8.3 INDUSTRIAL CHEMICAL POLLUTION OF ECOSYSTEMS

College Board Topics 8.2, 8.3, 8.7, 8.8

Related Reading: Chapter 14, pages 358 - 374

Learning Objectives and Essential Knowledge

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
STB-3.B Describe the impacts of human activities on aquatic ecosystems.	**STB-3.B.7** Heavy metals used for industry, especially mining and burning of fossil fuels, can reach the groundwater, impacting the drinking water supply.
	STB-3.B.10 When elemental sources of mercury enter aquatic environments, bacteria in the water convert it to highly toxic methylmercury.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
STB-3.C Describe endocrine disruptors.	**STB-3.C.1** Endocrine disruptors are chemicals that can interfere with the endocrine system of animals.
STB-3.D Describe the effects of endocrine disruptors on ecosystems.	**STB-3.D.1** Endocrine disruptors can lead to birth defects, developmental disorders, and gender imbalances in fish and other species.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
STB-3.H Describe the effect of persistent organic pollutants (POPs) on ecosystems.	**STB-3.H.1** Persistent organic pollutants (POPs) do not easily break down in the environment because they are synthetic, carbon-based molecules (such as DDT and PCBs).
	STB-3.H.2 Persistent organic pollutants (POPs) can be toxic to organisms because they are soluble in fat, which allows them to accumulate in organisms' fatty tissues.
	STB-3.H.3 Persistent organic pollutants (POPs) can travel over long distances via wind and water before being redeposited.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
STB-3.I Describe bioaccumulation and biomagnification.	**STB-3.I.1** Bioaccumulation is the selective absorption and concentration of elements or compounds by cells in a living organism, most commonly fat-soluble compounds.
	STB-3.I.2 Biomagnification is the increase in concentration of substances per unit of body tissue that occurs in successively higher trophic levels of a food chain or in a food web.
STB-3.J Describe the effects of bioaccumulation and biomagnification.	**STB-3.J.1** Some effects that can occur in an ecosystem when a persistent substance is biomagnified in a food chain include eggshell thinning and developmental deformities in top carnivores of the higher trophic levels.
	STB-3.J.2 Humans also experience harmful effects from biomagnification, including issues with the reproductive, nervous, and circulatory systems.
	STB-3.J.3 DDT, mercury, and PCBs are substances that bioaccumulate and have significant environmental impacts.

SUGGESTED SKILL

Concept Explanation

1.B

Explain environmental concepts and processes.

SUGGESTED SKILL

Mathematical Routines

6.B

Apply appropriate mathematical relationships to solve a problem, with work shown (e.g., dimensional analysis).

SUGGESTED SKILL

Scientific Experiments

4.A

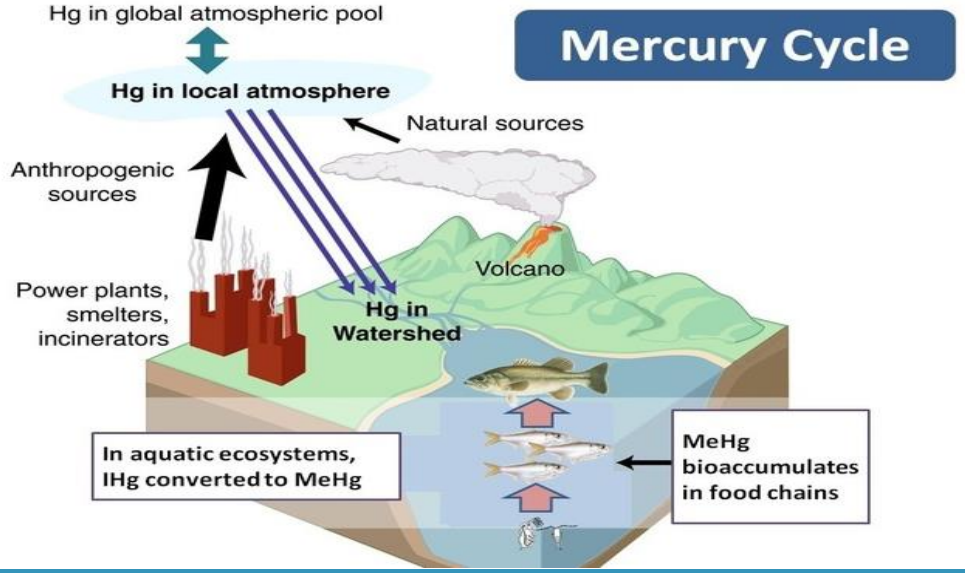
Identify a testable hypothesis or scientific question for an investigation.

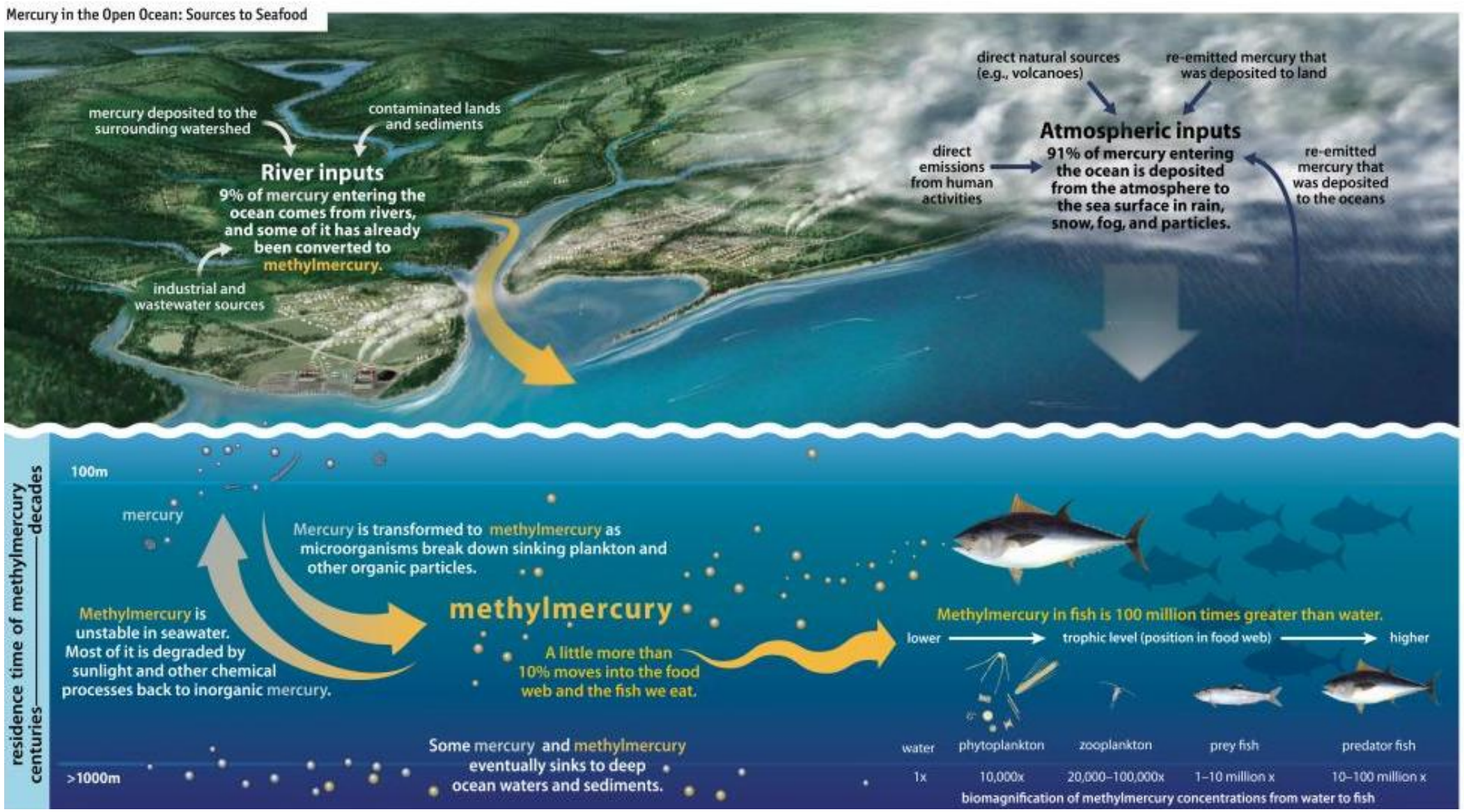
Industrial pollution of aquatic ecosystems - Mercury

- **Mercury** is considered the most toxic heavy metal in the environment.
  - Inorganic mercury (Hg^{2+}), has low toxicity, attaches to PM released by combustion and is deposited in soil/water wherever PM settles.
  - Coal combustion is the main contributor of Hg^{2+}
  - Hg^{2+} can also be released if coal ash storage ponds overflow & runoff into surface waters.
  - Trash incineration, burning medical waste, and heating limestone for cement production can also release Hg^{2+} into the environment.

Four vials of tadpoles after one month in normal water for the first batch, and in water containing 0.6PPB and 1.26PPB and 2.5PPB (parts per billion) of methylmercury for the three bottles at right.

- Hg^{2+} deposited in aquatic ecosystems is converted to the much more toxic form, organic ***Methylmercury (CH_3Hg^+ or MeHg)*** by phytoplankton and bacteria.
  - Methylmercury is readily incorporated into lipids found in neurons and inhibits nervous system function (***neurotoxin***) as a result.
  - Methylmercury can also lead to miscarriages and birth defects (***teratogen***).





- Methyl mercury bioaccumulates in organisms and biomagnifies in ecosystems, reaching the highest concentrations in aquatic predators at the top of the food chain.

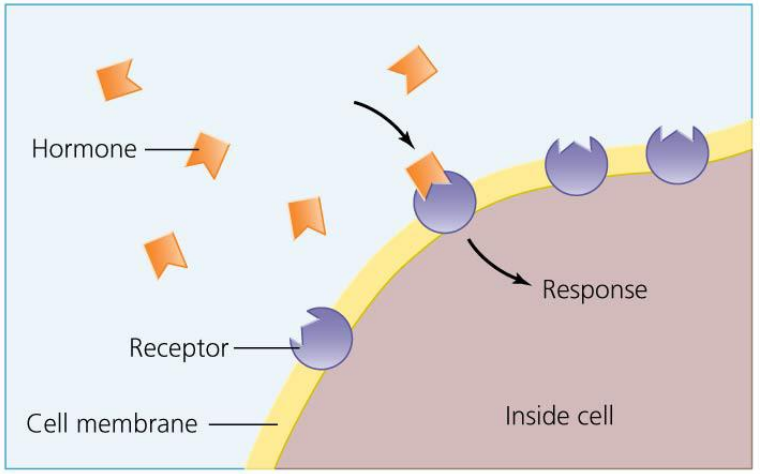
Other heavy metals

- ***Arsenic (As):*** naturally occurring element in rocks underground that can dissolve into drinking water
  - Natural release into groundwater can be worsened by mining
  - Arsenic was formerly used as an ingredient in many pesticides and may linger in soils.
  - Used in wood treatments to prevent fungal rot and termite damage (pressure treated lumber)
  - Coal ash and particulate matter can spread arsenic over large areas.
- Toxicity of arsenic (As)
  - Carcinogenic (lungs, bladder, kidneys)
  - Endocrine disrupting
    - Blocks receptor proteins on cell surfaces from receiving steroidal signals

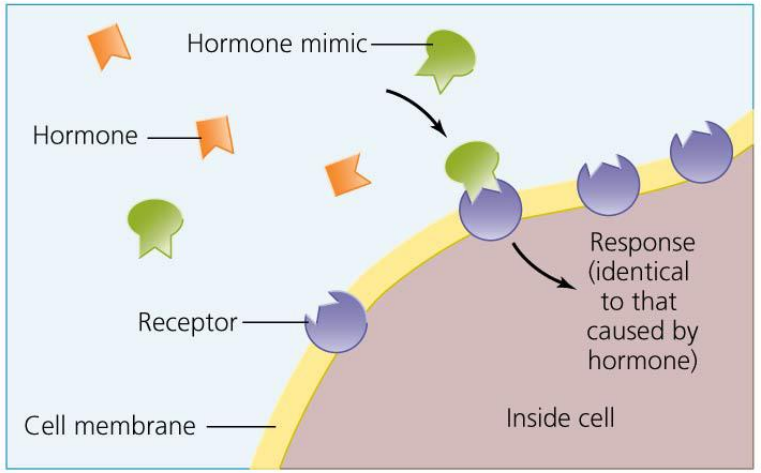
- ***Lead (Pb):*** the most abundant heavy metal pollutant
  - Old paint (in homes), Old water pipes, Car batteries (lead acid batteries), used as a glaze in some pottery
  - PM from vehicle exhaust before lead was phased out of gas in 1970s.
  - Also released in PM of coal combustion
- The use of lead has been phased out in the develop world, but lead is still commonly used in less developed countries
- Toxicity of Lead (Pb)
  - Neurotoxicant (damages central nervous system, especially in children)
  - Endocrine disruptor

Pathway inhibiting chemicals

- ***Pathway inhibitors*** are toxicants that block steps in a biochemical pathway
  - Many inhibit key enzymes in the pathway
  - The herbicide Atrazine inhibits enzymes in the Calvin cycle of photosynthesis.
  - Cyanide inhibits electron carrier proteins in the ETC of the mitochondria, blocking cellular respiration.
- ***Endocrine disruptors*** are pathway inhibitors that interfere with the endocrine (hormonal) systems of animals.
  - Hormones stimulate growth, development, sexual maturity
  - Work with extremely small concentrations.
- Endocrine disrupting chemicals interfere with normal signals
  - Block hormones, preventing signals from working
  - Mimic hormones, causing a change. (many mimic estrogen)



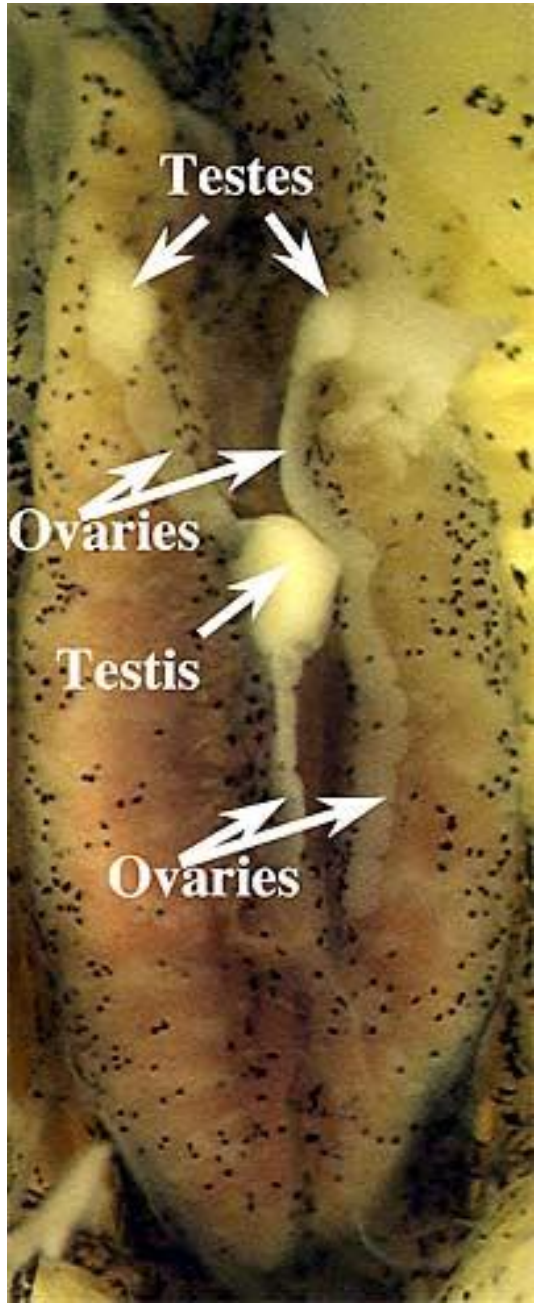
(a) Normal hormone binding



(b) Hormone mimicry

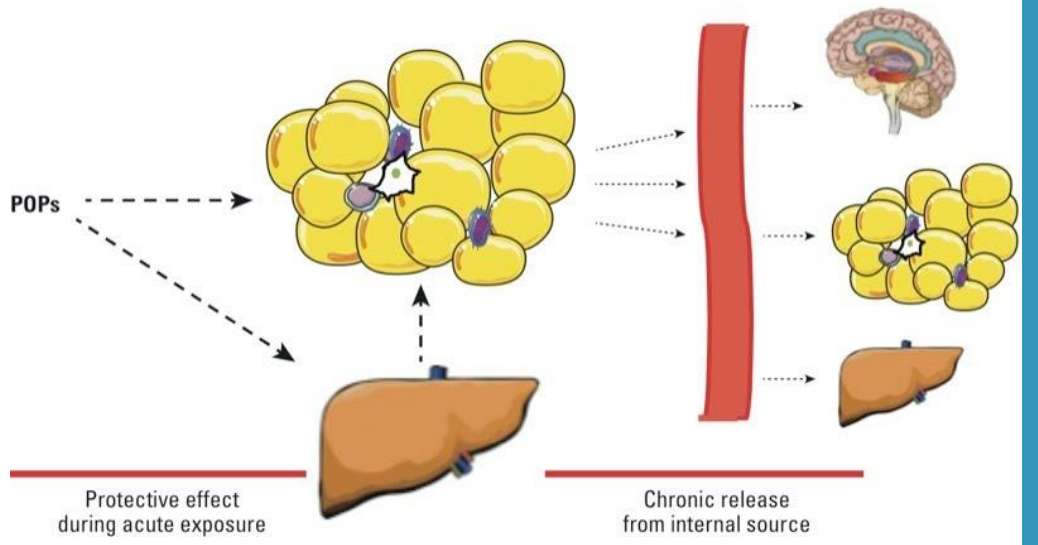
Endocrine Disrupting chemicals

- ***Atrazine*** binds to receptors that should convert estrogen into testosterone in male frogs, resulting in higher estrogen levels/lower testosterone levels.
  - Lowers sperm count and in some cases , causes gender reversal and the development of eggs in the testes or ovary formation
- ***Human medications*** that pass through urine & into sewage or are flushed down toilet are a common source of endocrine disrupting chemicals (meant to influence human hormones, so they can also disrupt animals')
  - Ex: Birth control pills
- ***Heavy metals*** such as mercury, lead and arsenic may act as endocrine disruptors
- ***Phthalates*****:** compounds used to make plastic more flexible (#3 plastics) and in cosmetic manufacturing (fragrances).
- ***Bisphenol A (BPA):*** used to make hard plastics and epoxy. Common in food storage containers.
- ***Polyfluoroalkyl Substances (PFAS):*** non stick coatings of cookware
- Many of these synthetic chemicals enter surface & groundwater through improper disposal of chemical waste, and landfill leaching.



Persistent Organic Pollutants (POP's)

- Persistent (long-lasting) Organic (carbon-based) Pollutants
  - Synthetic (human-made) compounds that do not easily breakdown in the environment.
  - Fat-soluble, meaning they also accumulate and persist in animals' fat tissue instead of passing through the body (don't easily dissolve into blood/urine).
  - Many POP's are also endocrine disruptors.
- POP's travel long distances through wind and water, impacting ecosystems far away.
  - Wastewater release from industrial processes, leachate from landfills or improperly buried industrial waste, pesticide production and use, and emissions from burning wastes
  - Enter soils/water, assimilated by plants (producers), eaten by animals (consumers), stored in fatty tissues, eaten by humans.
  - May also enter humans and other higher consumers through drinking water.

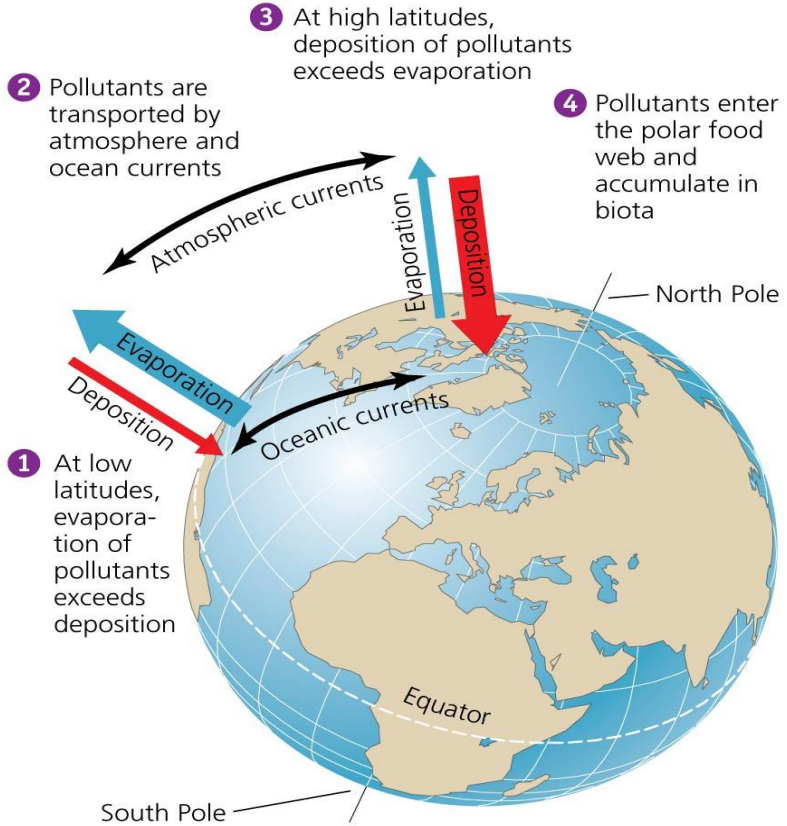


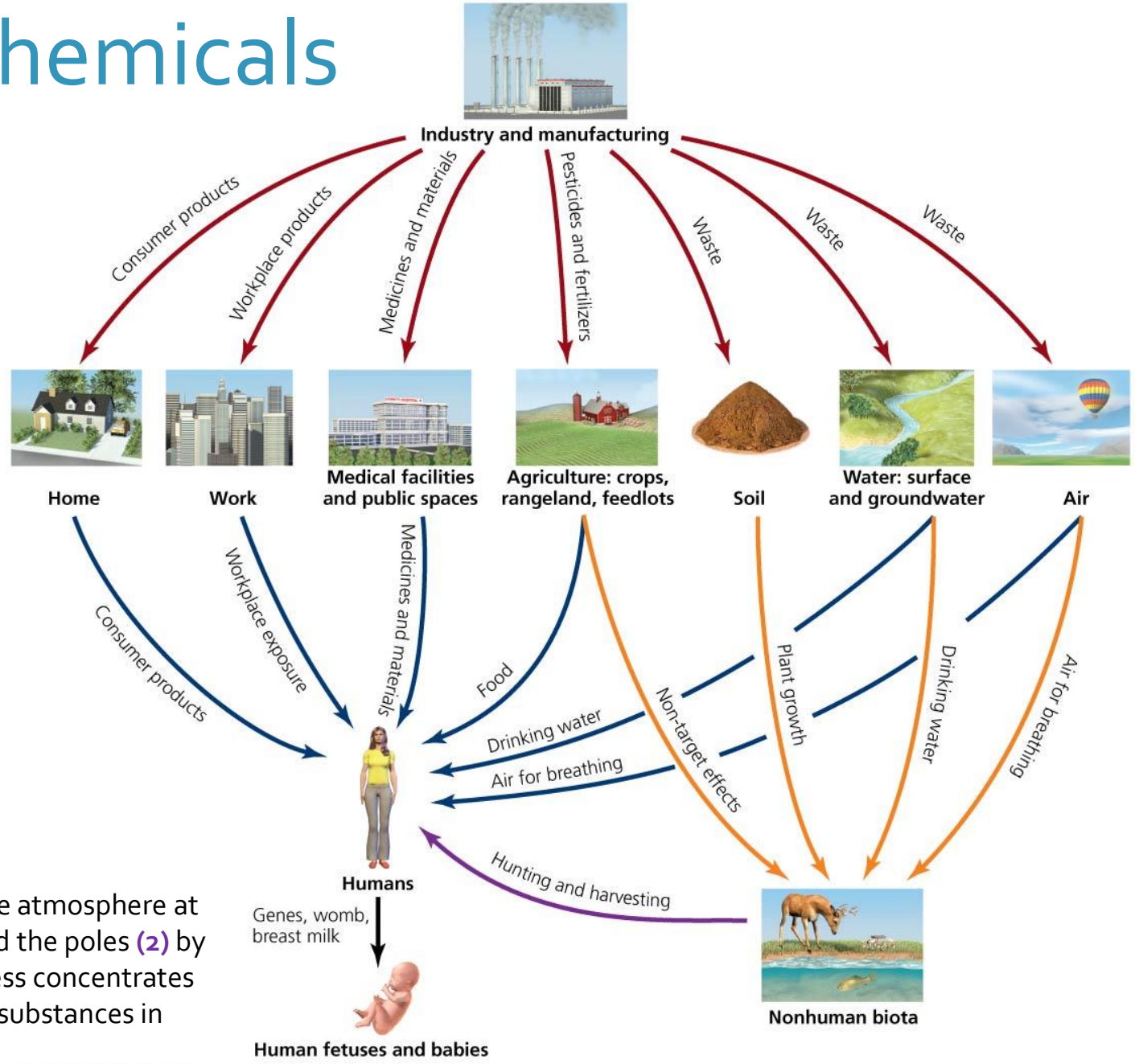
Can slowly be released from fatty tissue into blood stream and impact brain & other organs over time (esp. reproductive system)

Examples

- ***DDT***: mostly phased out insecticide, still used in malarial regions of the world.
- ***Polychlorinated Bisphenols (PCB's)***: paints plastics and other chemical products.
- ***Polybrominated Diphenyl Ethers (PBDE's):*** Fire retardant used on textiles (upholstery, carpet, etc)
- ***Dioxins***: pesticide production and combustion byproduct.
- ***Phthalates***: plastics

Routes of synthetic chemicals in the environment

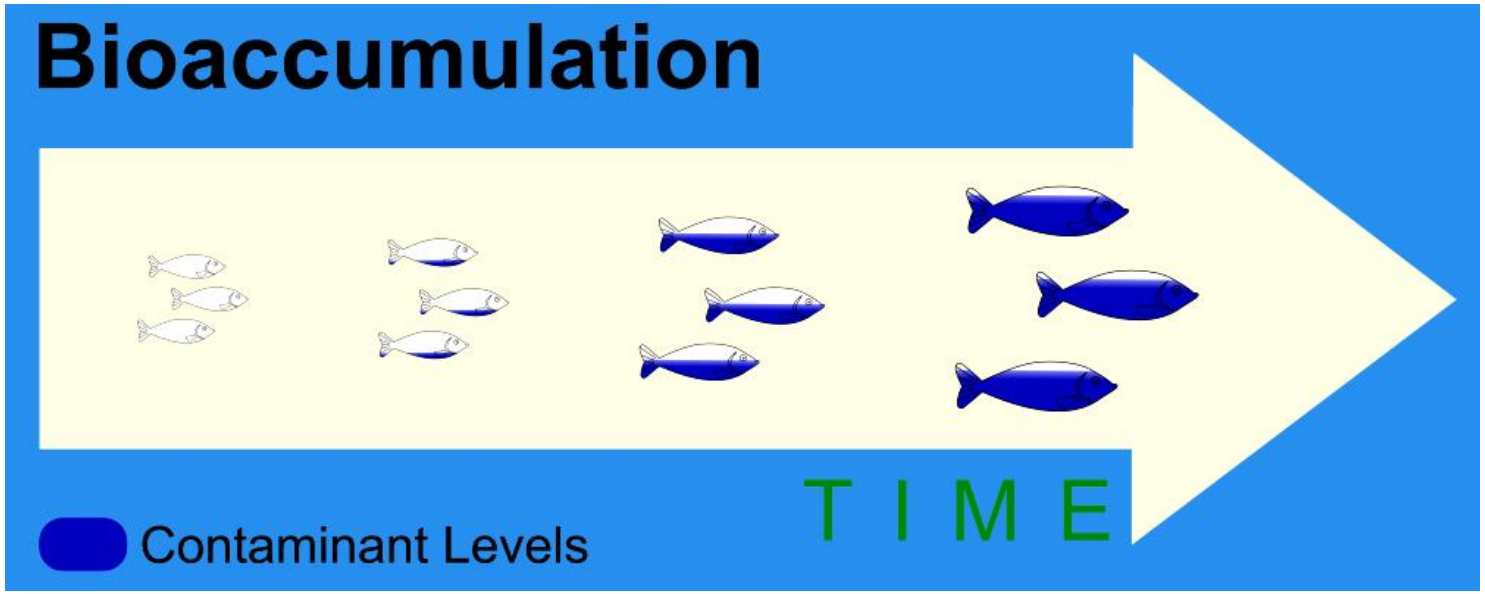




In global distillation, pollutants that evaporate and rise high into the atmosphere at lower latitudes (1), or are deposited in the ocean, are carried toward the poles (2) by atmospheric currents of air and ocean currents of water. This process concentrates pollutants near the poles (3) and causes elevated exposure to toxic substances in polar regions (4).

Toxins may accumulate in tissues over time

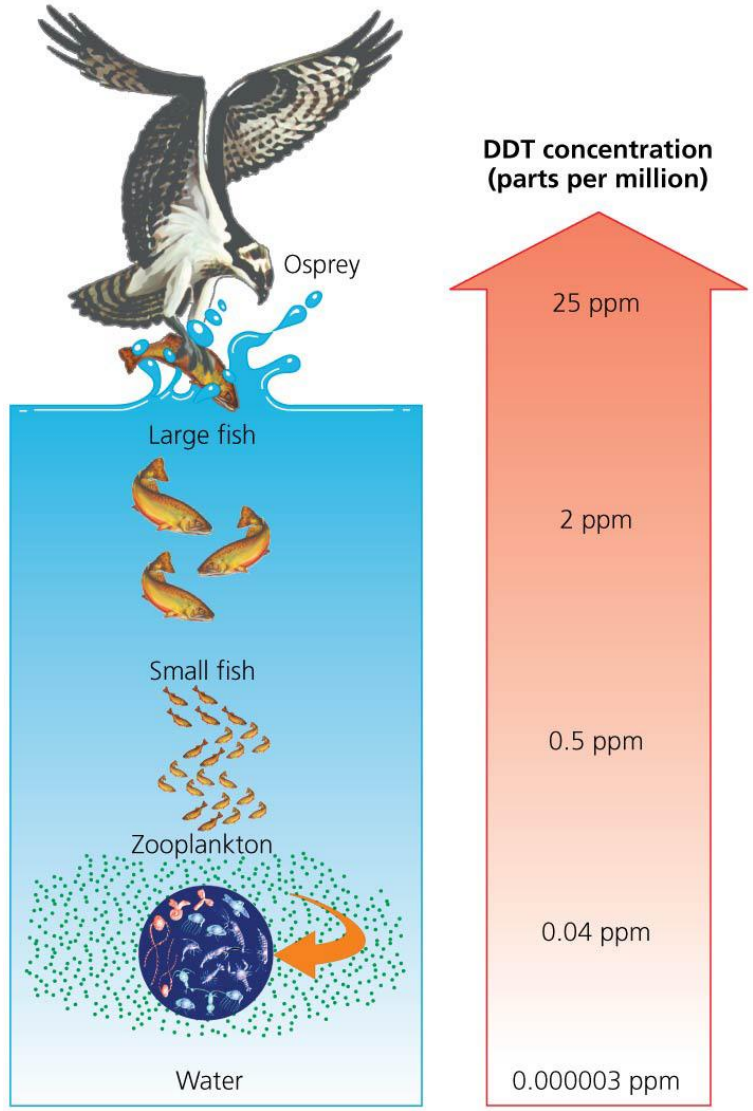
- **Toxicants in the body can be excreted, degraded, or <u>stored</u>.**
  - Fat-soluble toxicants such as POP's and Heavy metals (methylmercury) don't dissolve easily in water.
  - Therefore, they don't easily enter the blood where they could be filtered out by kidneys, into the urine and excreted.
  - Instead POP's and heavy metals are stored in fatty tissue and the liver where they build up over time.



- ***Bioaccumulation***
  - Process of toxicants building up in biological tissues during a lifetime to greater concentration than in the environment.

Toxins accumulate in higher trophic level species

- ***Biomagnification***
  - Process that occurs when concentrations of toxicants become magnified in higher levels of the food chain.
- POP's and heavy metals like mercury are often present in relatively low levels in the environment.
  - These substances are assimilated by producers into organic compounds in their tissues where they bioaccumulate throughout their lives.
  - Higher consumers acquire these toxins as they consume producers or other species who have consumed producers.
  - Because of the 10% rule, organisms at each successive trophic level need to eat more biomass to receive enough energy.
  - POP's/ heavy metals reach higher concentrations in the tissues of these top consumers.
- Bioaccumulation of DDT caused the near extinction of peregrine falcons and bald eagles due to thinning eggshells (big reason for ESA).
- Eating species from high trophic levels (tuna, swordfish, shark) in some ecosystems can pose a risk to human populations.
  - Especially pregnant women, children, and those for whom fish is a large percentage of their diet.



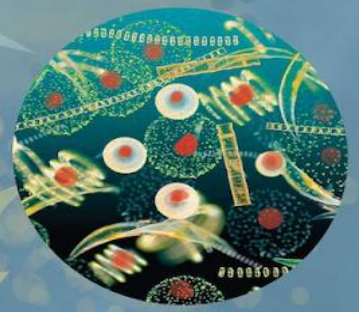
BIOMAGNIFICATION AND BIOACCUMULATION

How can pollutants have long-term effects on organisms?

Even when pollutants are not dangerous enough to kill animals outright, their presence can have lasting effects on food webs through **bioaccumulation** and **biomagnification**.

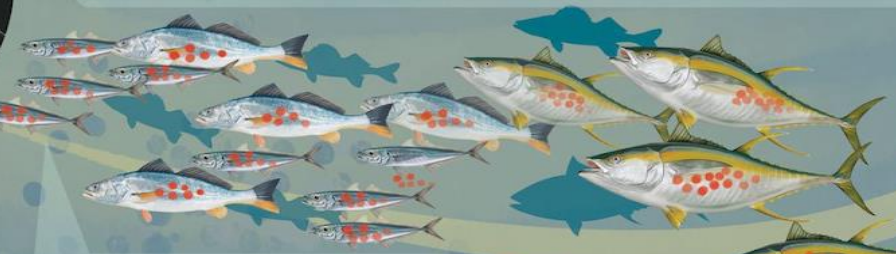
Toxins may increase in concentration as they are passed up the food chain, a process called **biomagnification**.

Pollutants such as **polychlorinated biphenyls (PCBs)** enter the ocean as industrial waste and are absorbed by microscopic **phytoplankton** at the bottom of the food chain.



PCBs

Even though phytoplankton absorb only a tiny amount, small creatures called **zooplankton** eat large quantities of the phytoplankton, taking in all the PCBs from what the phytoplankton eat.

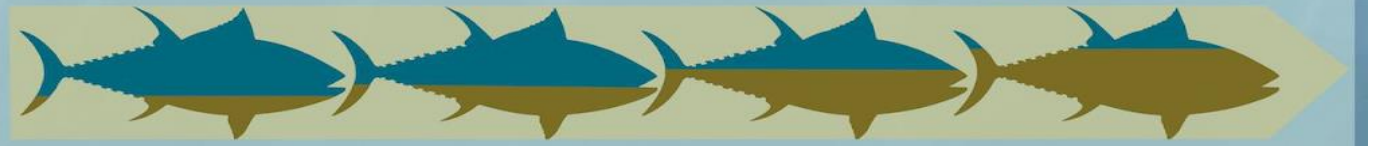


Small fish then feed on the zooplankton, continuing to **magnify** the amount of PCBs up the food chain.

In the waters of the Pacific Northwest, **apex predators** like the killer whale (Orcinus orca) end up with the highest concentrations of toxins due to biomagnification.

TIME

Level of mercury



Bioaccumulation occurs when pollutants build up in a single organism's body over time. Mercury, for example, is a pollutant that has entered waterways and lakes through industrial processes. Fish and shellfish absorb the mercury directly from their environment, and although they may only absorb small amounts at a time, the mercury can remain in the fish's body for months or even longer. This leads to the mercury building up, or **accumulating**, in the fish's body, posing a danger to any organism that eats the fish.

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