open ocean to coastal regions

- Marine plastics likely facilitate horizontal gene transfer and may disseminate antibiotic resistance genes

https://www.youtube.com/watch?v=eaCHH5D74Fs

The environment

The known unknowns of plastic pollution

So far, it seems less bad than other kinds of pollution (about which less fuss is made)

The Economist (2018) 3 March

China Has Refused To Recycle The West's Plastics. What Now?

•

Sara Kiley Watson

A worker sorts plastic bottles at a recycling center in China.
Jie Zhao/Corbis via Getty Images

For more than 25 years, many developed countries, including the U.S., have been sending massive amounts of plastic waste to China instead of recycling it on their own.

Some 106 million metric tons — about 45 percent — of the world's plastics set for recycling have been exported to China since reporting to the United Nations Comtrade Database began in 1992.

But in 2017, China passed the National Sword policy banning plastic waste from being imported — for the protection of the environment and people's health — beginning in January 2018.

Now that China won't take it, what's happening to the leftover waste?

According to the authors of a new study, it's piling up.

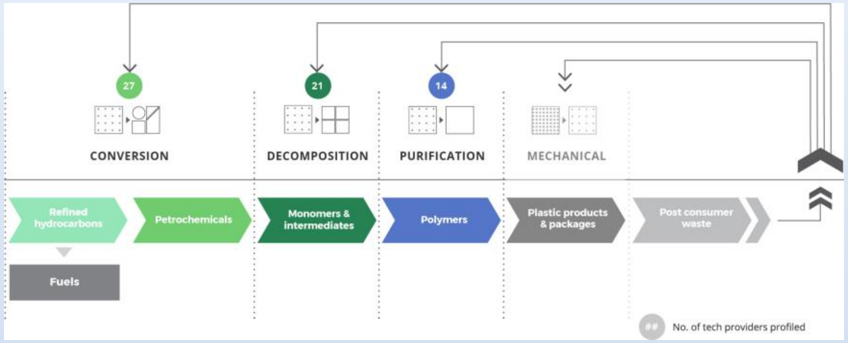
https://www.npr.org/sections/goatsandsoda/2018/06/28/623972937/china-has-refused-to-recycle-the-wests-plastics-what-now

ACCELERATING CIRCULAR SUPPLY CHAINS FOR PLASTICS

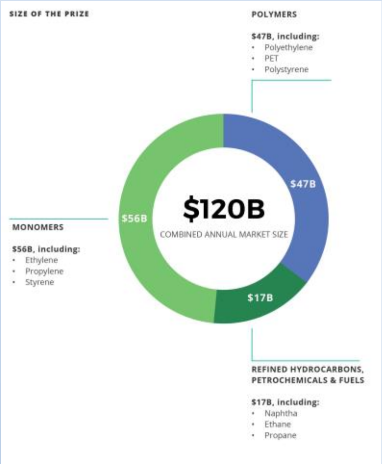
A Call to Action for Investors, Brands, and Industry to Invest in Transformational Technologies That Will Stop Plastic Waste, Keep Materials in Play, and Grow Markets

CLOSED LOOP partners

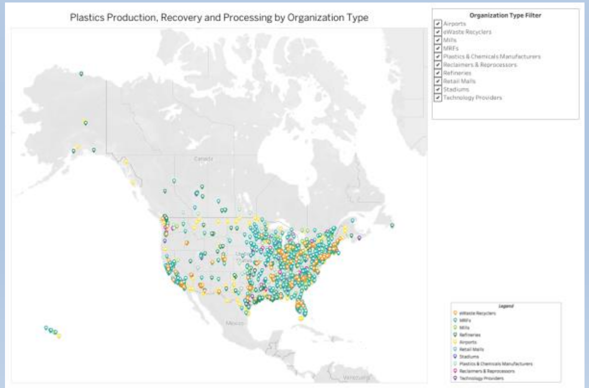
1. TECHNOLOGIES THAT KEEP PLASTICS IN PLAY MUST BE PART OF THE SOLUTION TO END PLASTICS POLLUTION



2. THERE IS REAL DEMAND FOR PLASTICS AND OTHER MATERIALS ACROSS THE SUPPLY CHAIN



3. THIS IS POSSIBLE. THE INNOVATION EXISTS TO MEET THE DEMAND

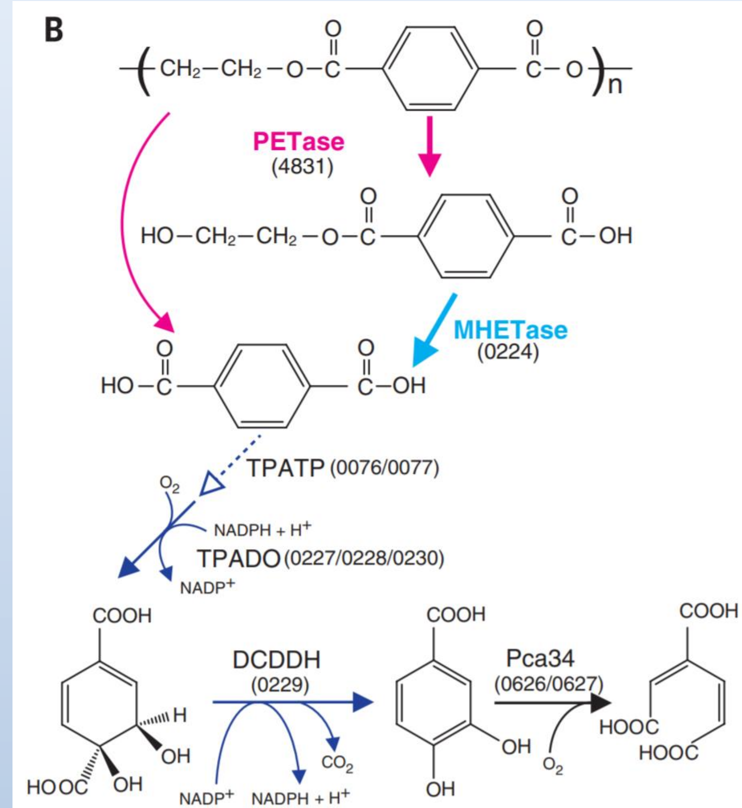


http://www.closedlooppartners.com/plastics/

A bacterium that degrades and assimilates poly(ethylene terephthalate)

Shosuke Yoshida,[1,2]* Kazumi Hiraga,[1] Toshihiko Takehana,[3] Ikuo Taniguchi,[4] Hironao Yamaji,[1] Yasuhito Maeda,[5] Kiyotsuna Toyohara,[5] Kenji Miyamoto,[2]† Yoshiharu Kimura,[4] Kohei Oda[1]†

Poly(ethylene terephthalate) (PET) is used extensively worldwide in plastic products, and its accumulation in the environment has become a global concern. Because the ability to enzymatically degrade PET has been thought to be limited to a few fungal species, biodegradation is not yet a viable remediation or recycling strategy. By screening natural microbial communities exposed to PET in the environment, we isolated a novel bacterium, *Ideonella sakaiensis* 201-F6, that is able to use PET as its major energy and carbon source. When grown on PET, this strain produces two enzymes capable of hydrolyzing PET and the reaction intermediate, mono(2-hydroxyethyl) terephthalic acid. Both enzymes are required to enzymatically convert PET efficiently into its two environmentally benign monomers, terephthalic acid and ethylene glycol.



- *Ideonella sakaiensis* 201-F6
- Uses PET as its major energy and carbon source
- Converts PET into two environmentally benign monomers

Yoshida et al. (2014) Science