ENSC 201*
Environmental Toxicology and Chemical Risks

Biomagnification of chemicals in aquatic food webs: the Great Lakes example

pp 267-279; 274-287; 366-377; 400-401; Wright and Welbourn

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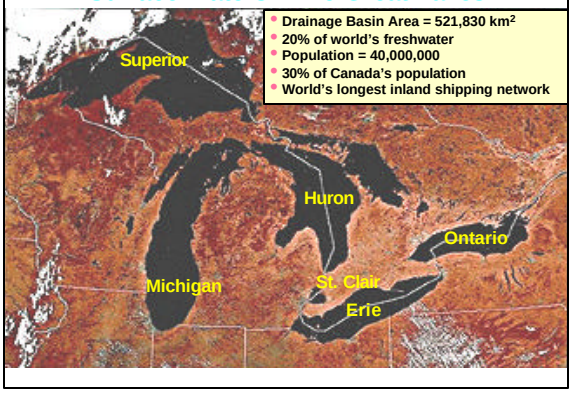
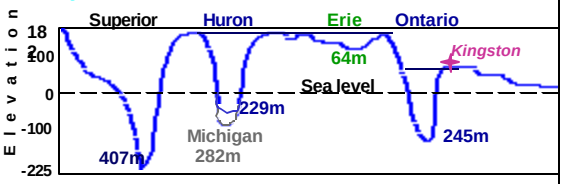
Surface Waters - The Great Lakes



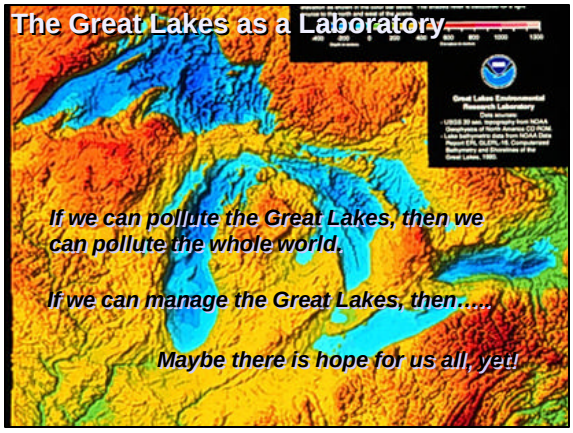
- Drainage Basin Area = 521,830 km^2
- 20% of world's freshwater
- Population = 40,000,000
- 30% of Canada's population
- World's longest inland shipping network

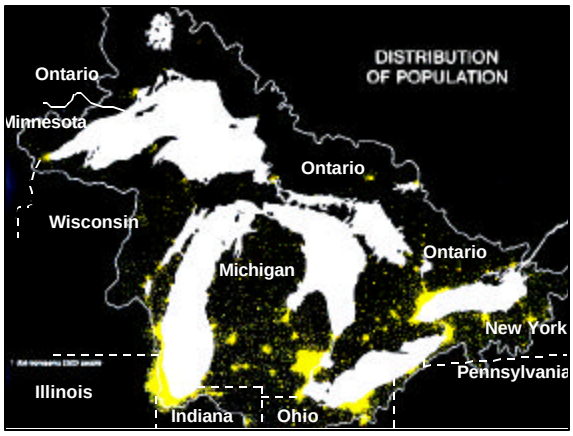
Physical Characteristics of the Great Lakes

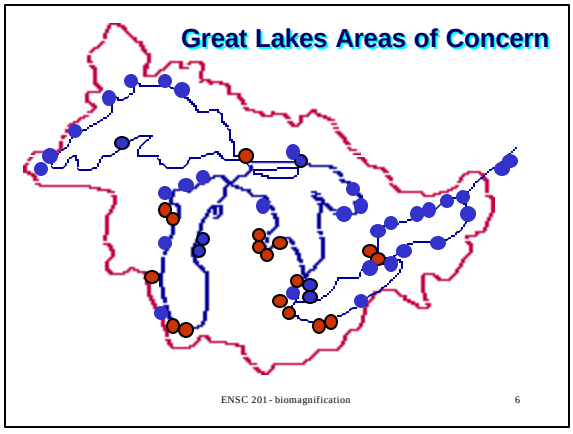


Lake	Area (km^2)	Mean Depth (m)	Volume (km^3)	Retention Time (yrs)
Superior	82100	147	12100	191
Michigan	57800	85	4920	99
Huron	59600	59	3540	22
Erie	25700	19	484	2.6
Ontario	18960	86	1640	6

- "Capital' vs `interest' (Fossil water)


The Great Lakes as a Laboratory
If we can pollute the Great Lakes, then we can pollute the whole world.
If we can manage the Great Lakes, then…..
Maybe there is hope for us all, yet!


DISTRIBUTION OF POPULATION
Ontario
Minnesota
Ontario
Wisconsin
Ontario
Michigan
New York
Pennsylvania
Illinois
Indiana
Ohio


Great Lakes Areas of Concern
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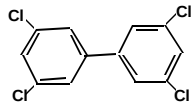
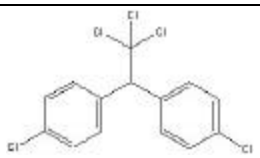
Organic Chemicals of Concern

- Pesticides
  - DDT; atrazine; TFM
- Industrial Chemicals
  - Acrylamides
- Hydrocarbons
  - Petroleum, Coal tar
- Persistent Organic Pollutants (POPs)
  - Dioxins, Furans, PCBs, PBDEs, DDT
- Volatile organic compounds (VOCs)
  - BTEX – Benzene, Toluene, Xylene
- Organometallics
  - methyl mercury
  - tetraethyllead
  - selenomethionine

POPS

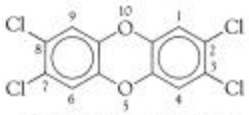


tetrachlorobiphenyl

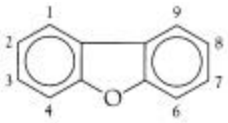


DDT
(dichlorodiphenyltrichloroethane)

- Other chlorinated pesticides:
  Toxaphene, Lindane, Chlordane, Dieldrin



2,3,7,8-tetrachlorodibenzo-p-dioxin
(2,3,7,8-TCDD)



dibenzofuran

POPS

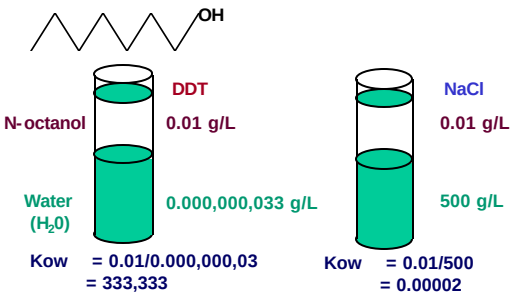
IMPORTANT CHEMICAL CHARACTERISTICS:

- Persistent (half-life of months or years)
- Bioconcentrate and Bioaccumulate
  (hydrophobic or lipophillic)
- *Highly Toxic*

Accumulation of toxic chemicals

- **Bioconcentration** – the extent to which concentrations of chemicals in organisms exceed their concentrations in the environment (one source only; lab exposures)
  - Bioconcentration factor (BCF) = C_{tissue}/C_{water}
- **Bioaccumulation** – extent to which chemicals are retained
  - reflects persistence (multiple sources; field exposures)
  - net of: uptake – (excretion + metabolism)
  - Bioaccumulation factor (BAF) = C_{tissue}/C_{water}
- **Biomagnification** - increase of chemical concentrations at successively higher trophic levels (lipid soluble and persistent compounds)
  - Biomagnification factor (BMF) = $C_{predator}/C_{prey}$
- **Bioavailability** – the proportion of a chemical in the environment that can be taken up by an organism

Estimating Bioconcentration Factors



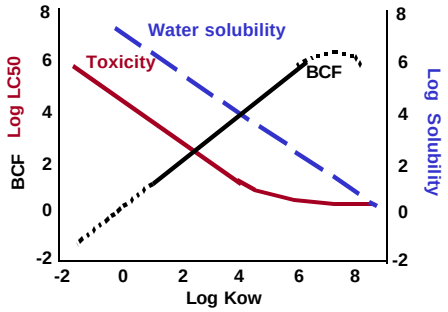
Kow = 0.01/0.000,000,03 = 333,333

Log Kow = 5.52

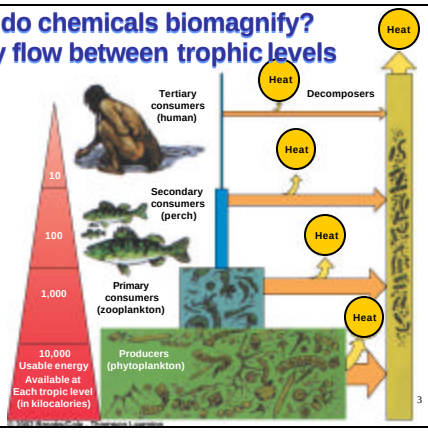
Kow = 0.01/500 = 0.00002

Log Kow = -4.69

Lipid solubility vs toxicity and water solubility



Why do chemicals biomagnify?
Energy flow between trophic levels



3

Biomagnification

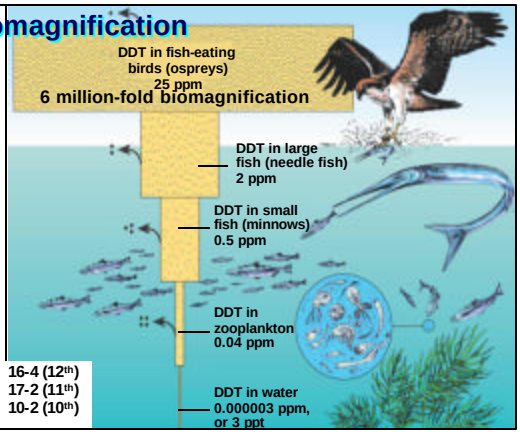


Fig. 16-4 (12th)
17-2 (11th)
10-2 (10th)

Energetics basis for biomagnification

$E_{in} = E_{maint} + E_{stored} + E_{digestion} + E_{excreted}$
(Heat) (Growth Reproduction) (faeces)

Gull: Conversion Efficiency for Energy (CE) = E_{stored} / E_{in} = 4 / 100 = 4.0%

PCB (pesticide): persistent, toxic, bioaccumulates

$PCB_{in} = PCB_{stored} + PCB_{excreted}$

CE (PCB) = PCB_{stored} / PCB_{in} = 95%

BMF (PCB) = $Œ_{PCB} / Œ_{energy}$ = 95/4 = 23.8 x

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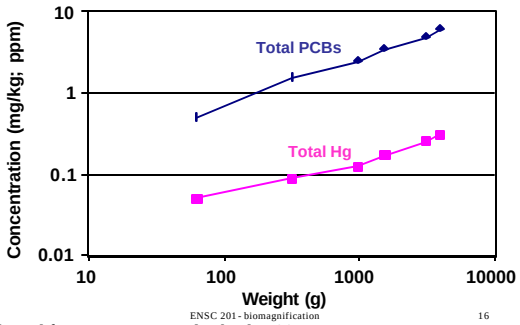
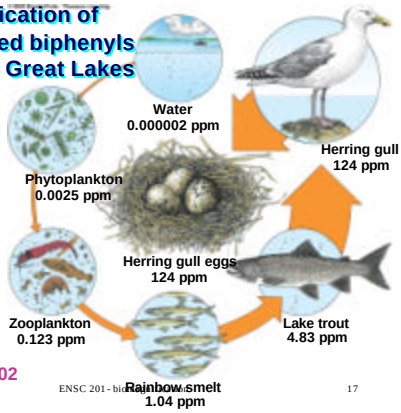
Effect of fish size on concentrations of PCBs and Hg in Lake trout



Adapted from Borgmann and Whittle 1991

Biomagnification of polychlorinated biphenyls (PCBS) in the Great Lakes



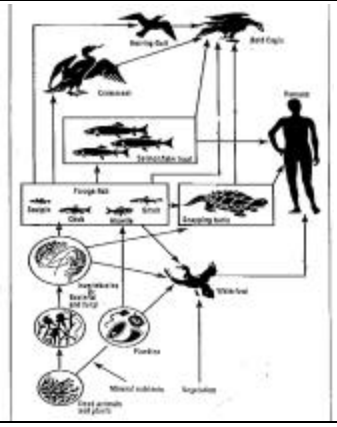
BMF $_{gull/trout}$
= 124/4.83
= 25.7

BAF $_{gull/water}$
= 124/0.000002
= 62,000,000

POPS

IMPORTANT ECOLOGICAL AND BIOLOGICAL CHARACTERISTICS:

- Diet and position in the food web (primary producer vs carnivore vs top predator)
- Numbers of trophic levels in an ecosystem
- Age, Size, and Fat content



Simplified Great Lakes food web

What are the consequences of Biomagnification?

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Consequences of biomagnification of POPS

Humans – impaired mental capacity

- infants (from mothers who eat Great Lakes fish)
  - learning & cognitive impairments
  - seems to persist through adolescence

Wildlife – impaired reproduction

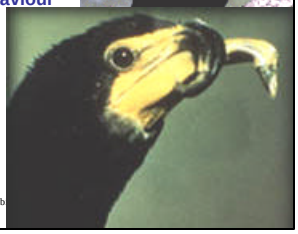
- Sexual Maturation of Adults
  - Endocrine disruption
- Embryotoxicity and Recruitment Failure
  - Deformities, hemorrhaging, edema
  - Induction of CYP1A enzymes

Fish Eating Mammals: Wasting Syndrome

- Mink, otters
- Reproductive Impairment
  - Changes in parental behaviour
  - Wasting Syndrome:
    - embryonic edema
    - haemorrhaging
    - deformities
    - thymic involution
    - reduced growth
    - CYP1A induction (Cytochrome P450 or mixed function oxygenase enzymes)
- Economic losses to mink ranchers
- Population crash??

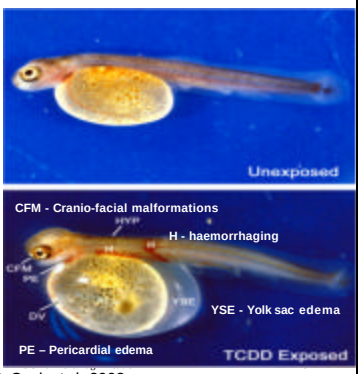
Fish Eating Birds: Chick Edema Disease

- Gulls, terns, cormorants, eagles, osprey, herons
- Reproductive Impairment
  - Egg shell thinning (DDT and related compounds)
  - Changes in nesting behaviour
  - Chick Edema Disease
    - embryonic edema
    - hemorrhaging
    - deformities
    - CYP1A induction
- Population crash



Fish: Blue Sac Disease

- Lake trout, rainbow trout, coho salmon, chinook salmon, and many others
- Blue Sac Disease:
  - embryonic edema
  - hemorrhaging
  - deformities
  - CYP1A induction (Receptor Mediated Toxicity?)
- Recruitment failure
- Population crash ☠ destruction of fisheries



Source: Wisconsin Sea Grant; Cook *et al*. 2003

Spatial and Temporal Trends

Geography as a modifier of exposure and impacts

- Upper Great Lakes vs Lower Great Lakes
- Fish migration, Tributaries, and Dams

Are things getting better??? – temporal trends

Suggested supplementary reading

Borgmann , U. and D.M. Whittle, 1991. Contaminant concentration trends in Lake Ontario lake trout (*Salvelinus namaycush*) - 1977 to 1988. J. Great Lakes Res. 17:368_381.

Bowerman WW, Best DA, Grubb TG, Zimmerman GM,Giesy J.P 1998. Trends of Contaminants and Effects in Bald Eagles of the Great Lakes Basin. Environmental Monitoring and Assessment 53 (1): 197_212

Bowerman WW, Giesy JPp , Best DA, et al., 1995. A Review of Factors Affecting Productiv ity of Bald Eagles in the Great_lakes Region _ Implications for Recovery. En vironmental Health Perspectives 103: 51_59 Suppl . 4

Cook, P.M. *et al.* 2003. Effects of aryl hydrocarbon receptor- mediated early life stage toxicity on lake trout populations during the 20th century. Environmental Science and Technology 37:3864-3877.

Giesy JP, Verbrugge DA,OthoutRA, et al. 1994. Contaminants in Fishes from Great_lakes_influenced Sections and Above Dams of 3 Michigan Rivers .1. Concentrations of Organo_Chlorine Insecticides, Polychlorinated_biphenyls, Dioxin Equivalents, and Mercury. Archives of Environmental Contamination and Toxicology 27 (2): 202_212

Giesy JP, Verbrugge DA,OthoutRA, et al. 1994. Contaminants in Fishes from Great Lakes_influenced Sections and Above Dams of 3 Michigan Rivers .2. Implications fo r Health of Mink. Archives of Environmental Contamination and Toxicology 27 (2): 213_223

Huestis , S. Y., M. R. Servos, D. M. Whittle and D. G. Dixon, 1996. Temporal and age_related trends in levels of polychlorinated biphenyl congeners andorganochlorine contaminants in Lake Ontario lake trout (*Salvelinus namaycush*). J. Great Lakes Res. 22:310_330.