Determining ecological risks of microplastics: current challenges and paths forward

April 24, 2019
Research and public interest in environmental effects of MPs is very high.

From Connors et al Envir. Tox. Chem. 2017

The Amount of Plastic Will Continue to Rise

WE MADE PLASTIC. WE DEPEND ON IT. NOW WE’RE DROWNING IN IT.
Some confusion between macro and microplastics?

- Macroplastics clearly visible and a cause for concern
- Macroplastics certainly a source of MPs
Many types of MPs
• MPs in many media: personal care products, wastewater, stormwater, etc
• Challenging to determine which type(s) of MPs should be monitored and evaluated from a risk perspective

Can an ecological risk assessment (ERA) framework help evaluate risks of MPs and inform management actions?
How is an ERA structured?

Starts with **Problem formulation:**

- Identify assessment endpoints: valued ecological resources and specific attributes that capture what we want to protect
- Identify measurement endpoints: relevant, measurable characteristics of valued resources and their attributes
- Conceptualize what we know, what we think we know, and what we want to know
Assessment Endpoints

• Valued ecological resource
• Explicitly defined so that it provides a clear focus for the assessment
• Provides a link between measurable endpoints and the steps necessary to achieve the management goal
• Represents a combination of a valued resource and ecologically relevant characteristics
• Selected based on their relevance to management objectives, susceptibility to stressors of concern, and ecological importance
Examples of Assessment Endpoints

- Abundance and spatial extent of striped bass juveniles
- Abundance and distribution of native oysters
- Diversity and abundance of rare or threatened and endangered species
- More abundant recreational opportunities (e.g., boating, fishing, swimming)

The more explicit the assessment endpoint, the more risk analyses are likely to be useful

e.g., High-quality fish community integrity
Measurement Endpoints

- Measurable attribute of the assessment endpoint
- May use a surrogate indicator for the assessment endpoint in order to have a measurable endpoint for risk analyses.

Examples

<table>
<thead>
<tr>
<th>Assessment Endpoint</th>
<th>Measurement Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse pelagic fish community</td>
<td>Fish IBI, metrics</td>
</tr>
<tr>
<td>Abundant striped bass juveniles</td>
<td>CPUE of striped bass juveniles in surveys</td>
</tr>
<tr>
<td>Estuarine benthic macroinvertebrate community abundance and diversity</td>
<td>Diversity of benthic species; proportion of sensitive taxa or species having certain biological traits</td>
</tr>
<tr>
<td>Abundant healthy eel grass beds</td>
<td>Aerial coverage of eel grass from satellite images</td>
</tr>
</tbody>
</table>
Conceptual Model

• Describes pathways between:
  ▪ human activities *(sources of stress)*
  ▪ *stressors* (may be physical, chemical, or biological)
  ▪ *assessment endpoints*

• Should yield predictions or risk hypotheses of how human activities affect the valued ecological resources

• Based on ecological experience and best professional judgment

• May be assessment endpoint – focused [what stressor(s) most responsible for risk to valued resource?]  OR

• May be stressor-focused [e.g., What is the ecological risk of chemical X at my site or in general? – may have multiple assessment endpoints]  OR

• May be both stressor and assessment endpoint focused
Assessment endpoint-focused:
Scallop abundance
Waquoit Bay, MA
Model III: Microplastics Toxicokinetics/Toxicodynamics

From: EPA microplastics expert workshop June, 2017
Stressor and Assessment Endpoint Focused Conceptual Model

Other stressors

MPs

Water column

Eel grass

Larval fish

Striped bass juvenile abundance

Plankton

Sediments
Risk Analyses

- Identify risk hypotheses or testable linkages between sources, stressors and assessment endpoints
- Identify appropriate ways to analyze linkages or hypotheses
- Implement analysis plan and interpret results of analyses
- Often an iterative process as results are obtained; not necessarily linear process
Risk Characterization

- Integrates exposure and effects
- Traditionally relies on known effect thresholds (e.g., LC50s, NOECs), species sensitivity distributions, minimum levels for sustained population survival and reproduction
- Identify strength of relationships derived from analyses
- Identify uncertainties, data gaps, confounding factors
How can we apply an ERA framework to the problem of MPs?
Traditional paradigm

- Physical, chemical or biological stressor is readily quantified unambiguously

- Sources of the stressor are typically known or assumed based on BPJ

- Laboratory experiments often used to provide effects information

Microplastics

- MPs may encompass many forms, types, sizes; challenging to quantify

- Sources may be diffuse and may influence types of MPs; MPs produced intentionally (e.g., microbeads) and MPs from degradation of macroplastics

- Effects information may be specific to a site, types of MPs, etc
Determine MP Exposure: What factors affect MP exposure to receptors of interest?

Direct exposure:
Ingestion of MPs in water column and sediments

Fate of MPs depends on relative density of MP—lighter ones float while heavier ones may accumulate in sediments
Physico-chemical properties of MPs can influence which type of MPs are available for uptake.

Lambert et al 2017 IEAM 13: 470-475
What do we know about exposure of MPs to biota?

Some types of flora and fauna have been studied more than others; data gaps

de Sa et al

Science of the Total Environment 645 (2018) 1029-1039
Ingestion of microplastics by fish: what’s the appropriate size range? Jovanovic IEAM 2017 13:510-515

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample size (nr of fish examined)</th>
<th>Fish with microplastics in GI tract (%)</th>
<th>Average nr of particles per fish ± SD</th>
<th>Average nr of particles per fish only fish that ingested microplastics ± SD</th>
<th>Cutoff length of analyzed microplastics</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Pacific Gyre</td>
<td>670</td>
<td>35</td>
<td>2.1 ± 5.78</td>
<td>5.88 ± n.d</td>
<td>N/A</td>
</tr>
<tr>
<td>North Pacific Gyre</td>
<td>141</td>
<td>9.2</td>
<td>0.11 ± n.d</td>
<td>1.15 ± n.d</td>
<td>&gt;700 μm</td>
</tr>
<tr>
<td>English Channel</td>
<td>504</td>
<td>36.5</td>
<td>0.7 ± n.d</td>
<td>1.9 ± 0.1</td>
<td>N/A</td>
</tr>
<tr>
<td>North Sea</td>
<td>1203</td>
<td>2.6</td>
<td>N/A</td>
<td>N/A</td>
<td>200 μm–5 mm</td>
</tr>
<tr>
<td>North and Baltic Sea</td>
<td>290</td>
<td>5.5</td>
<td>0.08 ± n.d</td>
<td>1.44 ± n.d</td>
<td>500 μm–5 mm</td>
</tr>
<tr>
<td>North and Baltic Sea</td>
<td>406</td>
<td>23</td>
<td>0.24 ± n.d</td>
<td>N/A</td>
<td>100 μm–5 mm</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>535</td>
<td>8.2–10.4</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Australia and Southern Ocean</td>
<td>342</td>
<td>0.3</td>
<td>0.01 ± n.d</td>
<td>2 ± n.d</td>
<td>&gt;330 μm</td>
</tr>
<tr>
<td>South Africa urban harbor</td>
<td>70</td>
<td>73</td>
<td>3.8 ± 4.7</td>
<td>5.1 ± n.d</td>
<td>N/A, measured 200 μm–15 mm</td>
</tr>
<tr>
<td>Tokyo Bay</td>
<td>64</td>
<td>77</td>
<td>2.34 ± 2.5</td>
<td>3.06 ± n.d</td>
<td>&gt;200 μm</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>761</td>
<td>11</td>
<td>0.13 ± n.d</td>
<td>1.2 ± 0.54</td>
<td>250 μm–5 mm 6% &gt;5 mm</td>
</tr>
<tr>
<td>Norwegian coast</td>
<td>302</td>
<td>3</td>
<td>0.05 ± n.d</td>
<td>1.77 ± n.d</td>
<td>N/A, measured 3.2–41.7 mm</td>
</tr>
<tr>
<td>Coast of Portugal</td>
<td>263</td>
<td>19.8</td>
<td>0.27 ± 0.63</td>
<td>1.4 ± 0.66</td>
<td>N/A</td>
</tr>
<tr>
<td>Adriatic Sea</td>
<td>125</td>
<td>28</td>
<td>0.39 ± n.d</td>
<td>1.39 ± n.d</td>
<td>&lt;5 mm</td>
</tr>
<tr>
<td>Balearic Islands, Mediterranean</td>
<td>337</td>
<td>58</td>
<td>2.17 ± n.d</td>
<td>3.75 ± 0.25</td>
<td>&lt;5 mm–5 mm</td>
</tr>
<tr>
<td>Spain, Atlantic and Mediterranean</td>
<td>212</td>
<td>17.5</td>
<td>0.27 ± n.d</td>
<td>1.56 ± 0.5</td>
<td>N/A measured 0.38–3.1 mm</td>
</tr>
<tr>
<td>Italy, Mediterranean</td>
<td>121</td>
<td>18.2</td>
<td>0.24 ± n.d</td>
<td>1.32 ± n.d</td>
<td>N/A measured 0.63–164.50 mm</td>
</tr>
<tr>
<td>Turkey, Mediterranean</td>
<td>1337</td>
<td>58</td>
<td>1.36 ± n.d</td>
<td>2.36 ± n.d</td>
<td>26 μm–5 mm</td>
</tr>
</tbody>
</table>
MPs in fish: Function of relative abundance or feeding behavior?

Figure 3. Types of plastics recovered from digestive tracts of Japanese anchovy (Engraulis japonicus).
(a) Percentage by shape. (b) Percentage by polymer.

Tanaka and Takada 2016, Scientific RepoRts | 6:34351 | DOI: 10. 1038 / srep34351
Rainbow fish PBDE concentration after exposure to food only, clean microbeads (MBs), MBs spiked with PBDEs, and PBDE concentration on sorbed MBs


MPs a vector of contaminant exposure to aquatic life?
How important is indirect exposure of MPs?

Uptake of MPs from food items; trophic transfer
Trophic transfer of MPs a critical pathway?

Evidence that seals obtained MPs from ingesting fish that had accumulated MPs

Number of particles per scat subsample - seals

Nelms et al. 2018

Environmental Pollution 238 (2018) 999–1007
What Do We Know About MP Effects on Biota?
Studies have examined effects of different MP types, locations, and type of species

de Sa et al
Physical effects well described for some fish species – particularly larval stages, icthyoplankton

- Starvation due to MP blockages in gut
- Mobility effects – reduced predator avoidance
- Consumption of MPs over actual prey, reduction in feeding performance
- Apparent satiation from ingestion of MPs but lack of nutrition – poor growth, eventual death
- Intestinal perforations, ulcerations, and other mechanical injuries from sharp MP objects
European perch growth with polystyrene MP exposure

Lönnstedt* and Eklöv, 2016, Science: 352
Effects of polystyrene MP on European perch survival

Lönnstedt* and Eklöv, 2016, Science: 352
Behavioral effects

European perch activity and movement in response to polystyrene MP exposure

Fig. 1. Fish behavior when exposed to polystyrene microplastic particles. Mean (±SE) number of (A) lines crossed (a measure of activity), (B) total distance moved (mm), and (C) total time spent inactive (s) for 10-day-old *P. fluviatilis* were affected by microplastic concentration (control, average, or high).

Lönnstedt* and Eklöv, 2016, Science: 352
Toxicological effects of MPs?

Studies suggest effects of different MPs with adsorbed metals, PCBs, pharmaceuticals, pesticides, endocrine disrupting compounds; But jury still out

de Sa et al

Risk Characterization: Integrating Exposure and Effects

Challenging to characterize risks without clear effects thresholds of MPs

May be more tractable if focus on effects of particular types and size range of MPs using controlled lab and field studies
Path forward using ERA framework

• Set spatial/geographic boundaries for the ERA
  ▪ Chesapeake Bay?
  ▪ Potomac estuary?

• Identify assessment endpoints
  ▪ Striped bass population characteristics?
  ▪ Blue crab populations?
  ▪ Oyster populations?
  ▪ Others?
Path forward using ERA framework

• Which measures of MP exposure and effect can be compiled and analyzed fairly readily based on existing monitoring information for desired assessment endpoints?

• How well do the data and measures reflect the assessment endpoint?

• What resources are needed (new studies, funding) to obtain desired measures of exposure and effect?
Critical Data Gaps and Uncertainties from an ERA Perspective
What are some of the critical questions/unknowns?

- What is the true exposure of aquatic organisms to MPs?
- Are the size fractions of MPs usually being sampled appropriate from an ecological exposure and effects view? What is the occurrence and potential effects of MPs smaller than 300 microns?
- Are adverse effects on aquatic biota possible at concentrations found in worst-case scenarios?
- Can metals and trace organic compounds adsorbed to MPs be a risk concern, given their concentrations in nature and chemical uptake rates?

From G.A. Burton WERF White Paper 2017
Challenges ahead

- No standard methods exist for sampling and quantifying MPs, making it difficult to compare studies or reliably predict exposure, effects, hazards, or risks.
- Improved MP exposure models for effluent discharges and other sources into receiving waters are needed to predict whether MPs may be a stressor of concern.
- Measurement methods for MPs vary significantly and there is no universal protocol for sample preparation, which can make results difficult to compare.
- Much of the effects information for MPs stems from direct exposure studies; indirect effects due to trophic transfer have been less explored.
- Need more information relating organismal effects of MPs to population level consequences
Thank You!

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