Potential impacts of microplastics on marine, freshwater and terrestrial organisms:

What we know, and what we need to know to better assess risk

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As of 2015, ~6300 Mt of plastic waste had been generated, 9% of which had been recycled, 12% incinerated, and 79% accumulated in landfills / the environment. If current trends continue, ~12,000 Mt of plastic waste will be in landfills or the environment by 2050. (Mt = metric ton)

https://carolbrendlerbooks.com/tag/bakelite/
Plastics and climate change...

Plastic production is also inherently linked to climate change because it is made from fossil fuels.
Microplastics …

- Plastic production is outpacing the capacity for disposal, recycling, and reuse
- We are unable to effectively remove microplastic debris on a large scale once it is already in the water
- Many aquatic/marine organisms affected, terrestrial largely unknown
- Primary and secondary sources of microplastics
- Tendency to accumulate in coastal zones, estuaries, soils
- Shape and size can affect toxicity, as can some associated chemicals

Jambeck et al. 2015; Andrady 2011, Lusher et al. 2013, Rochman et al. 2013,2019; Brander et al. 2011, Steinbarger et al. in prep
Microplastic fate, still data poor…

Microplastics studies in commercial fisheries

Baechler, Stienbarger, Horn, Joseph, Taylor, Granek, Brander in press, *Lim Oce Litrs*
Research findings

- Plastics and fibers (increasingly) are found in hundreds of species of freshwater and marine organisms, some terrestrial (birds, worms)

- Ingestion of small plastic pieces can affect growth, can cause liver stress, and may affect other important functions like immune response and respiration.

- Plastic consumption occurs across food webs, sometimes beginning with small pieces in zooplankton and microzooplankton, with transfer upward to larger organisms.

A recent study found that 100% of animals sampled from the Mariana Trench contained plastic.

Athey et al. in revision, Limno Ocean Letters
Jamieson et al. 2017, Nat Eco Evo: 0051
Greven et al. 2016, Env Tox Chem 35:3093-3100
Rochman et al. 2013, Sci Reports: 3
Cesa et al. 2017, Sci Total Env 598: 116-1129
Botterell et al. 2018. Env Poll 245:98-110
Setala et al. 2018. Microplastic Contam Aq Env, Elsevier
Brander et al. unpublished (research in progress)
Plastic is also an issue for sessile organisms. Plastic can combine with other stressors to cause disease and mortality.

Plastic debris stresses coral through light deprivation, toxin release, and anoxia, giving pathogens a foothold for invasion.

Lamb et al. 2018, Science 359: 460-462
Exposure routes...

Watts, Lewis, Goodhead, Beckett, Moger, Tyler & Galloway (2014)
Uptake and Retention of Microplastics by the Shore Crab Carcinus maenas.
Environmental Science & Technology. 10.1021/es501090e
Tintinnid ciliate

Complex single-celled eukaryote ~100-120 µm
- Eat algae, bacteria, at the base of fresh and marine food webs
- Preyed upon by copepods, larval fish

Widely distributed in marine and freshwater

Use cilia to create a current when randomly encountering food items

Athey et al. in review, *Limno Ocean Letters*
Echevarria et al., 2014, *FEMS Microbiology, Ecology*
Food web impacts ...
Toxicity...

• Size and shape matter
  • Zebrafish, grass shrimp, sheepshead minnow, and water fleas (all common aquatic test organisms) respond more negatively to fibers or irregularly shaped fragments than spheres
  • Can also affect propensity to accumulate or to be ingested
  • Smaller particles can be translocated to internal organs (e.g. liver)

• Polymers can cause oxidative stress in fish and invertebrates
  • Upon exposure to microplastics cells may produce reactive oxygen species that can cause structural damage

Rethinking Microplastics as a Diverse Contaminant Suite

Focus articles are part of a regular series intended to sharpen understanding of current and emerging topics of interest to the scientific community.
ADVERSE OUTCOME PATHWAY

Conceptual framework to understand how a toxicant’s effect on a cell could lead to an adverse outcome for an organism or population.

Toxicant

Chemical Properties

Molecular Responses

Gene Activation
Protein Production
Altered Signaling
Protein depletion

Organ Responses

Altered Physiology
Disrupted Homeostasis
Altered tissue development or function

Organism Responses

Lethality
Impaired Development
Reduced reproduction
Altered swimming

Population Responses

Population Size
Recruitment
Extinction

Regulatory endpoints

Ankley et al. 2010
The challenge in assessing risk is to use environmentally relevant concentrations of microplastics when dosing animals for testing, but this is difficult since most environmental sampling is done on larger particle sizes than those being consumed or internalized by aquatic animals at the base of food webs.
So many microplastics, so little time...

High throughput testing using adapted fish early life stage toxicity tests could be used to evaluate large numbers of plastic types, sizes, and amounts ...
As with soluble pollutants, studies evaluating microplastic toxicity in combination with increased temperatures associated with climate change find increased toxicity in some cases. Other factors like hypoxia, salinity, and ocean acidification should be considered too.

DeCourten, Romney, Brander 2019
Madeira et al. 2016, Ecological Indicators
PUTTING IT ALL TOGETHER

In an ecosystem, top-down and bottom-up effects can be more important than direct stressor impacts.

Bruder et al. 2019, Frontiers Env Sci
Microplastics in water: no proof yet they are harmful, says WHO

Report calls for more research and warns against complacency over the issue

Tentative ‘effect’ thresholds for microplastics have been recently proposed by various authors for the marine environment. However, the Dossier Submitter has concluded there is currently insufficient information to derive a robust predicted no effect concentrations (PNECs) for microplastics, that could be used to justify a conclusion that risks are adequately controlled, either based on current exposures in the environment or exposures that are forecast to occur in the future. ECHA (European Chemicals Agency)

Microplastics are increasingly found in drinking water, but there is no evidence so far that this poses a risk to humans, according to a new assessment by the World Health Organization.

However, the United Nations body warned against complacency because more research is needed to fully understand how plastic spreads into the environment and works its way through human bodies.
Need better estimates of environmental concentrations of smaller microplastics that appear to be easily ingested / assimilated by vulnerable organisms and life stages

Risk assessment should be based on size, shape, and the role of chemicals added at higher concentrations during manufacturing (e.g. plasticizers)

High throughput testing similar to that used to assess soluble chemical toxicity could be modified for microplastics assays

Consideration of multiple stressors, such as factors associated with climate change (temperature, hypoxia, salinity stress, etc) is important
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Questions ?
Simultaneous processes affecting the relative importance of microplastics acting as a vector of pollutants

**Blue oval** = Microplastic. **Green oval** = Natural prey item. **Black oval** = Other source than microplastic.

**Black arrows** indicate transfer of microplastic. **Red arrows** indicate HOC transfer to organism. **Green arrows** indicate HOC transfer from organism. Arrow widths represent qualitative indication of relative importance of the pathway.

Per fish individual, processes occur simultaneously for same as well as different HOC, complicating interpretation of field data.

Per fish individual, processes increasing or decreasing body burdens occur simultaneously for different HOC. Per HOC, uptake from natural path (6) plus nonmicroplastic source (7) generally overwhelms uptake from microplastic ingestion.

Koelmans et al. 2016, Env Sci Tech