The risk assessment of microplastics using the Bayesian network relative risk model-San Francisco Bay

Wayne G. Landis, Emma Sharpe
Institute of Environmental Toxicology and Chemistry
Western Washington University
Huxley College of the Environment, Bellingham, WA
email:landis@wwu.edu

In collaboration with Diana Lin
San Francisco Estuary Institute
Outline for the talk

1. Microplastics as an interesting and ubiquitous stressor
2. Modern risk assessment using Bayesian networks
3. San Francisco Bay example
4. Application to the Chesapeake Bay
Microplastics as an interesting and ubiquitous stressor

- A variety of compositions
- A variety of sizes
- Many different shapes and sizes
- Can be found in mixtures in the environment with other plastic materials, chemicals and biologicals

SEM-Jared Stine, OSU

Tire materials
Polyacetic acid
Polystyrene
Low Density Polyethylene

5µm
E. coli 1-2 µm
Special series in the January issue of Integrated Environmental Assessment and Management-10 papers.

Integrated Environmental Assessment and Management — Volume 00, Number 00—pp. 1–16
Received: 12 June 2019  Returned for Revision: 17 July 2020  Accepted: 23 September 2020

Special Series

The Origin, Development, Application, Lessons Learned, and Future Regarding the Bayesian Network Relative Risk Model for Ecological Risk Assessment

Wayne G Landis*†
†Institute of Environmental Toxicology and Chemistry, Huxley College of the Environment, Western Washington University, Bellingham, Washington, USA
The basic methods of the Bayesian network relative risk model have been demonstrated in a variety of cases.
Modern risk assessment using Bayesian networks

Directed Acyclic graph-left to right-some draw them vertical.

Bayesian networks (BN) are directed acyclic graphs
Bayesian Networks (BNs)-even shorter introduction-

Parent Nodes

Effect 1
Effect 2

Impact

Child Node

The result in the child node is determined by a conditional probability table (CPT).
Bayesian Networks (BNs)-short introduction

Bayesian networks are Directed Acyclic Graphs (DAGs) that represent relationships between variables.

Source $\rightarrow$ Stressor $\rightarrow$ Habitat $\rightarrow$ Effect $\rightarrow$ Impact

In other words cause-effect pathways also known as conceptual models.
It does get more involved—an example from Landis et al 2020.

Pesticides and water quality with Chinook salmon as an endpoint.

**Conceptual model of cause and effect**

**The BN that describe and quantifies the predictions**
This is a diagram of the basic risk assessment approach, the boxes are nodes, and the arrows are the cause-effect interactions. The functions describe how the probability distributions for each node interact and result in an estimate of risk to valued ecological services (impacts).

History and details reviewed in Landis (2021)
The generic marine conceptual model

Straw-man Conceptual Model for Microplastics-Marine/Estuarine

**Sources**
- Land use types
  - Agriculture
  - Residential
  - Commercial
  - Industrial
- Transportation
- Effluents
  - Wastewater and Industrial treatment
- Waste Disposal dumping
  - historical or current
- Shipboard dumping
  - Commercial
  - Military
  - Recreational
- Long-range transport
  - Tsunami events
  - Atmospheric transport
  - Transportation
  - Large rivers

**Stressors**
- Plastics
  - Defining and classifying multiple types and size ranges
  - Physical interactions, interference,
  - Plasticizers and other materials composing the plastic
  - Absorbed materials from use as containers
- Tire Particles from Roads and Stormwater
- Absorbed or Adsorbed environmental pollutants
  - Metals
  - PCBs, PDBEs, PFOSs, Dioxins and furans, EDCs
  - Pharmaceuticals
  - Antibiotics
- Invasive species
  - Bacteria-virus
  - Protists
  - Fungi
  - Emergent Diseases
  - Spores/resistant forms

**Habitat/Location**
- Marine gyres
  - North Atlantic Gyre
  - North Pacific Gyre
- Estuaries
  - Puget Sound
  - Chesapeake Bay
  - San Francisco Bay
  - Newport
- Coastal Ocean
  - Gulf of Mexico
  - English Channel
  - Salish Sea
  - Pacific Coast
  - Black Sea
- Urbanized Embayments
  - Boston Harbor
  - Portland
  - Tokyo Bay
  - Antwerp
  - Pearl Harbor
  - San Diego

**Effects**
- Habitat Effects
  - Loss of production
- Fish/Mammals/Birds
  - Direct effects - egg, larval, adult mortality
  - Indirect effects - behavioral, sensory, neurotoxicity, immuno-suppression, disease, change in age structure, species abundance and diversity, trophic structure and function
- Community Structure
  - Invertebrate community structure, change in phytoplankton biomass, change in trophic transfer of nutrients/energy
- Bioconcentration/Biomagnification
  - Tissue contamination
  - Trophic transfer:

**Impacts**
- Ecological Services including but not limited to:
  - Water quality, quantity, fishability, swimability
- Species
  - Key invertebrate, fish, reptiles, mammals and birds
- Fisheries
  - Key species
  - Suitability for human consumption
- Recreational uses
  - Fisheries
  - Hunting
  - Boating
  - Park Activities
  - Swimming
  - Picnicking
  - Boating, canoeing
  - Sunbathing
- ESA Listed Species
San Francisco Bay Microplastic risk assessment teaming with SFEI

A case study is very useful. Ours is the San Francisco Bay. It is broken into 12 risk regions based on land use, drainages, and characteristics of the marine system.
Site-specific San Francisco Bay Microplastic Risk Assessment structure.

<table>
<thead>
<tr>
<th>Source</th>
<th>Stressor</th>
<th>Habitat</th>
<th>Effect</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation (roadways, bikes, etc.)</td>
<td>Microplastics (0.1 μm - 5 mm)</td>
<td>Water Column (Depth profile)</td>
<td>Acute toxicity (Short-term exposure)</td>
<td>Pacific Herring (Clupea pallasii)</td>
</tr>
<tr>
<td>Stormwater runoff (Storm drains)</td>
<td>Nano plastics (&lt; 0.1 μm)</td>
<td>Subtidal</td>
<td>Chronic toxicity (Longer-term exposure)</td>
<td>Chinook Salmon (Oncorhynchus tshawytscha)</td>
</tr>
<tr>
<td>Soils/dumps (Fishing nets, primary plastics, etc.)</td>
<td>Tire Wear Particles (Chemical composition resembling tires)</td>
<td>Tidal</td>
<td>Alteration of habitat (Changes to critical habitat)</td>
<td>Olympia Oyster (Ostrea lurida)</td>
</tr>
<tr>
<td>Wastewater treatment plant (effluent, sludge, etc.)</td>
<td></td>
<td></td>
<td>Trophic transfer (Transfer along the food web)</td>
<td></td>
</tr>
<tr>
<td>Agriculture (Sewage sludge, slow-release fertilizers)</td>
<td></td>
<td></td>
<td>Bioaccumulation/biomagnification (accumulation within organism)</td>
<td></td>
</tr>
<tr>
<td>Atmospheric deposition (Precipitation, ambient particulates)</td>
<td></td>
<td></td>
<td>Indirect Effects (e.g. reduction in food source, etc.)</td>
<td></td>
</tr>
<tr>
<td>Freshwater tributaries (Creeks, rivers, Delta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A wide arrange of sources of micro and nanoplastics- and tires
## Site-specific San Francisco Bay Microplastic Risk Assessment

<table>
<thead>
<tr>
<th>Source</th>
<th>Stressor</th>
<th>Habitat</th>
<th>Effect</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation (roadways, bikes, etc.)</td>
<td>Microplastics (0.1 µm - 5 mm)</td>
<td>Water Column (Depth profile)</td>
<td>Acute toxicity (Short-term exposure)</td>
<td>Pacific Herring (<em>Clupea pallasii</em>)</td>
</tr>
<tr>
<td>Stormwater runoff (Storm drains)</td>
<td>Nano plastics (&lt; 0.1 µm)</td>
<td>Subtidal</td>
<td>Chronic toxicity ( Longer-term exposure)</td>
<td>Chinook Salmon (<em>Oncorhynchus tshawytscha</em>)</td>
</tr>
<tr>
<td>Soils/dumps (Fishing nets, primary plastics, etc.)</td>
<td>Tire Wear Particles (Chemical composition resembling tires)</td>
<td>Tidal</td>
<td>Alteration of habitat (Changes to critical habitat)</td>
<td>Olympia Oyster (<em>Ostrea lurida</em>)</td>
</tr>
<tr>
<td>Wastewater treatment plant (effluent, sludge, etc.)</td>
<td></td>
<td></td>
<td>Trophic transfer (Transfer along the food web)</td>
<td></td>
</tr>
<tr>
<td>Agriculture (Sewage sludge, slow-release fertilizers)</td>
<td></td>
<td></td>
<td>Bioaccumulation/ biomagnification (accumulation within organism)</td>
<td></td>
</tr>
<tr>
<td>Atmospheric deposits (Precipitation, ambient particulates)</td>
<td></td>
<td></td>
<td>Indirect Effects (e.g. reduction in food source, etc.)</td>
<td></td>
</tr>
<tr>
<td>Freshwater tributaries (Creeks, rivers, Delta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Shorthand for a large number of materials that have in common being of plastic**
### Site-specific San Francisco Bay Microplastic Risk Assessment

E. Sharpe presentation with discussion on Thursday.

<table>
<thead>
<tr>
<th>Source</th>
<th>Stressor</th>
<th>Habitat</th>
<th>Effect</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation (roadways, bikes, etc.)</td>
<td>Microplastics (0.1 µm - 5 mm)</td>
<td>Water Column (Depth profile)</td>
<td>Acute toxicity (Short-term exposure)</td>
<td>Pacific Herring (Clupea pallasii)</td>
</tr>
<tr>
<td>Stormwater runoff (Storm drains)</td>
<td>Nano plastics (&lt; 0.1 µm)</td>
<td>Subtidal</td>
<td>Chronic toxicity (Longer-term exposure)</td>
<td>Chinook Salmon (Oncorhynchus tshawytscha)</td>
</tr>
<tr>
<td>Soils/dumps (Fishing nets, primary plastics, etc.)</td>
<td>Tire Wear Particles (chemical composition resembling tires)</td>
<td>Tidal</td>
<td>Alteration of habitat (Changes to critical habitat)</td>
<td>Olympia Oyster (Ostrea lurida)</td>
</tr>
<tr>
<td>Wastewater treatment plant (effluent, sludge, etc.)</td>
<td></td>
<td></td>
<td>Trophic transfer (Transfer along the food web)</td>
<td></td>
</tr>
<tr>
<td>Agriculture (Sewage sludge, slow-release fertilizers)</td>
<td></td>
<td></td>
<td>Bioaccumulation/biomagnification (accumulation within organism)</td>
<td></td>
</tr>
<tr>
<td>Atmospheric deposition (Precipitation, ambient particulates)</td>
<td></td>
<td></td>
<td>Indirect Effects (e.g. reduction in food source, etc.)</td>
<td></td>
</tr>
<tr>
<td>Freshwater tributaries (Creeks, rivers, Delta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where in the San Francisco Bay—there is also a map
### Site-specific San Francisco Bay Microplastic Risk Assessment-E. Sharpe presentation with discussion on Thursday.

<table>
<thead>
<tr>
<th>Source</th>
<th>Stressor</th>
<th>Habitat</th>
<th>Effect</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Microplastics (0.1 µm - 5 mm)</td>
<td>Water Column</td>
<td>Acute toxicity (Short-term exposure)</td>
<td>Pacific Herring (Clupea pallasii)</td>
</tr>
<tr>
<td>Stormwater runoff</td>
<td>Nano plastics ( &lt; 0.1 µm)</td>
<td></td>
<td>Chronic toxicity (Longer-term exposure)</td>
<td>Chinook Salmon (Oncorhynchus tshawytscha)</td>
</tr>
<tr>
<td>Soils/dumps</td>
<td>Tire Wear Particles (Chemical composition resembling tires)</td>
<td></td>
<td>Alteration of habitat (Changes to critical habitat)</td>
<td>Olympia Oyster (Ostrea lurida)</td>
</tr>
<tr>
<td>Wastewater treatment plant</td>
<td></td>
<td>Tidal</td>
<td>Trophic transfer (Transfer along the food web)</td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
<td></td>
<td>Bioaccumulation/biomagnification (accumulation within organism)</td>
<td></td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td></td>
<td></td>
<td>Indirect Effects</td>
<td></td>
</tr>
<tr>
<td>Freshwater tributaries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Effects seem the easiest but determining exposure-response is a challenge.
## Site-specific San Francisco Bay Microplastic Risk Assessment-E. Sharpe presentation with discussion on Thursday.

<table>
<thead>
<tr>
<th>Source</th>
<th>Stressor</th>
<th>Habitat</th>
<th>Effect</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong> (roadways, bikes, etc.)</td>
<td>Microplastics (0.1 µm - 5 mm)</td>
<td><strong>Water Column</strong> (Depth profile)</td>
<td><strong>Acute toxicity</strong> (Short-term exposure)</td>
<td><strong>Pacific Herring</strong> (<em>Clupea pallasii</em>)</td>
</tr>
<tr>
<td><strong>Stormwater runoff</strong> (Storm drains)</td>
<td>Nano plastics (&lt; 0.1 µm)</td>
<td><strong>Subtidal</strong></td>
<td><strong>Chronic toxicity</strong> (Longer-term exposure)</td>
<td><strong>Chinook Salmon</strong> (<em>Oncorhynchus tshawytscha</em>)</td>
</tr>
<tr>
<td><strong>Soils/dumps</strong> (Fishing nets, primary plastics, etc.)</td>
<td><strong>Tire Wear Particles</strong> (chemical composition resembling tires)</td>
<td><strong>Tidal</strong></td>
<td><strong>Alteration of habitat</strong> (Changes to critical habitat)</td>
<td><strong>Olympia Oyster</strong> (<em>Ostrea lurida</em>)</td>
</tr>
<tr>
<td><strong>Wastewater treatment plant</strong> (effluent, sludge, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Agriculture</strong> (Sewage sludge, slow-release fertilizers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Atmospheric deposition</strong> (Precipitation, ambient particulates)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Freshwater tributaries</strong> (Creeks, rivers, Delta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Endpoints determined by a diverse set of stakeholders.
Focus is on the description of the stressor portion of the conceptual model and some implication for estimating effects.
Stressor Characteristics—we are now treating Tire Wear Particles as a distinct category.
Microplastic distribution in San Francisco Bay
Type of microplastic

SEFI data-Diana Lin
Dataset compilation – Skyler Elmstrom
Plots-Emma Sharpe
Microplastic distribution in San Francisco Bay
Morphology
SEFI data-Diana Lin
Dataset compilation – Skyler Elmstrom
Plots-Emma Sharpe
Other contaminants exist and may interact as a component or in concert.

<table>
<thead>
<tr>
<th>Contaminant Name</th>
<th>Concentration Measurement Count</th>
<th>Max Concentration (ppb)</th>
<th>Exceedances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diazinon</td>
<td>5699</td>
<td>331</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>4105</td>
<td>9.4</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Malathion</td>
<td>1013</td>
<td>46</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Azinphos-methyl</td>
<td>151</td>
<td>6.53</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Dimethoate</td>
<td>968</td>
<td>16.4</td>
<td>IC</td>
</tr>
<tr>
<td>Dichlorvos</td>
<td>171</td>
<td>4.88</td>
<td>IA, IC</td>
</tr>
<tr>
<td>Methidathion</td>
<td>347</td>
<td>15.1</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Naled</td>
<td>59</td>
<td>8.24</td>
<td>FC, IA, IC</td>
</tr>
<tr>
<td>Phorate</td>
<td>133</td>
<td>3.5</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Imidacloprid</td>
<td>1094</td>
<td>165</td>
<td>IA, IC</td>
</tr>
<tr>
<td>Bifenthrin</td>
<td>1360</td>
<td>5.63</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Cyfluthrin</td>
<td>545</td>
<td>3.4</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Esfenvalerate</td>
<td>275</td>
<td>3.48</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>lambda-Cyhalothrin</td>
<td>403</td>
<td>1.61</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Permethrin</td>
<td>723</td>
<td>180.9</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Deltamethrin</td>
<td>208</td>
<td>62.3</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Cypermethrin</td>
<td>249</td>
<td>2.37</td>
<td>FA, FC, IA, IC</td>
</tr>
<tr>
<td>Fipronil</td>
<td>772</td>
<td>2.11</td>
<td>IA, IC</td>
</tr>
<tr>
<td>Fipronil Sulfide</td>
<td>74</td>
<td>0.26</td>
<td>IA</td>
</tr>
</tbody>
</table>

1 This includes all the concentration measurements recorded over zero. This does not take into account the level of quantification or the method detection level and is meant to serve only as a preliminary relative concentration count.

2 The maximum recorded concentration for each pesticide.

3 Using the EPA's aquatic life benchmarks for pesticides, if the max concentration was above any of the benchmarks it is notated as follows: IA = Invertebrate Acute, IC = Invertebrate Chronic, FA = Fish Acute, FC = Fish Chronic
Microplastics, Chesapeake Bay and risk assessment

1. Build spatially explicit conceptual models

2. The risk assessment process will point out the critical variables and identify data needs

3. Risk assessment as part of an adaptive management decision making process.
The goal is to manage ecological structures

Wyant, Meganck, Ham 1995

Long-time ago but understood that the systems were non-equilibrium and dynamic.

Wyant et al 1995
Adaptive Management and Risk Assessment

Adaptive Management and the applications of quantitative tools.

The LOOP

Ecological risk assessment:

- Inputs describing the potential outcomes from the remediation with measurements (monitoring)
- Estimates of risk to multiple endpoints across the management region.

Management and remediation options:

Decision making
Wayne Landis landis@wwu.edu
Emma Sharpe sharpee@wwu.edu
Website https://wp.wwu.edu/toxicology/

Twitter: @pnwmicroplastic
Instagram: @pnwmicroplastics
LinkedIn: Pacific Northwest Consortium on Plastics
YouTube: PNW Consortium on Plastics
Website: pnwmicroplastics.org

National Science Foundation Growing Convergence Research Big Idea - Grants #1935028 and #1935018