The Effects of Plastics in our Aquatic Environment
The albatross chick jumped to its feet, eyes alert and focused. At 5 months, it stood 18 inches tall and was fully feathered except for the fuzz that fringed its head.

All attitude, the chick straightened up and clacked its beak at a visitor, then rocked back and dangled webbed feet in the air to cool them in the afternoon breeze.
Manuscripts Published

Web of Science →
All Databases →
“plastic debris” OR
“microplastic”
Contamination

Macroplastics
(>5 mm)

Microplastics
(< 5mm)
Microplastics everywhere
High amounts of microplastics have been found not just in the sea and on beaches, but also in rivers and soils around the world, demonstrating how pervasive this modern pollution is. Sources include leakage from landfills, plasticulture, littering, and sewage sludge. Data from (1).

Amount reaching the ocean
4.8 to 12.7 million metric tons per year

Mismanaged plastic waste, leaked into the environment
31.9 million metric tons per year

Microplastic

Flow of plastic
Trends in research
Microplastics

Primary vs. Secondary (broken down bits of larger plastic products)

Categories (shape) – fragments, fibers, foam, sphere, pellet, film

Polymer Type – PP, PE, PVC, PET, PS, acrylic, styrene butadiene, PC, nylon...

Chemical Additives – UV Stabilizers, Flame Retardants, Plasticizers, etc...

Size – nm to µm to mm
Fig. 2. Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons).
What are the most significant sources of plastic debris?
Measuring the sources and sinks of microplastics in urban watersheds
Lake Ontario Sneak Peek

Study Area

Sampling Sites
- Wastewater Treatment Plant
- Background Sites
- Agriculture Sites
- Urbanized Watershed Sites
- Upstream Watershed of Agriculture Sites
- Upstream Watershed of Urbanized Sites

Sources
- Base map (Land Information Ontario, 2017)
- Watersheds (Ontario Water Assessment Tool, 2016)
- Sites (Chelsea Rochman, 2015)

Created by
Jelena Grbic at University of Toronto.

Grbic et al., in prep
L Ontario Sneak Peek

Grbic et al., *in prep*
L Ontario Sneak Peek

Category Summary

Wastewater Effluent: 90%
Agricultural Runoff: 3%
Urban Runoff: 1%
Reference: 6%

Grbic et al., in prep
Bivariate logistic regression results for independent variables showing significance with mean microplastics per liter. Diagnostics include standardized coefficients (beta values). Goodness-of-fit diagnostics include adjusted R-square. Independent model variables have been transformed to approach a normal distribution.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>$\beta$</th>
<th>Significance</th>
<th>Adj. R-Square</th>
<th>RSE (df=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed characteristics</td>
<td></td>
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<tr>
<td>Area</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Population Density</td>
<td>0.003</td>
<td>*</td>
<td>0.261</td>
<td>5.97</td>
</tr>
<tr>
<td>Road Length</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Plastic Industry$^t$</td>
<td>0.513</td>
<td>***</td>
<td>0.756</td>
<td>0.556</td>
</tr>
<tr>
<td>Slope</td>
<td></td>
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<tr>
<td>River traits</td>
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<tr>
<td>Flow</td>
<td></td>
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</tr>
<tr>
<td>Climate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Wind</td>
<td></td>
<td></td>
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<tr>
<td>Land cover</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Urban</td>
<td>0.196</td>
<td>***</td>
<td>0.480</td>
<td>5.008</td>
</tr>
<tr>
<td>Green$^t$</td>
<td>-0.127</td>
<td>**</td>
<td>0.373</td>
<td>0.892</td>
</tr>
<tr>
<td>Water$^t$</td>
<td>-0.927</td>
<td>**</td>
<td>0.315</td>
<td>0.933</td>
</tr>
<tr>
<td>Agriculture</td>
<td>-0.210</td>
<td>**</td>
<td>0.356</td>
<td>5.576</td>
</tr>
</tbody>
</table>

Symbol designation: $^t$ Variables log-transformed (two signs indicates predictor + response both transformed)

Significance codes: *** $< 0.001$, ** $< 0.01$, * $< 0.05$, + $< 0.1$, --- $> 0.1$
Microplastic contamination in the Great Lakes

**Categories (potential sources)**

- **Fragments** (litter, commercial processes)
- **Microbeads** (personal care products)
- **Line/Fibers** (rope, line/net, clothing, cig butts)
- **Foam** (packing, food containers, insulation)
- **Film** (plastic bags, wrapping)
- **Production Pellets / “Nurdles”**

Helm et al., *unpublished data*
Microplastic contamination in the Great Lakes

>800 species
Secretariat of the
Convention on Biological
Diversity, 2016

>220 species
FAO Report 2017
Microplastics in Lake Ontario nearshore fish

Munno et al., *unpublished data*
Microplastics in Great Lakes cormorants

Brookson et al., 2019 CJFAS
Impacts can be physical or chemical

Rochman 2015 Chapter in *Marine Anthropogenic Litter*
Fate of microplastic and nanoplastics in the body

Mussels: Browne et al., 2008 *ES&T*

Mice: Deng et al., 2017 *Scientific Reports*

Fish: Collard et al., 2017 *Environ Pollut*
Chemical Impact

Wastewater and runoff carry microplastics into waterways.

Plastic objects are broken down into smaller pieces by sunlight and surf action.

Marine plastics are often mistaken for food.

Persistent, bioaccumulative, and toxic compounds in seawater preferentially sorb to plastics.

At the same time, constituents of the plastics themselves, such as additives, leach into the tissues of organisms that consume the particles.

Bioaccumulation may be amplified by plastics shuttling pollutants into marine organisms.

Potential plastic-mediated bioaccumulation

More research is needed to learn how these processes ultimately affect body burdens in humans.

Image by Rolf Halden, Professor at Arizona State University
Chemicals from microplastics can transfer to wildlife.

Tanaka et al., 2015 *ES&T*
Tanaka et al., 2013 *Mar Pollut Bull*

Jang et al., 2016 *ES&T*

Rochman et al., 2014 *Science of the Total Environment*
### Table: Size of Plastic Debris and Level of Biological Organization

<table>
<thead>
<tr>
<th>Size of Plastic Debris</th>
<th>Level of Biological Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>nm</td>
<td>Assemblage</td>
</tr>
<tr>
<td>µm</td>
<td>Population</td>
</tr>
<tr>
<td>mm</td>
<td>Organism</td>
</tr>
<tr>
<td>cm</td>
<td>Organ system</td>
</tr>
<tr>
<td>m</td>
<td>Organ</td>
</tr>
<tr>
<td>km</td>
<td>Tissue</td>
</tr>
<tr>
<td></td>
<td>Cell</td>
</tr>
<tr>
<td></td>
<td>Organelle</td>
</tr>
<tr>
<td></td>
<td>Molecular assemblies</td>
</tr>
<tr>
<td></td>
<td>Macromolecules</td>
</tr>
<tr>
<td></td>
<td>Small molecules</td>
</tr>
<tr>
<td></td>
<td>Atoms</td>
</tr>
<tr>
<td></td>
<td>Subatomic particles</td>
</tr>
</tbody>
</table>

**Legend:**
- □ 0
- □ 1–5
- □ 6–10
- ◆ Correlative evidence

*Adapted from Rochman et al. Ecology 2015*
The Evidence Demonstrating Impacts to aquatic biota is Growing

Bucci, Rochman, et al. unpublished
**Effect Detected vs Not Detected**

Ecosystem
Assemblage
Population
Organism
Organ System
Organ
Tissue
Cell
Organelle
Molecular Assemblies
Macromolecules
Small molecules
Atoms
Subatomic Particles

Effect was Tested And Demonstrated

Effect was Tested And Not Demonstrated

Size of debris

# of Null Effects

- **Black**: > 30
- **Dark Blue**: 21 - 30
- **Blue**: 11 - 20
- **Light Blue**: 6 - 10
- **Very Light Blue**: 1 - 5
- **White**: 0

Bucci, Rochman, et al. unpublished
What makes an effect detected vs not detected?
- type of microplastic
- size of microplastic
- shape of microplastic
- taxa
- dose of microplastic
- length of exposure
Effects of microplastics on Fathead minnows?

Consistent size, colour, concentration, shape

Kennedy Bucci
1. Physical interaction

2. Chemical interaction

Control

No plastic

Microplastic fragments (100-500 µm)

Treatments

Low (140 particles/L)

High (1400 particles/L)

Low (140 particles/L)

High (1400 particles/L)

Bucci et al., unpublished
Mortality

Exposure scenario
- Physical
- Chemical

Polyethylene

Beached plastic

% Mortality

Bucci et al., unpublished
Developmental deformities

Severe spinal deformities

Ocular enlargement

Bucci et al., unpublished
Impacts to Humans

Pillars of Food Security

Food Security

- Sufficient food
- Safe food
- Nutritious Food

Ecological Impacts

Physical or Particle Toxicity

Alter Nutritional Value

Food Utilization ➔ Nutritional Status

Karami et al., 2018
Physical Impact of the Particle

What does the medical literature tell us?

hernia mesh

prosthetic hip
<table>
<thead>
<tr>
<th>Level of biological organization</th>
<th>Particle type and size</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macromolecules</td>
<td>PE 100 nm–30 μm</td>
<td>DNA damage, changes in gene and protein expression</td>
<td>Gelb et al., 1994; Brown et al., 2001; DeHeer et al., 2001; Gretzer et al., 2002; Petit et al., 2002; Ingram et al., 2004; Clohisy et al., 2006; Kaufman et al., 2008; Markel et al., 2009; Huang et al., 2010; Hallab et al., 2012; McGuinness et al., 2011; Samuelsen et al., 2009; Smith and Hallab 2010; Pearl et al., 2011</td>
</tr>
<tr>
<td></td>
<td>PS 50 nm–4.7 μm</td>
<td></td>
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<tr>
<td></td>
<td>PMMA 1 μm–2 μm</td>
<td></td>
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<tr>
<td></td>
<td>PC 1 μm–55 μm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organelles*</td>
<td>PMMA 10 μm</td>
<td>more micronuclei</td>
<td>Zhang et al., 2008</td>
</tr>
<tr>
<td>Cells</td>
<td>PS 20 nm–4.7 μm</td>
<td>cell clotting, necrosis, apoptosis, proliferation and loss of cell viability</td>
<td>Gelb et al., 1994; Brown et al., 2001; Gretzer et al., 2002; Bernard et al., 2007; Fröhlich et al., 2009; Samuelsen et al., 2009; Hallab et al., 2012; McGuinness et al., 2011</td>
</tr>
<tr>
<td></td>
<td>PE 300 nm–10 μm</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>PMMA 2 μm–35 μm</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>PS 20 nm–200 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PS 60 nm–200 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tissues</td>
<td>PE 600 nm–21 μm,</td>
<td>inflammation and bone osteolysis</td>
<td>Gelb et al., 1994; Clohisy et al., 2006; Markel et al., 2009; Pearl et al., 2011</td>
</tr>
<tr>
<td></td>
<td>PMMA 1 μm–35 μm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organs</td>
<td>PMMA 1 μm–10 μm</td>
<td>lesions</td>
<td>Zhang et al., 2008; Pearl et al., 2011</td>
</tr>
</tbody>
</table>

*An organelle is a specialized subunit within a cell (e.g. mitochondria) with a specific function.

PE (Polyethylene), PS (Polystyrene), PMMA (Poly(methyl methacrylate)), PC (Polycarbonate).
Widespread Contamination in habitats and animals – incl. seafood and drinking water.

Evidence of effects to wildlife – particularly macroplastics – including to populations and communities.

Evidence of effects of microplastics in lab animals, populations and communities.

Continue to aim toward a better understanding of sources, fate and impacts to humans and wildlife populations.
Next Big Questions and Research Needs for Microplastics:

• Identify local entry points for microplastics into the Great Lakes
• Understand the fate of microplastics and associated chemicals in the environment
• Determine ecologically relevant impacts of microplastics:
  • Environmentally relevant laboratory studies, laboratory ecosystem study (mesocosm), field studies, multi-stressor
• Identify impacts to human health and food security
• Improve methods for quantifying and characterizing microplastics in complex matrices.
In the meantime, we have enough science to begin to mitigate now and prevent future sources of plastic pollution.
Think Globally Act Locally
Most favoured option

Reduce: lowering the amount of waste produced

Reuse: using materials repeatedly

Recycle: using materials to make new products

Recovery: recovering energy from waste

Landfill: safe disposal of waste to landfill

Least favoured option
OPERATION CLEAN SWEEP

OBJECTIVE: ZERO PELLET LOSS
Testing microfiber mitigation

2 strategies: **both reduce microfibers** in washing machine effluent

![Box plots showing reduction in fibers](#)

- **Cora ball**
- **Lint LUV-R**

Photos: coraball.com / www.environmentenhancements.com

McIlwraith, et al. *in review*
City of Toronto example

90,700 to 138,000 microfibers per wash load (our study)

219 wash loads per household per year (NRC, 2011)

1,179,057 households (Statistics Canada, 2017)

= 23 to 36 trillion microfibers emitted per year
City of Toronto example

90,700 to 138,000 microfibers per wash load
(our study)

219 wash loads per household per year
(NRC, 2011)

1,179,057 households
(Statistics Canada, 2017)

= 23 to 36 trillion microfibers emitted per year

↓ 6 to 9 trillion microfibers
↓ 20 to 31 trillion microfibers
Treatment Efficiency

• Mean 92% reduction (n=3)
Community Outreach
JOIN THE DON RIVER CLEANUP!

#CLEANUPTHEDON

HELP THE U OF T TRASH TEAM
PICK UP LITTER ALONG THE DON RIVER WATERSHED

SUNDAY MAY 5TH AT 10 AM
FIVE LOCATIONS

SIGN UP ONLINE AT SHORELINECLEANUP.CA
Thank you!

chelsea.rochman@utoronto.ca
www.rochmanlab.com
Ontario Sneak Peek

Grbic et al., in prep
**Microplastics in Lake Ontario pelagic fish**

- In 100% of fish sampled
- 96.9% of microplastics in fish are fibers

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Beads &lt;1%</th>
<th>Fibers 96.9%</th>
<th>Films &lt;1%</th>
<th>Fragments 2.5%</th>
<th>Foams 0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Lakes (n = 21)</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Tributaries (n = 107)</td>
<td>0.00</td>
<td>0.50</td>
<td>0.00</td>
<td>2.50</td>
<td>0.00</td>
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<tr>
<td>Fish (n = 70)</td>
<td>0.00</td>
<td>0.25</td>
<td>0.00</td>
<td>5.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Rainbow smelt (*Osmerus mordax*)

Lake trout (*Salvelinus namaycush*)

Erdle et al., unpublished data
Number of particles (per litre of water)

Station

Fragment
Fibre
Method Development to better quantify and characterize microplastics

**HAZARD**

A **HAZARD** is something that has the potential to harm you

**RISK**

**RISK** is the likelihood of a hazard causing harm