Pollutants and Their Fate

- Fate: Once emitted, what does pollutant do?
  - Nothing...
  - Adversely impact human health
  - Adversely impact plants and animals (ecosystems)

- Ecotoxicology: the study of the harmful effects of chemicals on ecosystems
  - Deals with the emissions, transport, transformation, and effects on physical environment and species
  - "Ecology in the presence of toxicants"

- Pollutants enter ecosystems through discharges into the atmosphere, contamination of land, and entry into water.
Pollutants and Their Fate

- Chemical pollution has been linked to:
  - Decreased fertility in invertebrates, fish, reptiles, birds, and mammals
  - Toxicity
  - Decreased hatching success in fish, turtles, and birds
  - Abnormal glandular function in birds and mammals
  - Disruption
  - Feminization in males and masculinization in females in birds, fish, and invertebrates
  - Estrogen in water supplies (BCPs, HRTs)
  - Toddler girls, aggression, and bisphenol A in baby bottles (handout)

Table 5.1 Examples of Threatened or Endangered Animal Species

<table>
<thead>
<tr>
<th>Name</th>
<th>Group</th>
<th>Range</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>California condor</td>
<td>Birds</td>
<td>California, Arizona</td>
<td>Endangered</td>
</tr>
<tr>
<td>Whooping crane</td>
<td>Birds</td>
<td>North America</td>
<td>Endangered</td>
</tr>
<tr>
<td>Goliath grouper</td>
<td>Fish</td>
<td>Tropical oceans</td>
<td>Endangered</td>
</tr>
<tr>
<td>Whale shark</td>
<td>Fish</td>
<td>Worldwide</td>
<td>Threatened</td>
</tr>
<tr>
<td>Baboon</td>
<td>Mammals</td>
<td>Africa, Asia</td>
<td>Threatened</td>
</tr>
<tr>
<td>Chetah</td>
<td>Mammals</td>
<td>Africa, SW Asia</td>
<td>Endangered</td>
</tr>
<tr>
<td>American Alligator</td>
<td>Reptiles</td>
<td>SE USA</td>
<td>Threatened</td>
</tr>
<tr>
<td>Leatherback sea turtle</td>
<td>Reptiles</td>
<td>Worldwide</td>
<td>Endangered</td>
</tr>
</tbody>
</table>

See Table 5.1 in text for a more complete listing.

Problem Chemicals:

DDT (dichlorodiphenyltrichloroethane)

- A chlorinated hydrocarbon developed in the 1930s
- DDT was a very effective insecticide and did not easily degrade in the environment.
  - Effectiveness and persistence deemed very favorable aspects, thus worldwide usage
  - Very popular during World War II and instrumental in the reduction of typhoid and malaria
- Responsible for saving millions of lives (literally)
DDT Molecule

DDT (dichlorodiphenyltrichloroethane)

- Wide use in post WWII United States and abroad because of its cost-effectiveness
- Ubiquity = long-term detrimental effects?
- Rachel Carson’s *Silent Spring* (1962) fueled public opinion against DDT
- Subsequent experimental studies linked DDT to reproductive, teratogenic (effects embryo, fetus), neurological, and other effects
- Essentially banned in US in 1972

Unintended Consequence

- Increased incidence rate (until 2000)
  - Malaria infected 216 million people in 2011
  - 655,000 died in 2010 (mostly African kids)
- Most (except ardent anti-DDT activists) support *limited* reintroduction of DDT
  - The WHO backs this position
Problem Chemicals: Mercury

• “Minamata’s Disease”
  – Location: Minamata Bay region on the island of Kyushu, Japan
  – Problem: mystery illness recognized in 1956
  – Source: local plastics factory dumped mercury into the bay
  – Biotransformation: microbes + mercury = methyl mercury
  – Human exposure route: fish and shellfish consumption

Mercury, cont.

• Health endpoint: serious neurological problems identified (hundreds of cases)
  – Difficulty walking, swallowing, speaking, and hearing
  – Post mortem brain analysis revealed marked brain atrophy
  – Children born to expectant mothers who were exposed had a high rate of birth defects, including severe brain damage, mental impairment, and delayed development.
• Epidemiological investigation
  – Exposures to manganese and selenium (initial suspicions)
  – Mercury contamination proven following investigation

Pollutant versus Contaminant

• Pollutant: any chemical that produces or has the potential to produce actual environmental harm
• Contaminant: no implication of harm associated with its presence in a system
Pollution versus Contamination

- EPA Pollutant categories (some redundancy):
  - Agricultural Chemicals
  - Air Pollutants
  - Biological Contaminants
  - Carcinogens
  - Chemicals
  - Extremely Hazardous Substances
  - Microorganisms
  - Radiation
  - Soil Contaminants
  - Toxic Substances (Persistent Bioaccumulative Toxic Pollutants, Persistent Organic Pollutants)

Ecosystems and Compartments

- An ecosystem comprises populations and communities residing in a defined area.
  - They are aquatic (marine and freshwater) or terrestrial.
- Ecosystems can be viewed as being composed of a number of compartments:
  - An abiotic compartment (nonliving): contains air, water, soils, and sediments
  - A biotic compartment (living): composed of animal and plant life
  - We are concerned as toxicants move from one compartment to another

The Environment Viewed as Compartments and Ecosystems

- The Atmosphere
  - Fate of a Chemical in Air
- The Hydrosphere
- Soils
- The Biosphere
Atmosphere

• Composed of a number of layers:
  – Troposphere
  – Stratosphere
  – Mesosphere
  – Thermosphere

• Principal concern is the troposphere: surface — ~20 km

• Tropospheric air contains:
  – "Trace amounts" of CO, SO₂, H₂S, HNO₃, NH₃, HCHO, Pb, NOₓ, PM, and many others pollutants
  – Most of the atmospheric water
  – gases necessary to maintain life

• Stratosphere (20 – 50 km) also important
  – Why?

Atmospheric Fate

• Toxics Release Inventory (TRI): about half of atmospheric pollutants result from industrial discharges

• Pollutants reach the atmosphere directly or through transport from other compartments.
  – ___________ sources

• Airborne chemicals can enter into chemical reactions, such as oxidation and photolysis.
  – ___________ sources

• This ability to enter into chemical reactions results in the production of other pollutants.

Atmospheric Fate, cont.

• The fate of a chemical in the air depends on:
  – Input (e.g., rate, type of pollutant, source, etc.)
  – Dispersion (e.g., mixing from the wind and turbulence)
  – Transport (e.g., vertical and horizontal by wind)
  – Reactions and formation of secondary pollutants (e.g., chemical reactions such as oxidation and photolysis, and physical reactions such as absorption and adsorption)
  – Removal (e.g., through precipitation)

• Toxicology perspective
  – Cardio-respiratory problems
  – Acid deposition
The Hydrosphere

• Water covers approximately 70% of the surface of the earth.
• Cultures developed along oceans, rivers, and lakes.
  – More than 50% of the population of the United States resides in cities surrounding seaports and lakes.
• Inevitable contamination of waters from:
  – manufacturing plant discharges
  – accidental chemical spills
  – domestic sewage
  – agricultural, urban and rural runoff
  – atmospheric deposition

The Hydrosphere, cont.

• Chemical contaminants move within that medium because of water turbulence and diffusion.
• Toxicology perspective
  – Water-borne diseases, e.g., cholera
  – Water-contact diseases, e.g., schistosomiasis
  – Algal blooms
  – Fish kills

Soil

• Soil: complex mixture of organic matter, inorganic matter (e.g., silica and clay), water, and air.
• Extremely variable composition
  – Black/brown Iowa soil vs. red Georgia clay vs. Arizona sand
  – Farmland vs. urban soil
• Chemicals can be put into the soil directly by deliberate or unintentional means, or indirectly as the result of translocation from water and air.
  – Direct and deliberate: e.g., fertilizer, pesticides
  – Direct and unintentional: e.g., chemical leaks or spills.
Soil, cont.

- Toxicology perspective
  - Adverse impacts to food crops
  - Adverse impacts to groundwater supplies
  - Adverse impacts to surface water supplies (agricultural runoff)
  - Adverse impacts to burrowing animals

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Biosphere

- Plant/animal chemical exposure:
  - Direct absorption through the lungs, skin, or gills
  - Indirect through the consumption of food

- The direct absorption of chemicals from the environmental medium can result in bioaccumulation or bioconcentration.

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Biosphere, cont.

- Bioavailability of the chemical: that portion within the medium that is potentially available for direct uptake
  - If chemical is highly concentrated in sediment, bioavailability may be low to fish in the water column
  - Depends on many factors including sediment turbulence and the fish’s dependence for food from sedimentary organisms that enter the water column.
Biosphere, cont.

• A very lipophilic and environmentally persistent chemical such as DDT can be stored and accumulated in fatty tissue compartments. This is bioconcentration.

• The bioconcentration factor (BCF)

\[ \text{BCF} = \frac{\text{conc. in fish}}{\text{conc. in water}} \]

Toxicity in a Population

• The toxicity of chemicals on a population depends on many factors.

• Ecosystems are complex and made up of a multitude of animals and plants. The level of effect(s) of any chemical, on any one particular population of species, may be different from another in that community.

Toxicity in a Population, cont.

• Toxicity depends on many factors:
  – Species
  – Age
  – Gender
  – Exposure route
  – Form and activity of the chemical
  – Concentration or dose
  – Bioavailability
  – Primary route of exposure
  – Ability to be absorbed
  – Metabolism
  – Distribution within the body
  – Excretion
  – Presence of other chemicals
Factors affecting population growth

Graphical representation of the majority of responses to toxic insult

Case Study #1 “Mary Beth”

Risk assessment is accomplished through the review of all available research data reported for a potential toxic compound. In cancer risk assessment two general types of research are conducted that provide the data for risk assessment: epidemiology and toxicology. The two research types approach the problem very differently, with each having both strengths and weaknesses.

- Epidemiology Questions
  - Discuss the specific strengths and weaknesses of this study.
  - Discuss the general strengths and weaknesses of epidemiology for providing an answer to Mary Beth’s question.
- Toxicology Questions
  - Discuss the specific strengths and weaknesses of this study.
  - Discuss the general strengths and weaknesses of toxicology for providing an answer to Mary Beth’s question.