Bioaccumulation and Biomagnification

Bioaccumulation refers to how pollutants enter a food chain;

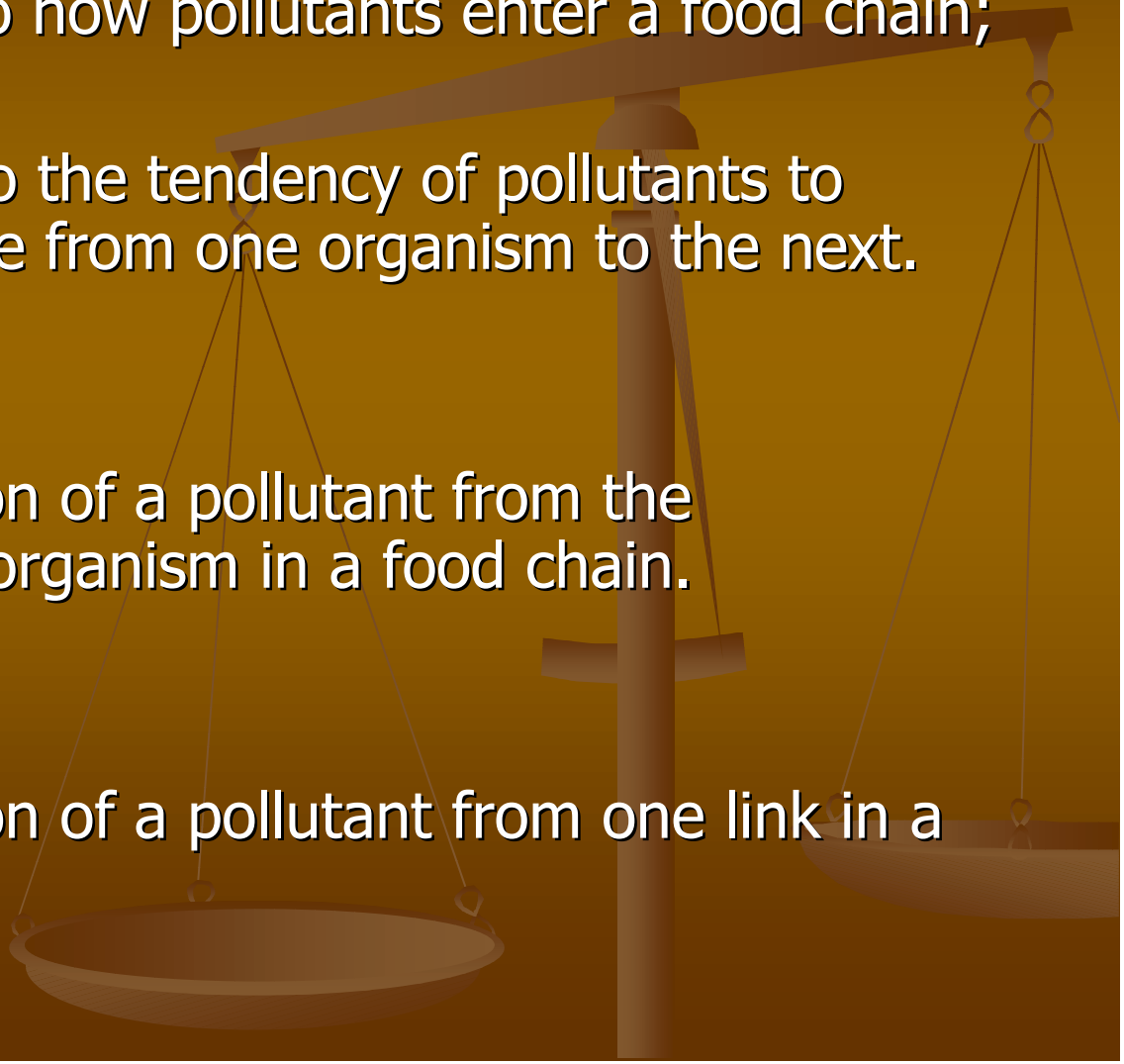
Biomagnification refers to the tendency of pollutants to concentrate as they move from one organism to the next.

Bioaccumulation:

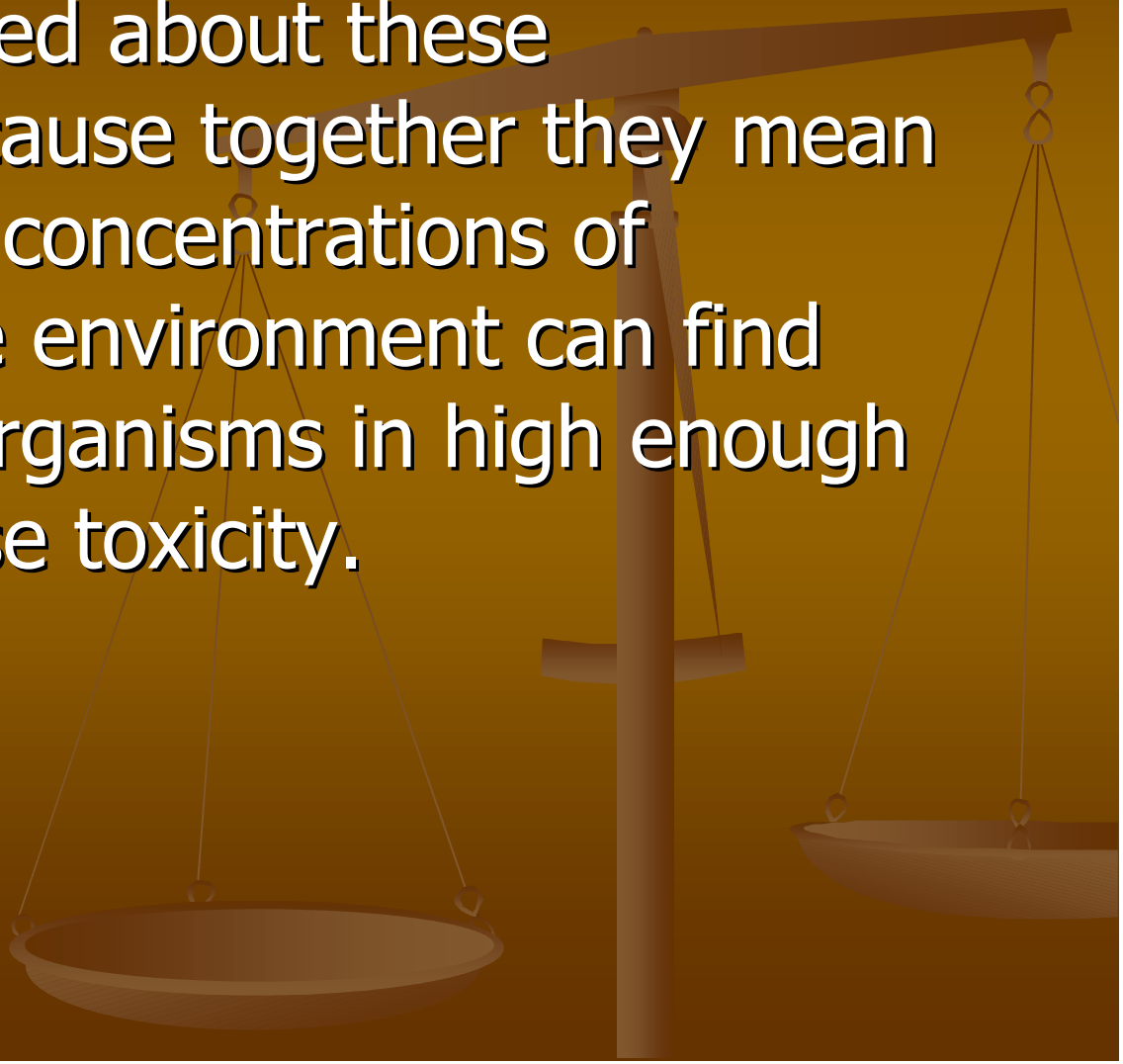
increase in concentration of a pollutant from the environment to the first organism in a food chain.

Biomagnification:

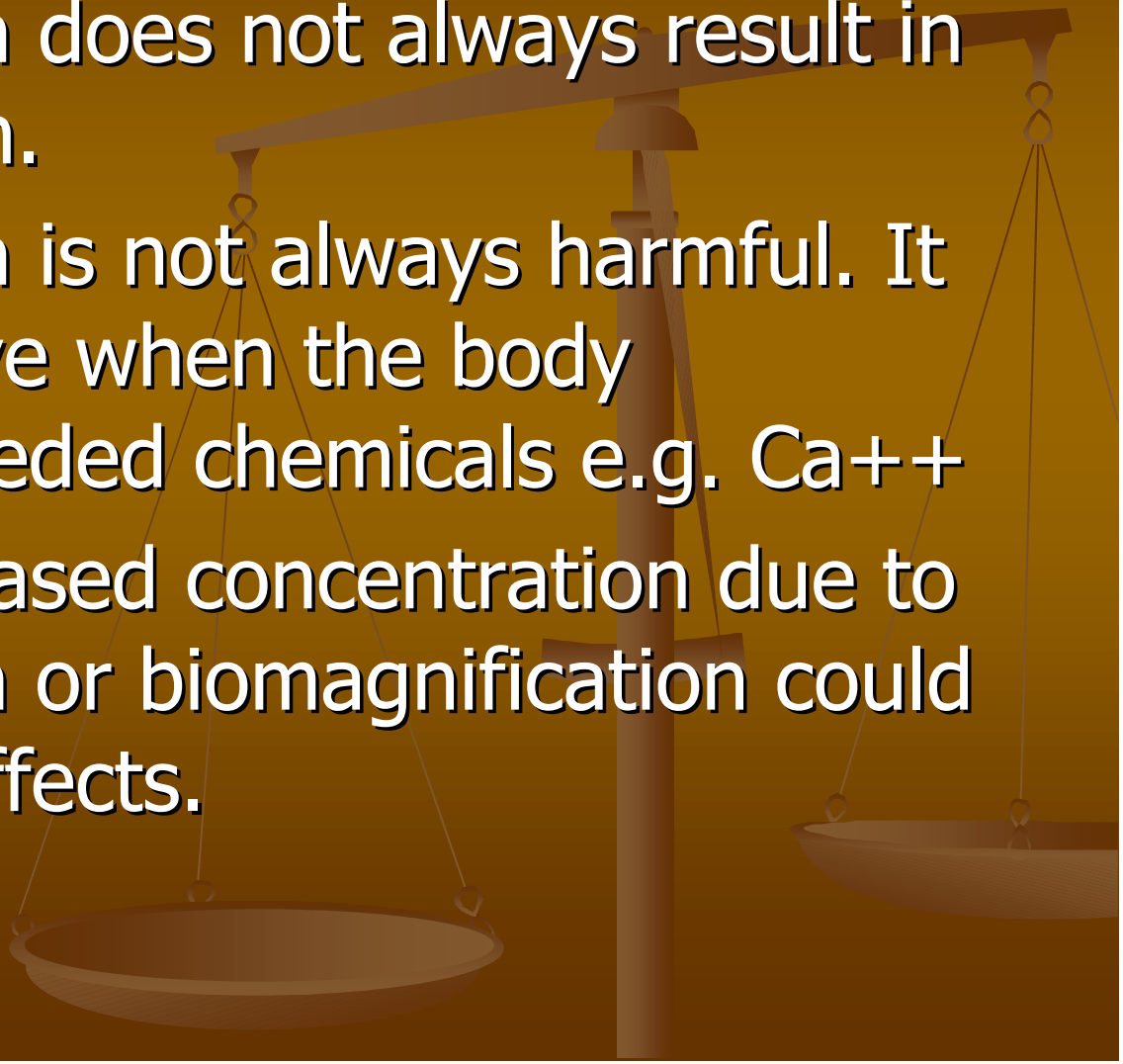
increase in concentration of a pollutant from one link in a food chain to another.



- We are concerned about these phenomena because together they mean that even small concentrations of chemicals in the environment can find their way into organisms in high enough dosages to cause toxicity.



- Bioaccumulation does not always result in biomagnification.
- Bioaccumulation is not always harmful. It can be protective when the body accumulates needed chemicals e.g. Ca++
- Generally, increased concentration due to bioaccumulation or biomagnification could result in toxic effects.



Factors for biomagnification to occur

- the pollutant must be:

  1. Long-lived (has a long t1/2). If a pollutant is short-lived, it will be broken down before it can become dangerous.

  2. Mobile. If it is not mobile, it will stay in one place and is unlikely to be taken up by organisms.

  3. Soluble in fats . If the pollutant is soluble in water it will be excreted by the organism. Pollutants that dissolve in fats, however, may be retained for a long time.

  4. Biologically active. If a pollutant is not active biologically, it may biomagnify, but we really don't worry about it much, since it probably won't cause any problems.

Classic example: DDT

- DDT stands for dichloro, diphenyl trichloroethane. It is a chlorinated hydrocarbon, a class of chemicals which often fit the characteristics necessary for biomagnification.
- DDT has a half-life of 15 years, which means if you use 100 kg of DDT, it will break down as follows:

Year	Amount Remaining
0	100 kg
15	50 kg
30	25 kg
45	12.5 kg
60	6.25 kg
75	3.13 kg
90	1.56 kg
105	0.78 kg
120	0.39 kg

After 100 years, there will still be over 0.78 kg of DDT in the environment.

DDT

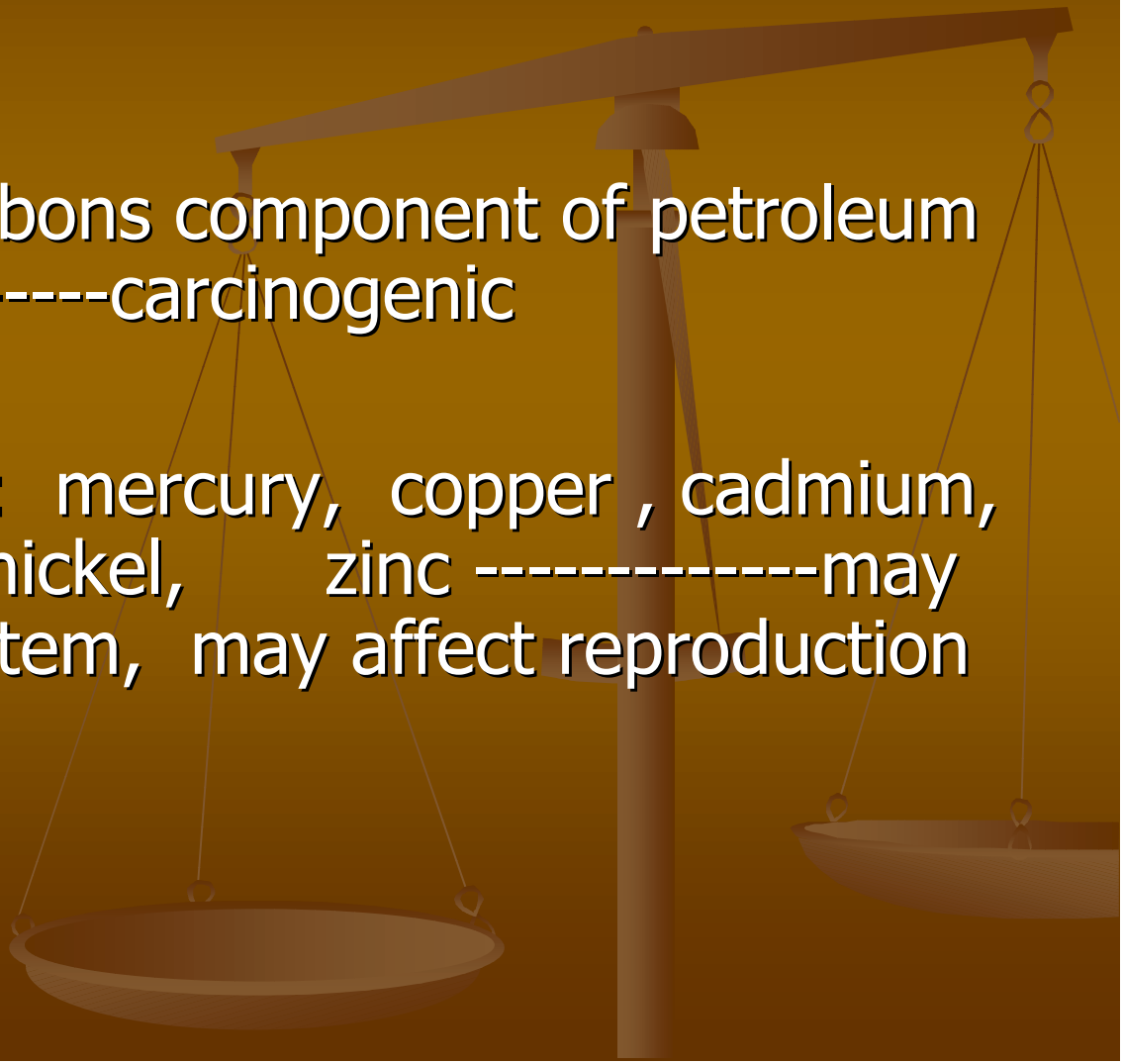
- DDT has low toxicity to humans (but high toxicity to insects, hence its use as an insecticide).
- DDT protects humans from insect-borne diseases, and protects crops as well.
- DDT was overused, and soon gained insect resistance, and became well known for its bioaccumulation and biomagnification properties. Hence its use was abandoned

study done in 1967 on Long Island Sound.

- Levels of DDT in tissues of various animals in the Sound showed bioaccumulation factors of 800x, and biomagnification factors up to 31 times. When we look at the whole food chain, the overall magnification is over 200,000x!
- water to zooplankton (water organisms): 800x
- zooplankton to fish #1: 31x
- fish #1 to fish #2: 1.7x
- fish #2 to gull: 4.8x
- overall biomagnification: 202,368x

- DDT isn't particularly lethal (except to insects, and we need many of them around),
- It has a number of sub-lethal effects. Most prominent is the phenomenon of shell-thinning in birds, which posed a threat of extinction of these birds
- Many populations have recovered following the banning of DDT in the US.
- Recently, some studies have shown effects on sex ratios in some species of birds, with the males becoming "feminized", presumably the result of compounds in the environment mimicing the female hormone estrogen.

Some chemicals with the potential to biomagnify:



- aromatic hydrocarbons component of petroleum products ----------carcinogenic
- Heavy metals: mercury, copper , cadmium, chromium, lead, nickel, zinc ----------may affect nervous system, may affect reproduction

Other pollutants:

- Other pollutants of importance are plastics, radioisotopes (which may be both toxic and radioactive!) and oil.

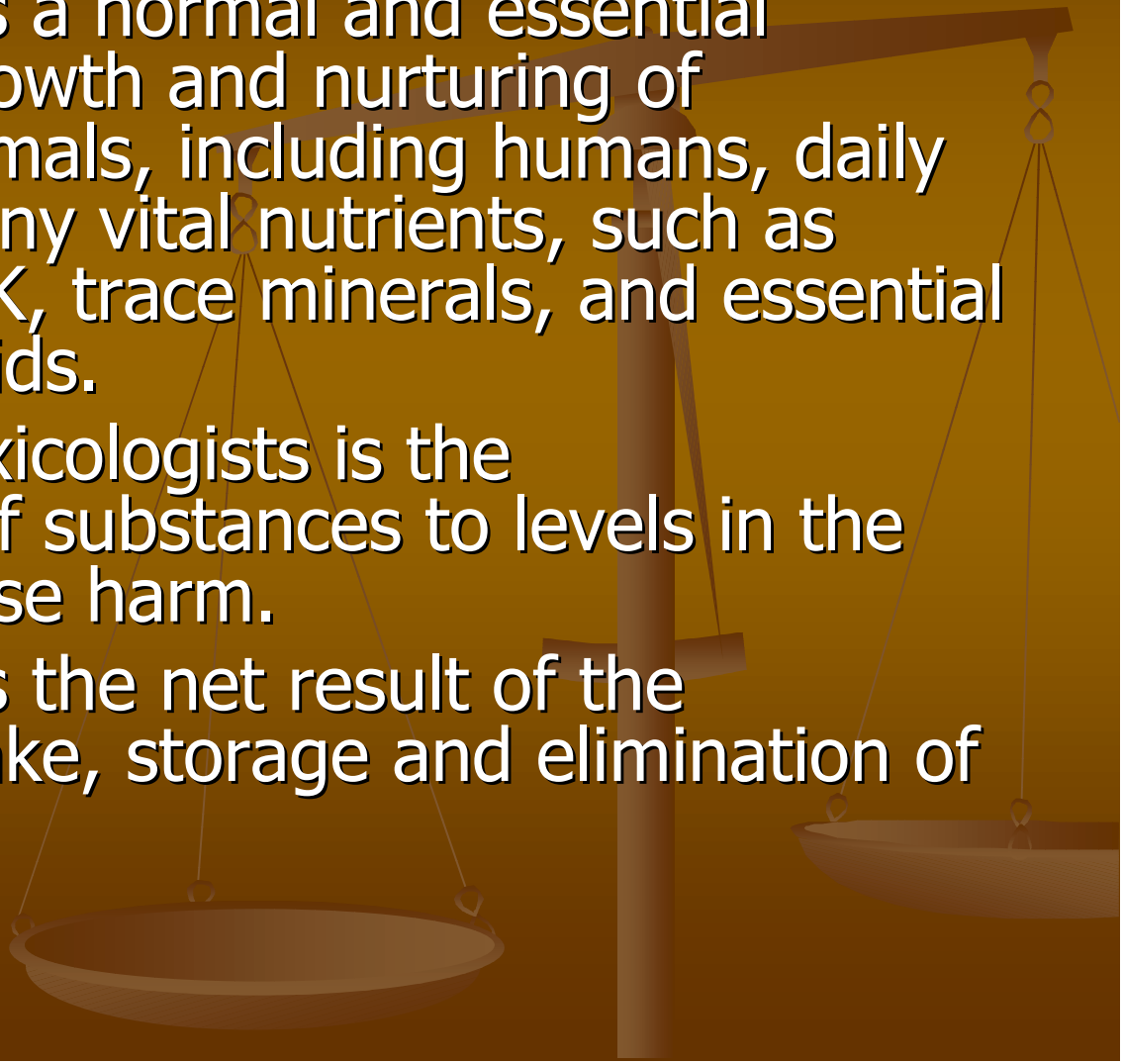
1. Plastics are eaten by many organisms and can cause mechanical injury, strangulation, or starvation.

2. Radioisotopes can damage biological molecules, particularly DNA, leading to cancer, other illnesses, or death.

3. Oil smothers aquatic organisms, cutting them off from oxygen. It can also infiltrate the insulating feathers of seabirds (or fur of sea-going mammals) and cause them to die from hypothermia (or cause them to sink).

Oil spills are a serious problem in marine environments.

- Bioaccumulation is a normal and essential process for the growth and nurturing of organisms. All animals, including humans, daily bioaccumulate many vital nutrients, such as vitamins A,D and K, trace minerals, and essential fats and amino acids.
- What concerns toxicologists is the bioaccumulation of substances to levels in the body that can cause harm.
- Bioaccumulation is the net result of the interaction of uptake, storage and elimination of a chemical.



Factors affecting bioaccumulation

- 1. Uptake: usually by passive diffusion of the lipid soluble substance
- 2. Storage: water soluble substances are less taken up and, therefore, less stored. But they are easily eliminated (Exceptions: Hg, Pb, Cu and other water-soluble chemicals that bind tightly to specific sites within the body----these may accumulate).

- 3. Elimination of a chemical: Chemicals that dissolve readily in fat but not in water tend to be more slowly eliminated by the body and thus have a greater potential to accumulate.
- There are exceptions, however.

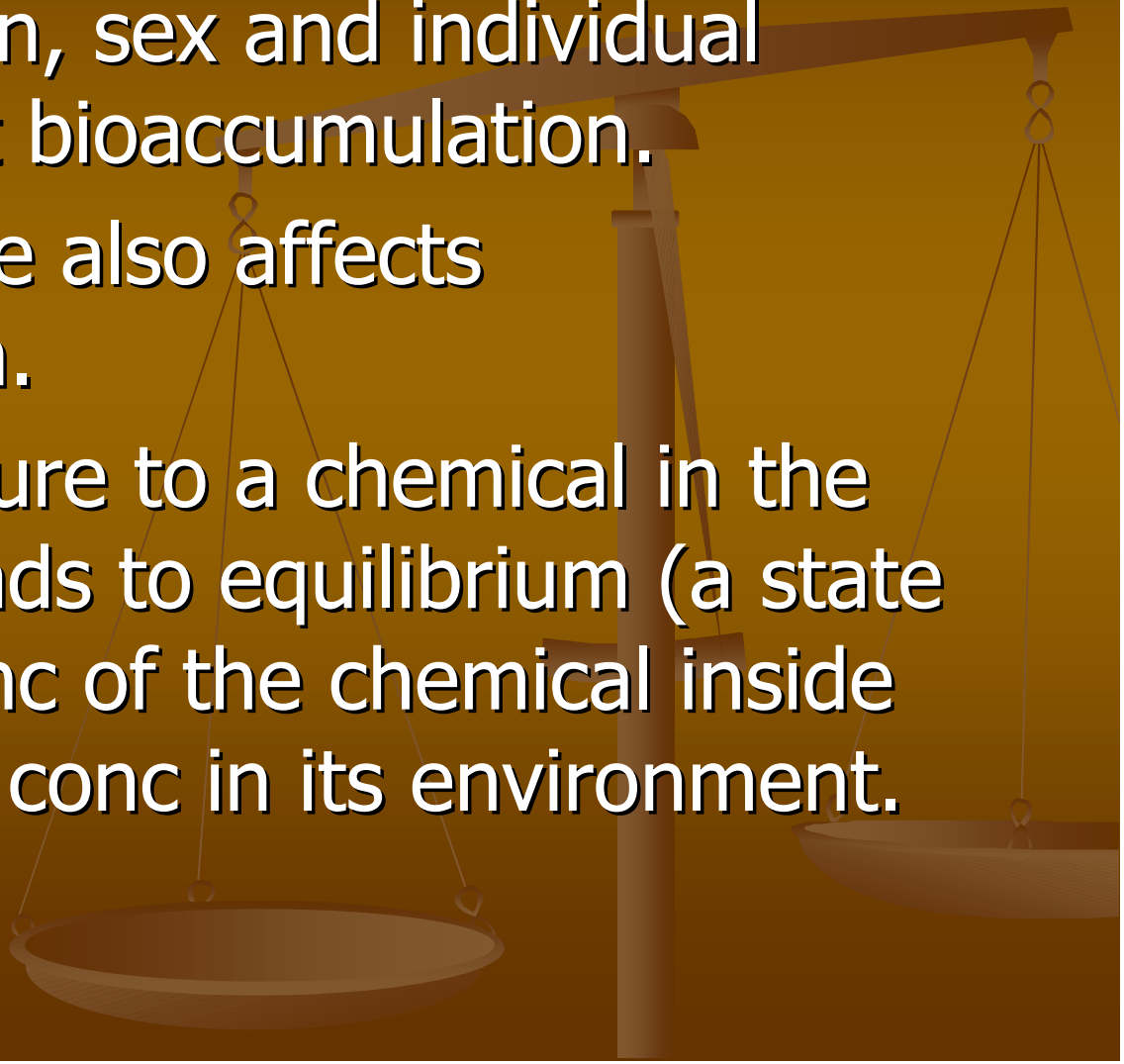
  Natural pyrethrins, insecticides that are derived from the chrysanthemum plant, are highly fat-soluble pesticides, but they are easily degraded and do not accumulate.

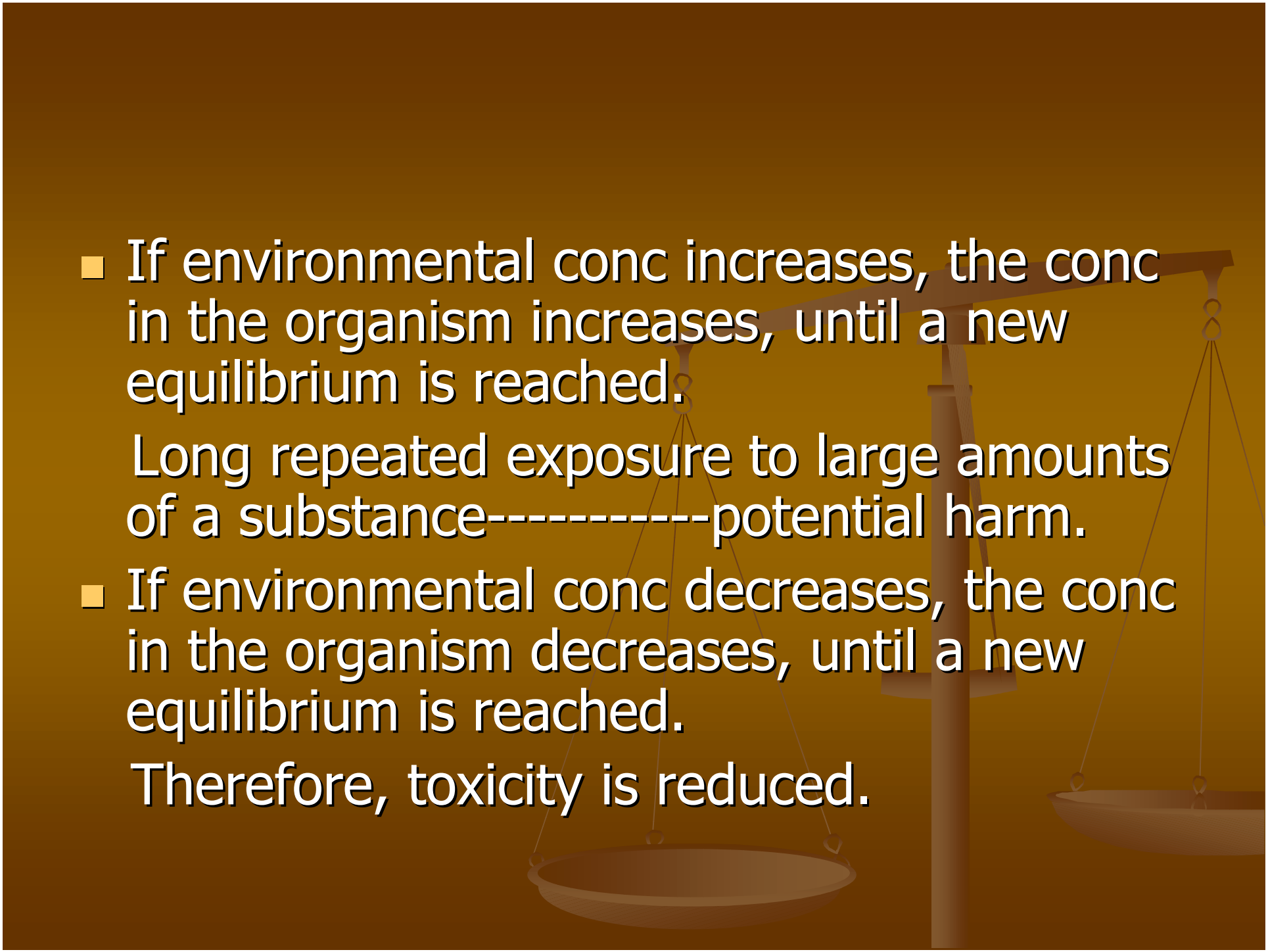
  The insecticide chlorpyrifos, which is less fat-soluble but more poorly degraded, tends to bioaccumulate.

- Usually, fat-soluble substances are stored in fatty tissue and begin to accumulate (process of detoxification). This is dangerous when there is demobilization of fat.
- Accumulation occurs if the time between uptake and elimination is prolonged.

- 4. Species, strain, sex and individual variations affect bioaccumulation.
- 5. Exposure time also affects bioaccumulation.

  Constant exposure to a chemical in the environment leads to equilibrium (a state in which the conc of the chemical inside the organism = conc in its environment.





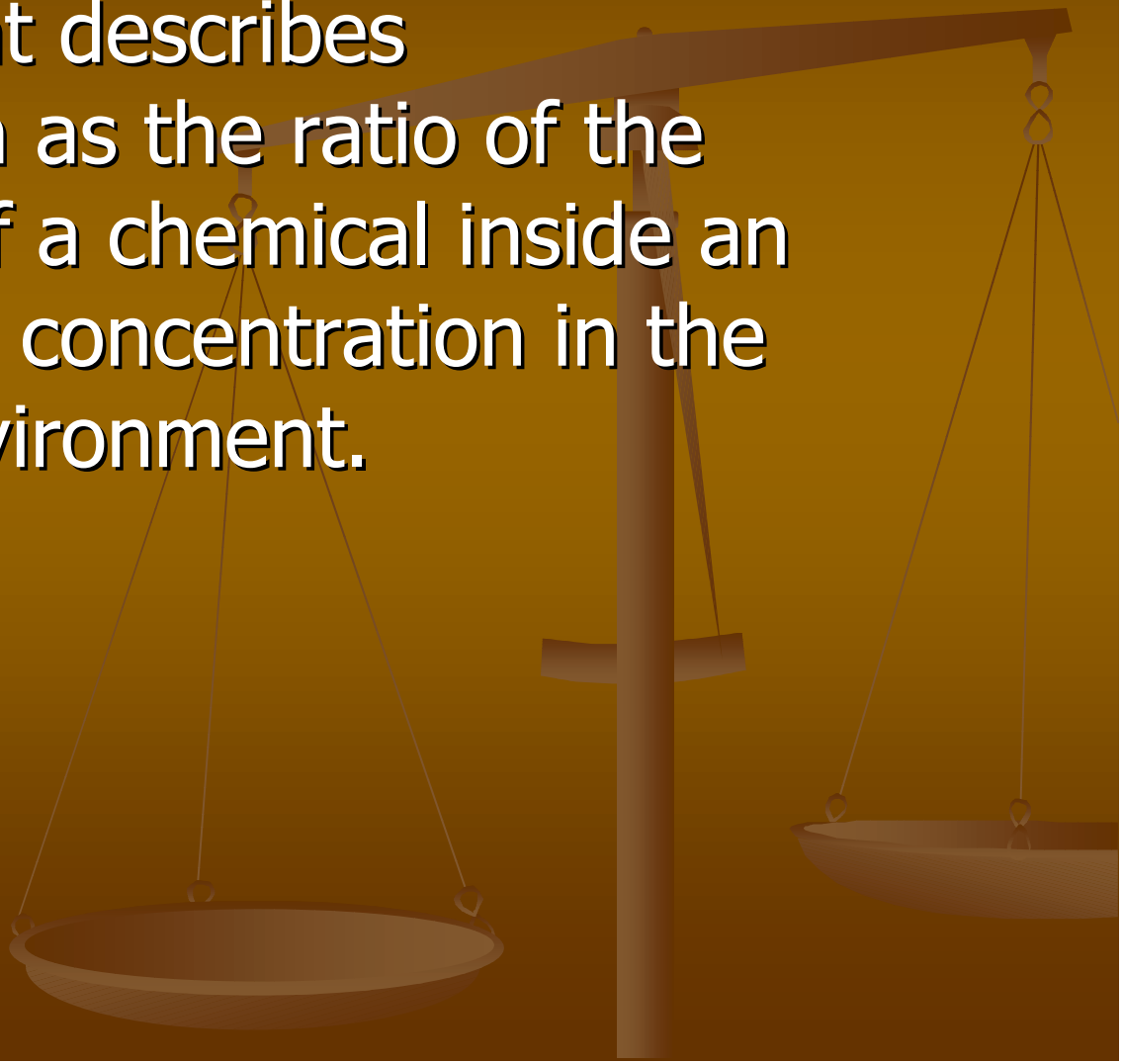
- If environmental conc increases, the conc in the organism increases, until a new equilibrium is reached.

  Long repeated exposure to large amounts of a substance----------potential harm.
- If environmental conc decreases, the conc in the organism decreases, until a new equilibrium is reached.

  Therefore, toxicity is reduced.

Bioaccumulation factor (Index)

- Is a number that describes bioaccumulation as the ratio of the concentration of a chemical inside an organism to the concentration in the surrounding environment.



Measurement of bioaccumulation Index (factor)

- Usually measured using fish.
- Score BI Log P ow

Score	BI	Log P ow
7	> 4000	> 6
3	1000 – 3999	5 – 5.99
2	700 – 999	4.5 – 4.99
1	300 – 699	4.00 – 4.49
0	<300	< 4.00
*	insufficient information	

The greater the numerical value of the hazard index, the greater the potential for harm and the greater the need for action

Octanol-water partition coefficient

- This is the ratio of the concentration of a substance in an octanol phase to the concentration of the substance in the water phase of an octanol-water mixture .
- This is a rapid and cheep method for risk assessment of bioconcentration.
- Usually expressed as the log 10

Accumulation Index in humans

- Ex. The dose of a drug given I.V. was
  500 mg (F = 1)
- If its conc in plasma at o time (Cpo)
  = 33.3 mg/L

Then, volume of distribution (Vd) = dose/Cpo = 500 mg/ 33.3 mg/L = 15 L

If CL = 6 L/h, then K el = CL/Vd

= 6 L/h/ 15 L = 0.4/h (i.e. 40%/h)

- K el = 0.7/t1/2 and t1/2 = 0.7/K el
- T1/2 = 0.7/0.4/h = 1.75 h
- Accumulation index $= \frac{1.44 \times t1/2}{T}$

T=Time interval between doses

If T = 6 h, then the accumulation index

= 1.44 X 1.75/6 = 0.42

- In a person with kidney disease using the same above drug (his GFR = 0.6 normal),
- His CL = 0.6 X 6 L/h =3.6 L/h
- His K el = CL/Vd = 3.6/15 = 0.24/h
- His t1/2 = 0.7/K el = 0.7/0.24 =2.92 h
- In order to have the same above accumulation index of 0.42
- 0.42 = 1.44 X t1/2/T
- T = 1.44 X 2.92/0.42 = 10 h
- If the diseased used the drug at intervals of 6 h, then the accumulation index would be = 1.44 X 2.92/6 = 0.7 (increased).

Extraction ratio

- Clearance means amount of blood cleared from a substance per unit time.
- Total body clearance

  = CL(r) + CL(h) + CL(others)

  Renal and hepatic clearances may be determined by determination of the extraction ratio of an organ.

  Extraction ratio could be employed for any other organ.

- Extraction ratio = the fraction of a substance removed in a single pass through the organ of elimination.
- It reflects organ function
- ER can be changed with disease and can vary with blood flow.
- Extraction ratio(ER)

$$= \frac{\text{C arterial- C venous}}{\text{C arterial}}$$

- Ex. Arterial plasma entering the liver contains 19 mg /L of a substance. Venous blood contains 10mg /L of the substance. Plasma flow (Q) to the liver is 0.4 L/h
- What is the liver ER? = 19-10/19 = 0.47
- What is the liver clearance rate?

CL rate = Q X ER

= 0.4 X 0.47 = 0.188 L/h