Contamination and effects of plastic debris in the marine 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.
Contamination

Macroplastics
(>5 mm)

Microplastics
(< 5 mm)
Fig. 2. Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons).
8 MILLION METRIC TONS OF PLASTIC ENTER THE OCEANS ANNUALLY + 80% COMES FROM LAND BASED SOURCES

Jambeck et al., 2015 Science
Plastic currents
A giant distribution system for marine plastics

15 to 51 trillion particles weighing 93 – 236 thousand metric tons – van Sebille et al., 2015 Environmental Research Letters

Source: Van Sebille, E., et al., A global inventory of small floating plastic debris, IOP Publishing, 2015; Cooperative Institute for Meteorological Satellite Studies

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Sample points used in the model

Microplastic concentration*
Kilograms per square kilometre

0  10

Surface current

North Pacific gyre

North Atlantic gyre

South Pacific gyre

South Atlantic gyre

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

>220 species
FAO Report 2017
Similar occurrence of anthropogenic debris in fish from each location

USA
-16 out of 64 fish (25%)
-6 of 11 species sampled

30 total pieces
0.5 ± 1.4 SD avg pieces /fish

Indonesia
-21 out of 76 fish (28%)
-8 of 12 species sampled

105 total pieces
1.4 ± 3.7 SD avg pieces/fish

No difference among species

Rochman et al., 2015 Sci Reports
49 species commercial fish

Many species of shellfish

Other commercial products

Rochman et al., 2015; van Cauwenberghe and Janssen, 2014; Li et al., 2015; Yang et al., 2015; Davidson and Dudas, 2016
Impact
Impacts can be physical or chemical.

Rochman 2015 Chapter in *Marine Anthropogenic Litter*
Impacts can be due to the plastic itself or the mixture of plastics and associated chemicals

Japanese Medaka (*Oryzias latipes*)

- **Negative Control**
- **Virgin Plastic**
- **Marine Plastic**

Fish Diet  | Virgin Plastic  | Marine Plastic
---|---|---
![Image](image_url)

Rochman et al., 2013, *Nature Scientific Reports*
# Liver Toxicity

<table>
<thead>
<tr>
<th>Treatment</th>
<th># Fish</th>
<th>Severe Glycogen Depletion</th>
<th>Lipidosis</th>
<th>Single Cell Necrosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>24</td>
<td>0%</td>
<td>21%</td>
<td>0%</td>
</tr>
<tr>
<td>Virgin-plastic</td>
<td>24</td>
<td>46%</td>
<td>29%</td>
<td>0%</td>
</tr>
<tr>
<td>Marine-plastic</td>
<td>19</td>
<td>74%</td>
<td>47%</td>
<td>11%</td>
</tr>
</tbody>
</table>

Rochman et al., 2013, *Nature Scientific Reports*
Are there ecological impacts?
Impacts described were grouped by size of debris and level of biological organization.
<table>
<thead>
<tr>
<th>Level of Biological Organization</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community/Assemblage</td>
<td>Altered species richness and evenness.</td>
</tr>
<tr>
<td>Population</td>
<td>Fecundity, % of eggs hatched, inhibition in larval settlement, reduced survival in offspring, change in population size due to increased substrate.</td>
</tr>
<tr>
<td>Organism</td>
<td>survival</td>
</tr>
<tr>
<td>Suborganismal</td>
<td>oxidative stress, changes in gene expression and enzyme activity, tumor promotion and inflammation.</td>
</tr>
</tbody>
</table>
PLASTIC DEBRIS

Rochman et al., 2016 Ecology

<table>
<thead>
<tr>
<th>Level of biological organization</th>
<th>Treatied Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assemblage</td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td></td>
</tr>
<tr>
<td>Organism</td>
<td></td>
</tr>
<tr>
<td>Organ System</td>
<td></td>
</tr>
<tr>
<td>Organ</td>
<td></td>
</tr>
<tr>
<td>Tissue</td>
<td></td>
</tr>
<tr>
<td>Cell</td>
<td></td>
</tr>
<tr>
<td>Organelle</td>
<td></td>
</tr>
<tr>
<td>Molecular Assemblies</td>
<td></td>
</tr>
<tr>
<td>Macromolecules</td>
<td></td>
</tr>
<tr>
<td>Small molecules</td>
<td></td>
</tr>
<tr>
<td>Atoms</td>
<td></td>
</tr>
<tr>
<td>Subatomic Particles</td>
<td></td>
</tr>
</tbody>
</table>

- 0
- 1 - 5
- 6 - 10

Correlative Evidence
Environmnetally relevant concentration of microplastic.

Asked questions about material type.

Asked questions relevant to community and population-level effects:

- settlement
- egg production, viability
- sperm motility
- larval yield
- assemblage change
Ecologically relevant experimental design:

1. **Dose**
   - Environmentally relevant concentration

2. **Exposure scenario**
   - E.g., Relevant duration, mechanism

3. **Life stage**
   - Larvae, juvenile or reproductive stage

4. **Questions**
   - E.g., Reproductive output, predator-prey interactions

Contaminated Site & Reference Site
Microplastics in fisheries and aquaculture
Status of knowledge on their occurrence and implications for aquatic organisms and food safety
Pillars of Food Security

Food Security

Sufficient food  Safe food  Nutritious Food

Food Utilization  Nutritional Status

FAO (Food and Agricultural Organization)
80% of individuals sampled
--Murray and Cowie, 2011

63% of individuals sampled
--Devriese et al., 2015

75% of individuals sampled
--Santana et al., 2016

Estimated Human Exposure

11,000 and 100,000 particles/yr
--Van Cauwenberghe and Jansen 2014, GESAMP 2016

175 particles/year
--Devriese et al. 2015
### Fate of microplastic and nanoplastics in the body

<table>
<thead>
<tr>
<th>Microplastics (0.1–5000 μm)</th>
<th>Nanoplastics (1–100 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 150 μm no absorption</td>
<td></td>
</tr>
<tr>
<td>&lt; 150 μm in lymph absorption ≤ 0.3%</td>
<td>≤ 100 nm access to all organs, translocation of blood-brain and placental barrier</td>
</tr>
<tr>
<td>= 110 μm in portal vein</td>
<td></td>
</tr>
<tr>
<td>≤ 20 μm access into organs (≤20000 nm)</td>
<td>Absorption up to 7%</td>
</tr>
</tbody>
</table>
Fate of microplastic and nanoplastics in the body

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

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

Mice: Deng et al., 2017 *Scientific Reports*
Physical Impact of the Particle

Mice: Deng et al., 2017 Scientific Reports
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>
<td></td>
</tr>
<tr>
<td></td>
<td>PMMA 1 µm–2 µm</td>
<td></td>
<td></td>
</tr>
<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>
</tr>
<tr>
<td></td>
<td>PMMA 2 µm–35 µm</td>
<td></td>
<td></td>
</tr>
<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).
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.

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

Image by Rolf Halden, Professor at Arizona State University
Jang et al., 2016 *ES&T*

Tanaka et al., 2015 *ES&T*

Tanaka et al., 2013 *Mar Pollut Bull*
Concentration of BDE-183 + BDE-209 at each station

Linear Regression: $F_{1,34} = 11.345$, $n = 36$, $P < 0.05$, $R^2 = 0.24$
Chemicals associated with the plastic debris

PBDEs (ng/g)
- Higher Br congeners: 90%
- 0.1-5

Chemicals detected in water samples

PBDEs (pg/L)
- Lower Br congeners: ~100%
- 0.3-3
What’s next for research?

- Fate of plastics and associated chemicals in marine ecosystems and seafood products

- Ecologically-relevant studies to assess impacts to wildlife and fish stocks

- Impacts to food safety and nutritional value
Widespread Contamination in habitats and animals – including seafood.

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.

In the meantime, we have enough science to begin to mitigate now and prevent future sources of plastic pollution.
What’s next for policy?

- 8 million metric tons of plastic enters the ocean each year (Jambeck et al., 2015 *Science*).

- Most policies occur on a very local scale, but plastic pollution does not observe borders, so why should policy?

- Policy is needed that scales with the magnitude of the problem.
What can we learn from other issues?

Stephanie B. Borrelle, Chelsea M. Rochman et al. PNAS 2017;114:9994-9997
Why we need an international agreement on marine plastic pollution

Stephanie B. Borrelle\textsuperscript{a,1}, Chelsea M. Rochman\textsuperscript{b,1,2}, Max Liboiron\textsuperscript{c}, Alexander L. Bond\textsuperscript{d}, Amy Lusher\textsuperscript{e}, Hillary Bradshaw\textsuperscript{c}, and Jennifer F. Provencher\textsuperscript{f}

- Reduction targets for plastic pollution
- Signatories from member states
- Annual reporting on success
- Global fund to support infrastructure and innovation

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Thank you!

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