Toxicology 101: Toxics and the Environment

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Topics to Be Covered

- Entry into the environment, persistence, and toxicity of:
  - polychlorinated biphenyls (PCBs)
  - dioxins and furans
  - Mercury (Hg)
  - pesticides
How Do Pollutants Find the Water?
Gas Exchange and Mass Balance

TOTAL AMOUNT THAT ENTERS LAKE = RAIN/SNOW + PARTICLES + ABSORPTION - VOLATILIZATION
Sediment Resuspension

Dredging

Shipping

Storms

Biotic Disturbance

EPA GLNPO, 2008
Food Chains and Food Webs

- **Food Chain** – sequence of organisms through which nutrients and energy move

- **Food Web** – series of interconnected food chains in an ecosystem
Food Chains

Though energy makes a one-way passage through ecosystems, essential nutrients, such as phosphorus (P), may be recycled.
Ecological Food Chains/Pyramids

- Most ecosystems have huge number of primary producers supporting a smaller number of herbivores, supporting a smaller number of secondary consumers
  - Second law of thermodynamics.
  - Ecosystems not 100% efficient.
  - 10% Rule
Food chains are not isolated units but are hooked together into **food webs**.
Why These Substances?

- Identified as having high potential to be:
  - Persistent
  - Bioaccumulative
  - Toxic

- Easily move between media

- Threat to human health and wildlife
“Persistent” defined by the International Joint Commission as having a half-life of eight weeks or greater

- Half-life = the amount of time that must elapse for the quantity of a sample to be reduced by 50%

- Resistant to degradation processes that transform “parent compound” to other, usually less toxic, substances
  - Biological requires microorganisms
  - Chemical includes hydrolysis, photolysis, and oxidation
PCBs in Great Lakes Fish

L. Mich
$t_{1/2} = 3.1$
$C_{min} = 1.9$

Slide courtesy GLFMP and Ron Hites, Indiana University
Lake Stratification

- Also known as “layering”, this phenomenon reduces mixing/dispersion, forcing pollutants to concentrate near the shoreline.
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Bioaccumulation

- “Bioaccumulative” – general term referring to potential for a substance to be stored (accumulate) in tissue
- Uptake from environment, food, and water
- Quantified through BAF
  - Ratio of amount in tissue to amount in ambient water where organism and food are exposed
  - “Bioconcentration” refers to water intake only
Michigan’s “BCCs”

- “Bioaccumulative Chemical of Concern”
- BAF greater than 1000
- Half-life not less than eight weeks
Michigan’s “BCCs” (cont’d)

- Chlordane
- **DDT/ DDE/ DDD**
- Dieldrin
- Hexachlorobenzene
- Hexachlorobutadiene
- Hexachlorocyclohexanes
- Lindane
- **Mercury**
- Mirex/Photomirex
- Octachlorostyrene
- PCBs
- Pentachlorobenzene
- **2,3,7,8-TCDD**
- 1,2,3,4-tetrachlorobenzene
- 1,2,4,5-tetrachlorobenzene
- Toxaphene
The Problem

BIOMAGNIFICATION!

4,800,000 ppt

???

690,000 ppt

98,000 ppt

14,000 ppt

2,000 ppt

0.10 ppt

ppt = parts per trillion (mercury concentration)

Slide courtesy USGS
Biomagnification of PCBs

LAKE ONTARIO BIOMAGNIFICATION OF PCBs

Mysis 45,000×

Phytoplankton 200×

Zooplankton 500×

Small 35,000×

Lake trout 2,800,000×

Herring gull 25,000,000×

www.pollutionissues.com/A-Bo/Bioaccumulation.html

EPA GLNPO, 2008
Biomagnification of Mercury

Source: New Jersey Mercury Task Force, January 2002
**Biomagnification**: Dramatic increase in the concentration of a chemical substance *in a food web* as it passes from lower trophic levels to higher trophic levels.

EPA, 2010
Why These Substances?

- Identified as having high potential to be:
  - Persistent
  - Bioaccumulative
  - **Toxic**

- Easily move between media
- Threat to human health and wildlife
Toxicity

- “Toxic” identifies ability for a substance to cause adverse effects
- “The dose makes the poison.” (Paracelsus)
- At a given exposure level
  - Will adverse effects occur?
  - What kinds of effects occur?
  - How severe/reversible are the effects?
PCBs

**Properties:**
- Synthetic organic compound
- Fat soluble
- Odorless
- Colorless
- Does not burn

**Uses:**
- Electrical industry – transformer oil
- Auto industry – hydraulic oil
- Paper industry – carbonless copy paper
- Agriculture – pesticide extender

- Banned in MI in 1976
- Banned nationally in 1979
Ecological Impacts of PCBs
PCBs in the Great Lakes

STATE OF THE LAKES

PCBs in Gull Eggs

Trends in average annual concentrations of PCBs in herring gull eggs at eight locations in the Great Lakes.

- indicates no data

PCBs in Fish

Lake Superior - Mean concentrations of PCBs (mg wet weight +/− standard error) in whole rainbow smelt and lake trout (age 4). Data were not available in consecutive years.

Lake Michigan - Mean concentrations of PCBs (mg wet weight +/− standard error) in whole Rainbow Smelt and Lake Trout (600-640 mm mean length). Data were not available in consecutive years.

Lake Huron - Mean concentrations of PCBs in whole rainbow smelt and walleye.

Lake Erie - Mean concentrations of PCBs (mg wet weight +/− standard error) in whole rainbow smelt and walleye.

Areas of Concern

The diamond symbol marks areas of concern. There are 43 Areas of Concern in the Great Lakes basin.

EPA GLNPO, 2008
Dioxins/Furans

- “Dioxins” are a group of 210 “congeners”, varying in number of chlorine atoms attached to rings.

- Term also used to describe family of chemicals (including some PCBs) with similar structure and mode of toxicity.

- 2,3,7,8-TCDD is most toxic.

- By-products of combustion and manufacturing of various chemicals.

- Effects in animals include:
  - Endocrine changes
  - Altered fetal development
  - Reduced reproductive capacity
  - Immunosuppression
Environmental Transfer of Dioxins

Diagram showing the transfer of dioxins among environmental reservoirs:

- **Sources** to **Import**
- **Food** to **Air**
- **Air** to **Export**
- **Soil** to **Water**
- **Water** to **Sediment**
- **Sediment** to **Deep Soil**

**Key:**
- **↓** = Flux
- **↑** = Depletion

EPA, 2006
Mercury

- Naturally occurring, element number 80
- Shiny silver liquid at room temperature
- Released during volcanic eruptions and through deep sea vents
- Used in early barometers, thermometers, sphygmomanometers, switches, dental amalgams, fluorescent lights
Environmental Cycling of Hg
Environmental Cycling of Hg
Formation of Methylmercury (MeHg)

http://www.pnas.org
Formation of MeHg
Formation of MeHg

Biogeochemical Cycle for Mercury

Formation of MeHg

http://www.genetics.uga.edu
Pesticides

- Both mimic estrogen
- DDT thinned shells of bird eggs, reproductive failure
- DDT banned in 1973 – credited with the “comeback” of the bald eagle
- Use of chlordane on food crops banned in 1978; all approved used terminated in 1988
Environmental Cycling of Pesticides

The pesticide cycle

- Degraded by ultra-violet light
- Deposited by rainfall
- Vaporized to atmosphere
- Absorbed by crop
- Leached below root zone by rain or irrigation
- Adheres to soil particles
- Degraded by bacterial oxidation or chemical hydrolysis
- Surface run off to lakes and rivers
- Leached to water courses
Tolerance Limits

- Minimum levels beyond which species cannot survive or reproduce
  - Many species have limits more critical for the young than the adults
Fish Contaminant Monitoring Program

- DNRE collects, processes, analyzes samples from 45 watersheds
  - PCBs
  - Dioxins and Furans
  - Chlorinated pesticides
  - Mercury
- Raw data and contact info available online at http://www.deq.state.mi.us/fcmp
Fish Contaminant Monitoring Program (cont’d)

- MDCH establishes trigger levels
- Publishes “Michigan Family Fish Consumption Guide”

- Additional information available online at:
  - [http://www.michigan.gov/mdch/1,1607,7-132-2944_5327-13110--,00.html](http://www.michigan.gov/mdch/1,1607,7-132-2944_5327-13110--,00.html)
  - [http://www.michigan.gov/mdch/0,1607,7-132-2945_5105_51514-200030--,00.html](http://www.michigan.gov/mdch/0,1607,7-132-2945_5105_51514-200030--,00.html)
Herring Gull Egg and Bald Eagle Monitoring Programs
We’re All In This Together!

NOTE:
This is a simplified representation of the food web showing the main pathways. Food (energy) moves in the direction of the arrows. The driving force is sunlight. Depictions of the various organisms are not to scale.

EPA GLNPO, 2008