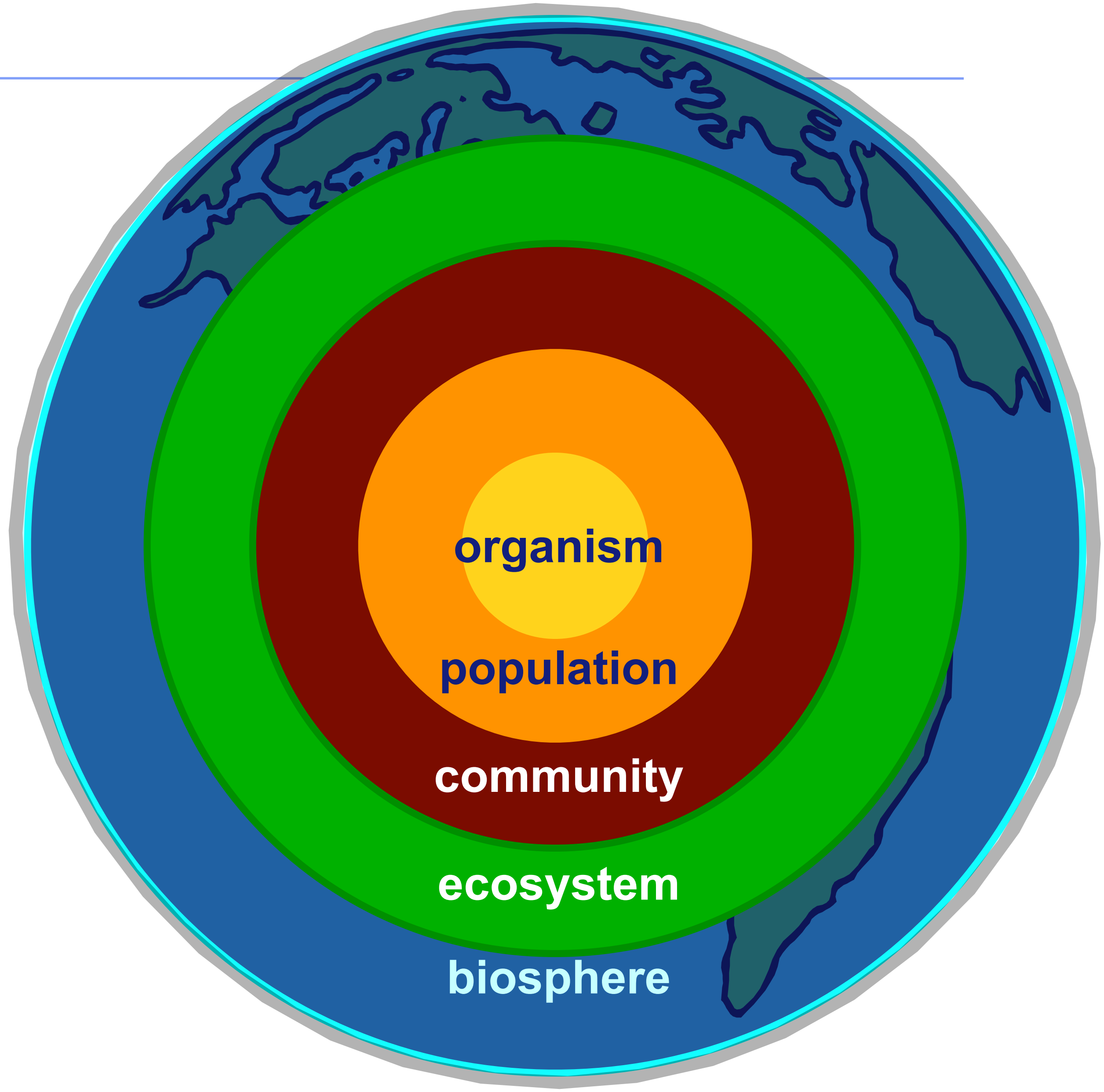
Ecosystems

Studying organisms in their environment



Ecosystems

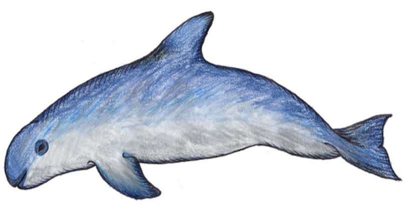
- Ecosystem = the entire community of organisms (organisms of all species) that live in an area and the abiotic factors they interact with.
  - ecosystems can be large (like a lake) or small (like the area under a fallen log)
    - Key Emergent Properites:
      1. Chemical Cycling
      2. Energy Flow

Ecosystems & Energy Flow

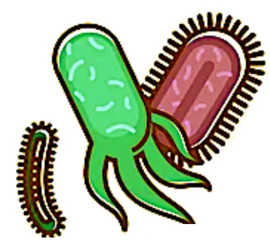
- **Essential Questions Regarding Ecosystems:**
  - What limits the production in ecosystems?
    - Limiting factors = those variables that are stopping growth
      - Ex: Soil may have low amounts of nitrogen (NO_3^-, NH_4^+, NO_2^-), a critical nutrient for plants. Nitrogen could be the limiting factor preventing plant growth because without nitrogen no amino acids or nucleotides could be made.
  - How do nutrients move in the ecosystem?
  - How does energy move through the ecosystem?
- **The Movement of Energy in Ecosystems**
  - Energy enters most ecosystems as sunlight with the help of photoautotrophs (plants, algae, cyanobacteria)
    - These autotrophs (producers) convert radiant energy into chemical energy.
      - Some of this energy is:
        - used to do work,
        - stored in the organic material that makes up their bodies
        - lost as heat (thermal energy) as energy is processed and work done

Ecosystems & Energy Flow

- The Movement of Energy in Ecosystems Continued…
  - Energy may enter some ecosystems from the chemical bonds of inorganic chemicals when sunlight is not available with the help of chemoautotrophs (certain bacteria)
    - These autotrophs (producers) use the energy in low-energy inorganic chemicals to help make high-energy organic compounds.
      - Some of this energy is:
        - used to do work,
        - stored in the organic material that makes up their bodies
        - lost as heat (thermal energy) as energy is processed and work done

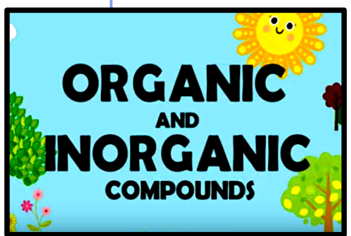


    - Heterotrophs (consumers & decomposers) absorb these high-energy organic chemicals
      - Some of this chemical energy is:
        - used to do work,
        - stored in the organic material that makes up their bodies
        - lost as heat (thermal energy) as energy is processed and work done



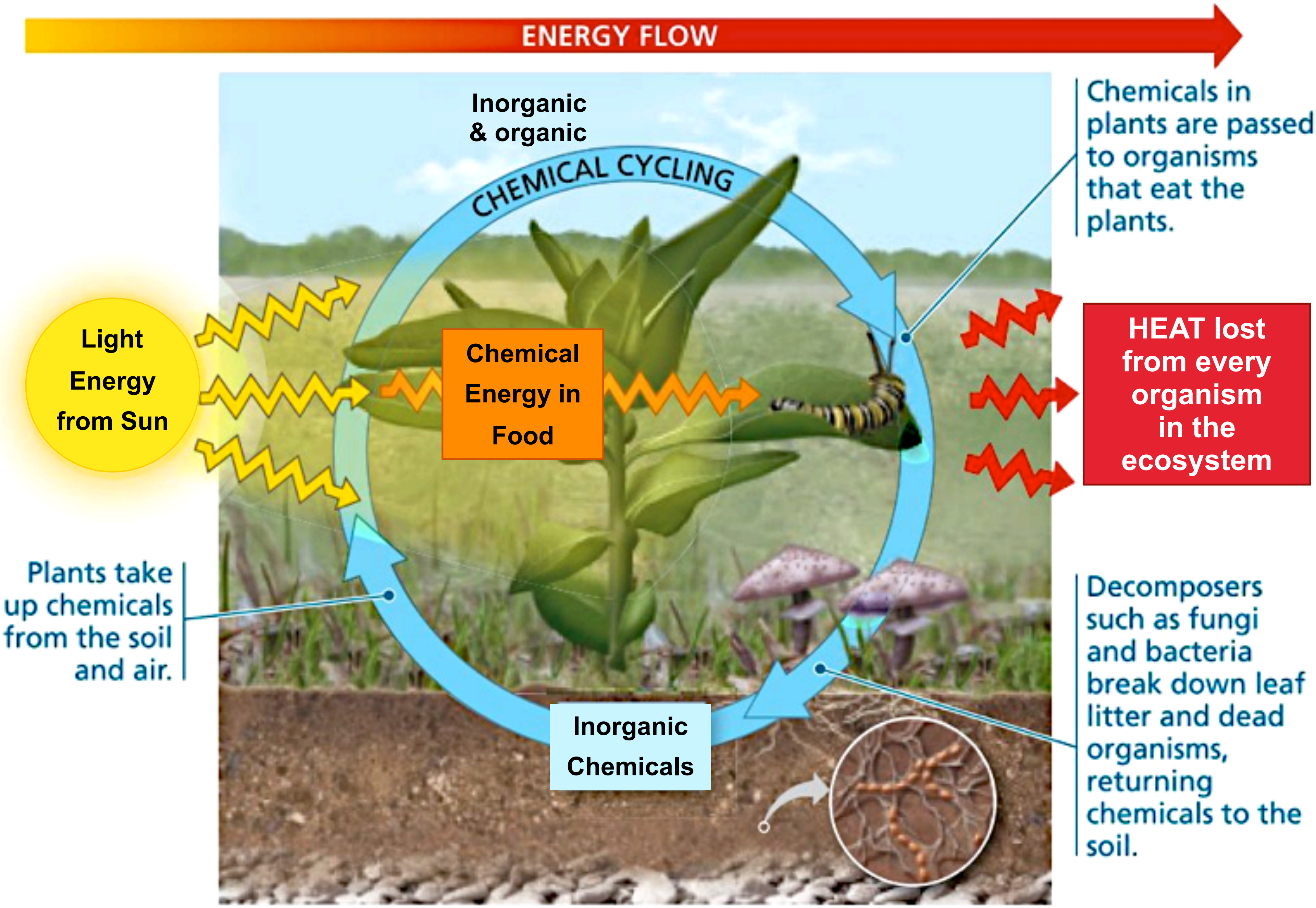
Ecosystems & Chemical Cycling

- The Movement of Matter in Ecosystems
  - Photosynthetic and chemosynthetic organisms (producers) take up these elements in inorganic form (ions and inorganic molecules) from the air, soil, and water
    - They incorporate these into organic molecules (such as proteins, carbohydrates, lipids, nucleic acids)



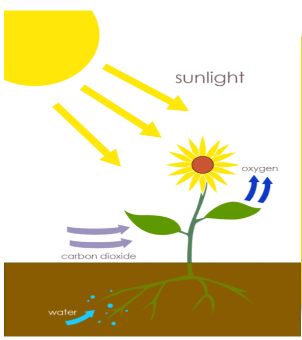
  - Through the metabolism of Producers, Consumers, Decomposers organic molecules (such as proteins, carbohydrates, lipids, nucleic acids) are converted back into inorganic form (ions and inorganic molecules) in the air, soil, and water.
    - Decomposers include certain bacteria and fungi that break down organic waste and dead organisms into inorganic material

- Energy and chemicals are transformed in ecosystems through processes like photosynthesis and the feeding relationships between organisms in communities.


ENERGY FLOW
Inorganic & organic
CHEMICAL CYCLING
Chemicals in plants are passed to organisms that eat the plants.
Light Energy from Sun
Chemical Energy in Food
HEAT lost from every organism in the ecosystem
Plants take up chemicals from the soil and air.
Decomposers such as fungi and bacteria break down leaf litter and dead organisms, returning chemicals to the soil.
Inorganic Chemicals

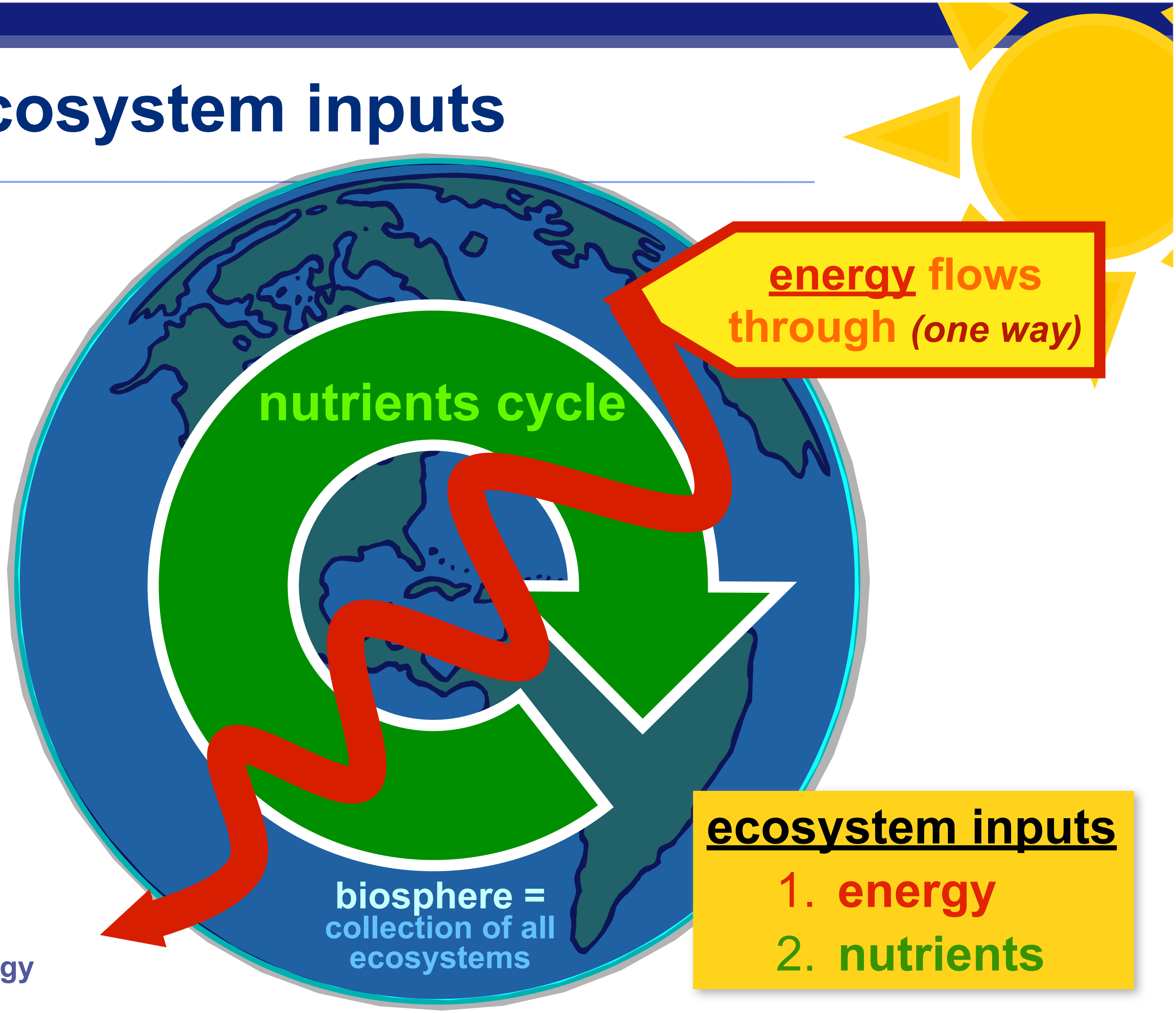
Ecosystem

- Ecosystems are **transformers of energy** & **processors of matter**
  - *First Law of Thermodynamics* - ***Energy cannot be created or destroyed, only transferred and transformed***
  - *Law of Conservation of Mass* - ***matter cannot be created or destroyed*** *(it cycles within an ecosystem or between ecosystems in the biosphere)*
- Ecosystems are self-sustaining
  - what is needed?
    - Ways to....



1. capture energy
2. transfer energy
3. cycle nutrients

Ecosystem inputs



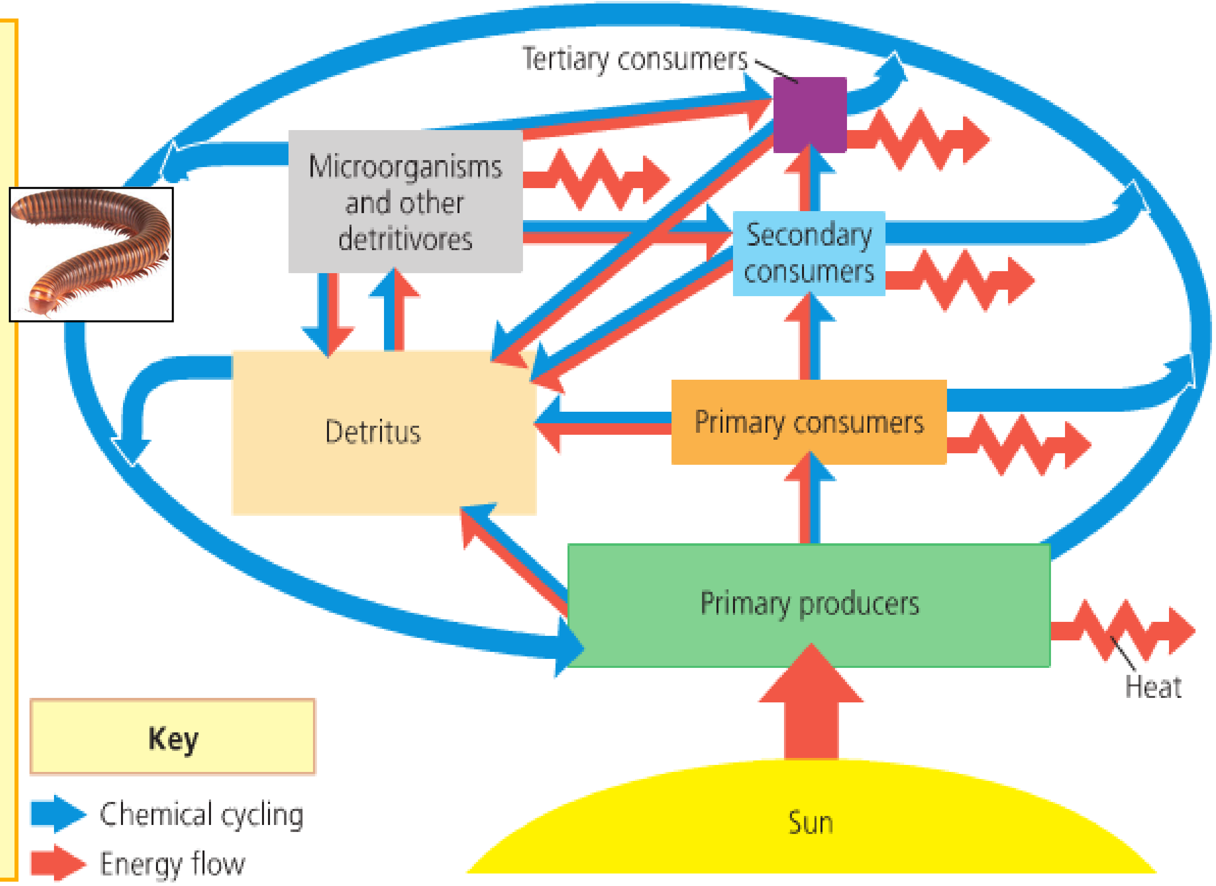
Like organisms, ecosystems are open systems

- Ecosystems absorb energy and matter/mass from outside
- Ecosystem release heat and waste products to the outside
    - Most ecosystem gains and losses of matter are small
        - However, if nutrient losses exceed nutrient inputs that lack of nutrient will eventually production in that ecosystem
            - Human activities can affect the balance of inputs & outputs in ecosystems

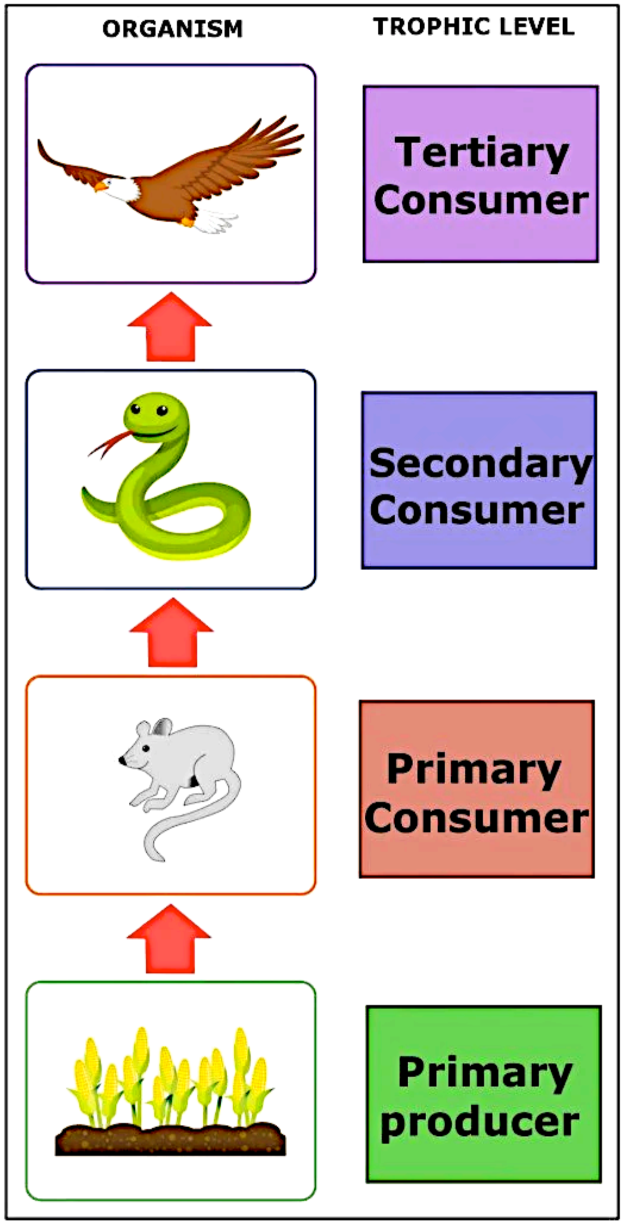
DETRITUS:
non-living organic material like bodies or fragments of dead organisms & fecal material.

DETRIVORES (earthworms, certain insects, vultures etc.)
Contribute to decomposition by feeding off decomposing dead organic matter/parts

DECOMPOSERS:
Fungi & Bacteria that in return molecular and ionic nutrients used by producers to the soils after absorbing organic matter at the molecular scale

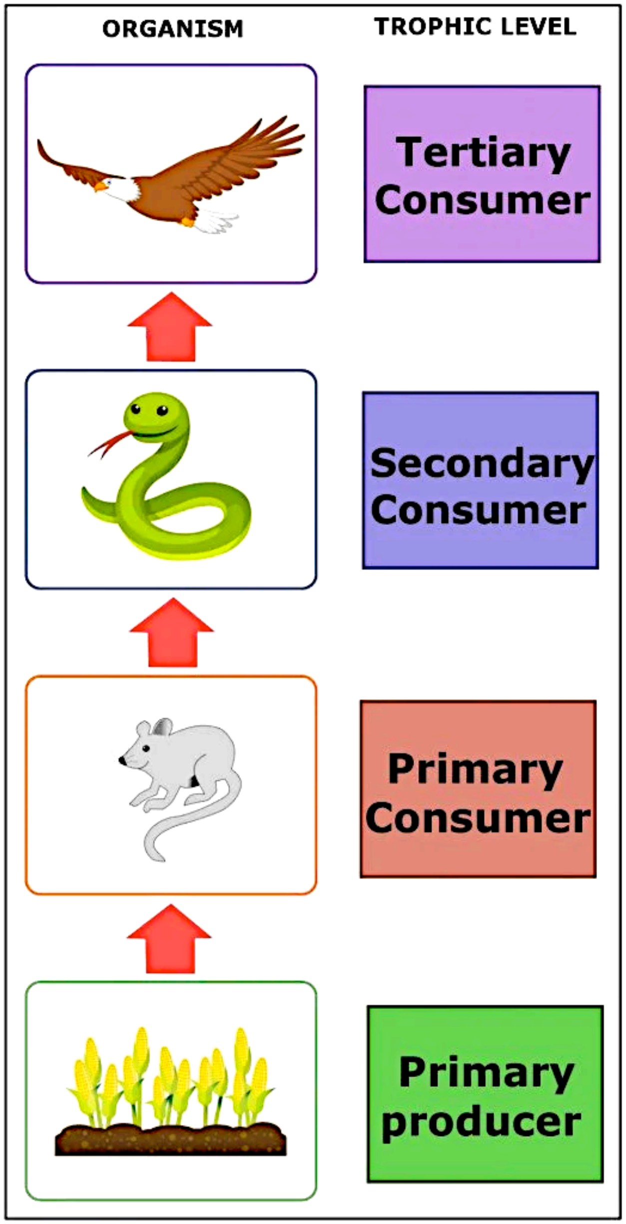


Trophic Levels in Ecosystems



- Ecologists group species in an ecosystem into trophic levels based on feeding relationships
  - The trophic level that supports ALL other organisms consists of autotrophs, also known as Primary Producers
    - Most autotrophs are photosynthetic plants, algae, and blue-green bacteria that light energy to synthesize sugars and other organic compounds which they use for cellular respiration and for building materials to grow
      - Some autotrophs are nonphotosynthetic chemotrophic bacteria in deep-sea hydrothermal vents
  - Arrows indicate direction of energy flow!

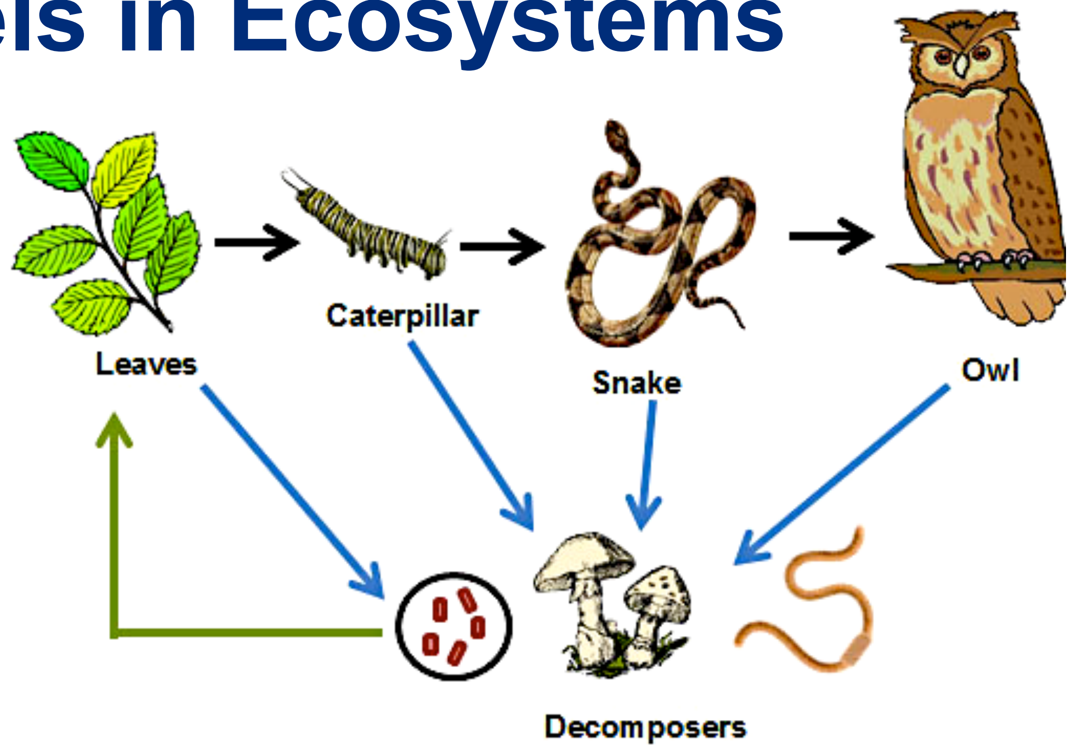
Trophic Levels in Ecosystems



- Organisms in the trophic levels above the primary producers are heterotophs, also known as Consumers
  - Consumers depend directly or indirectly for energy on the outputs of primary producers
    - Herbivores = Primary Consumers = eat plants and primary consumers
    - Carnivores = Secondary Consumers = eat herbivores
    - Carnivores = Tertiary Consumers = eat Secondary Consumers
    - Carnivores = Quaternary Consumers = eat Tertiary Consumers
      - Top carnivores or apex predators occupy the highest trophic level in an ecosystem

Trophic Levels in Ecosystems

- A final set of heterotophs, are known as Decomposers
  - Decomposers consume detritus (nonliving organic material like in feces, fallen leaves, dead organisms' bodies)
    - Mostly fungi and bacteria
      - Secrete enzymes that break down organic macromolecules of other organisms (producers & consumers) so they can absorb these organic molecules as nutrients *(along with water and ions/polyatomic ions)*
      - Through the secretion of metabolic waste produced as they metabolize organic molecules and when they die, decomposers return inorganic products back into the soil, air, and water.
        - FYI: Decomposers may be consumed by consumers in other trophic levels



- Decomposers end up recycling chemical elements from producers and consumers in ALL other trophic levels so they become available again in inorganic form to producers

All organisms lose HEAT as they perform work and metabolic functions

- **When is heat released from living cells (endo- or ectotherms)?**
  - **When a cell does WORK heat is lost!!!** *(nonspontaneous process)*
    - When ATPs are hydrolyzed to power endergonic chemical reactions, some of the chemical energy is lost as thermal energy (HEAT) while the rest of the energy gets stored in the chemical bonds of the products made.
    - When ATPs are hydrolyzed to phosphorylate proteins and these covalently-bonded phosphates are later removed (Ex: when ATP is powering the membrane pumps used for active transport) the chemical energy stored in the original ATP molecule is lost as thermal energy (HEAT)
    - When electrical or chemical gradients dissipate (disappear) as particles diffuse back down their gradients, some potential energy initially stored in the gradient and not moved into another gradient or onto another molecules built is lost as HEAT.
    - When GTPs are hydrolyzed to power the endergonic process of building polypeptides in ribosomes (dehydration synthesis), some of the chemical energy is lost as thermal energy (HEAT) while the rest of the energy gets stored in the peptide bonds of polypeptides/proteins.
    - When the terminal pyrophosphates (P-P) from dATP, dGTP, dTTP, dCTP are removed and then hydrolyzed into Pi and Pi to provide the energy DNA Polymerase needs to add the remaining dAMP, dCMP, dTMP, dCMP nucleotides to the growing DNA strand being built, some chemical energy is lost as thermal energy (HEAT) while the rest is stored in the phosphodiester bonds built.
    - When the terminal pyrophosphates (P-P) from ATP, GTP, UTP, CTP are removed and then hydrolyzed into Pi and Pi to provide the energy RNA Polymerase needs to add the AMP, CTP, UMP, CMP nucleotides to the growing RNA molecule being built, some chemical energy is lost as thermal energy (HEAT) while the rest is stored in the phosphodiester bonds built.

All organisms lose HEAT as they perform work and metabolic functions

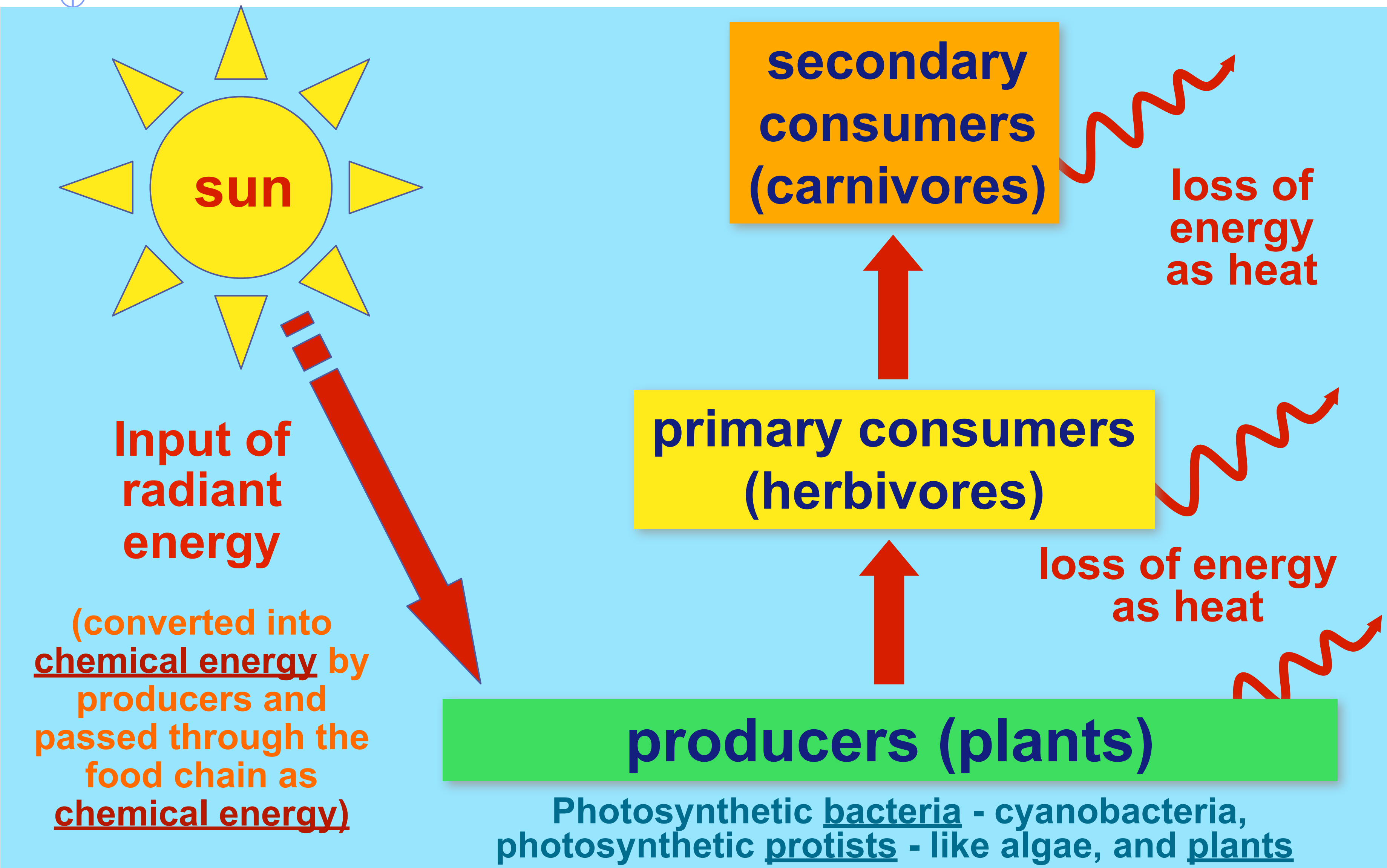
- In environments that have ambient temperatures lower than the body temperatures maintained by endotherms, Endotherms (where a temperature gradient continually exists between the body and outside) will lose more heat per unit of time than Ectotherms (whose body temperatures reach equilibrium with ambient temperatures)
  - Endotherms CAN use aerobic cellular respiration chemistry for more than just making ATP.
    - Endotherm can break down additional organic molecules (glucose, fats, acetyl-CoAs etc) to release thermal energy into the cell from the high-energy electrons obtained from these organic molecules to counteract their body's heat loss.

  - Most Ectotherms ONLY use aerobic cellular respiration chemistry to transfer chemical energy from high-energy organic molecules onto the ATP built.

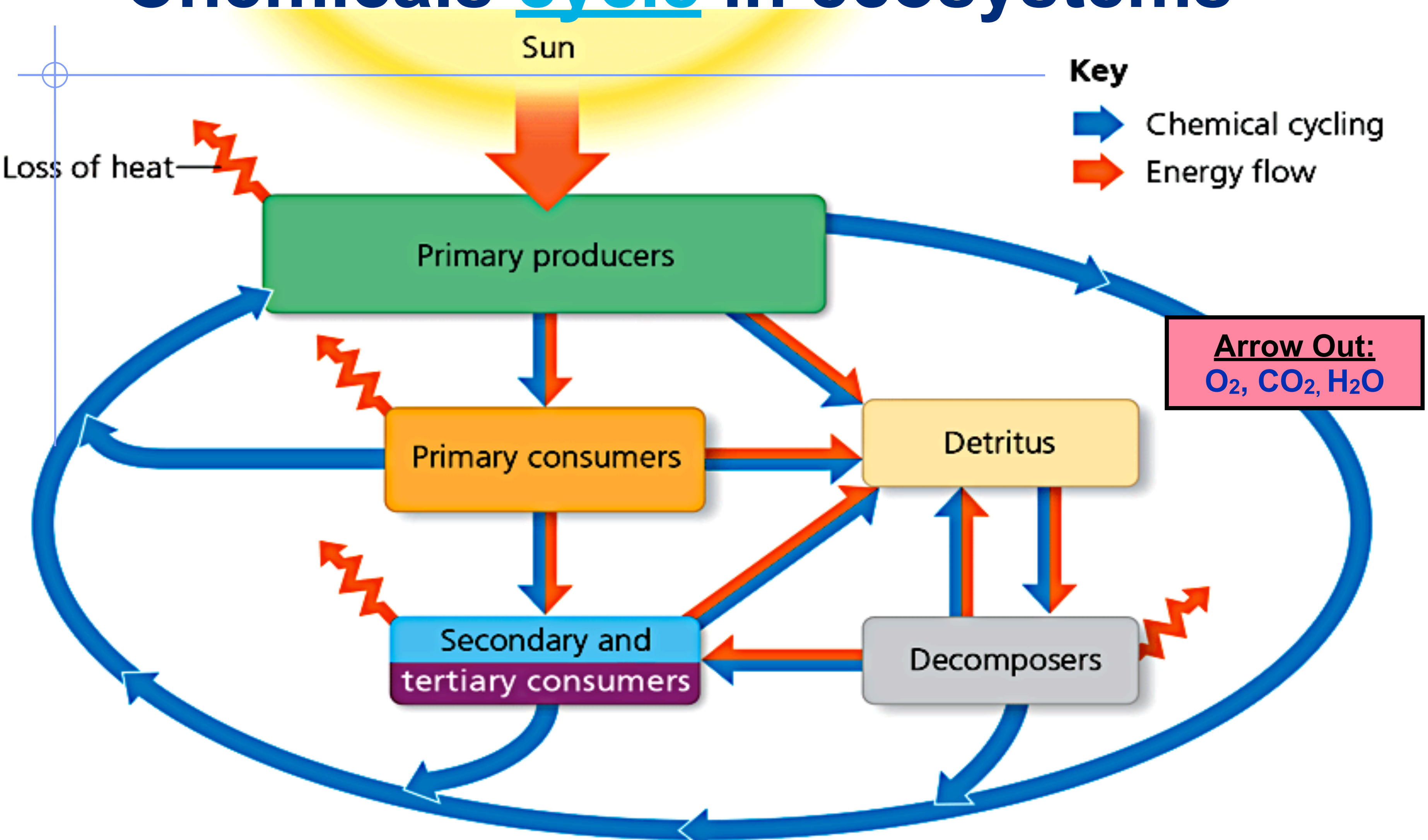
    - During this process some heat is still lost but they cannot "generate" additional heat beyond this.
      - Most Ectotherms CANNOT use aerobic cellular respiration chemistry to release additional heat from organic molecules necessary to maintain constant warmer body temperatures

Energy flows through ecosystems

(Organisms in every trophic level lose energy as HEAT)

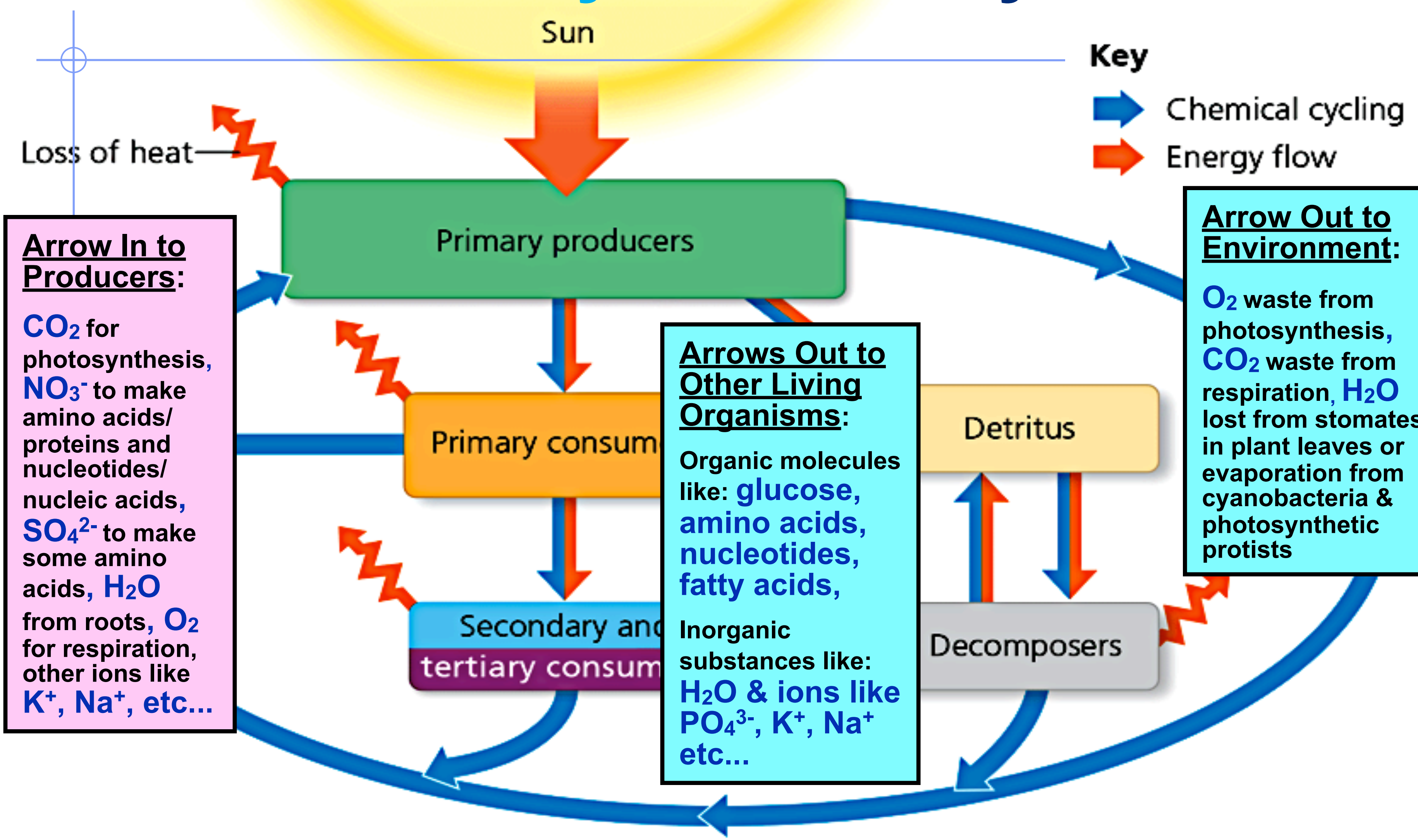


Chemicals cycle in ecosystems



- **Here, one blue arrow flows into primary producers but three flow out. For each arrow, describe an example of nutrient transfer that the arrow could represent, using specific organisms or components in your answer.**

Chemicals cycle in ecosystems



Arrow In to Producers:

CO_2 for photosynthesis, NO_3^- to make amino acids/ proteins and nucleotides/ nucleic acids, SO_4^{2-} to make some amino acids, H_2O from roots, O_2 for respiration, other ions like K^+, Na^+, etc…

Arrows Out to Other Living Organisms:

Organic molecules like: glucose, amino acids, nucleotides, fatty acids,

Inorganic substances like: H_2O & ions like PO_4^{3-}, K^+, Na^+ etc…

Arrow Out to Environment:

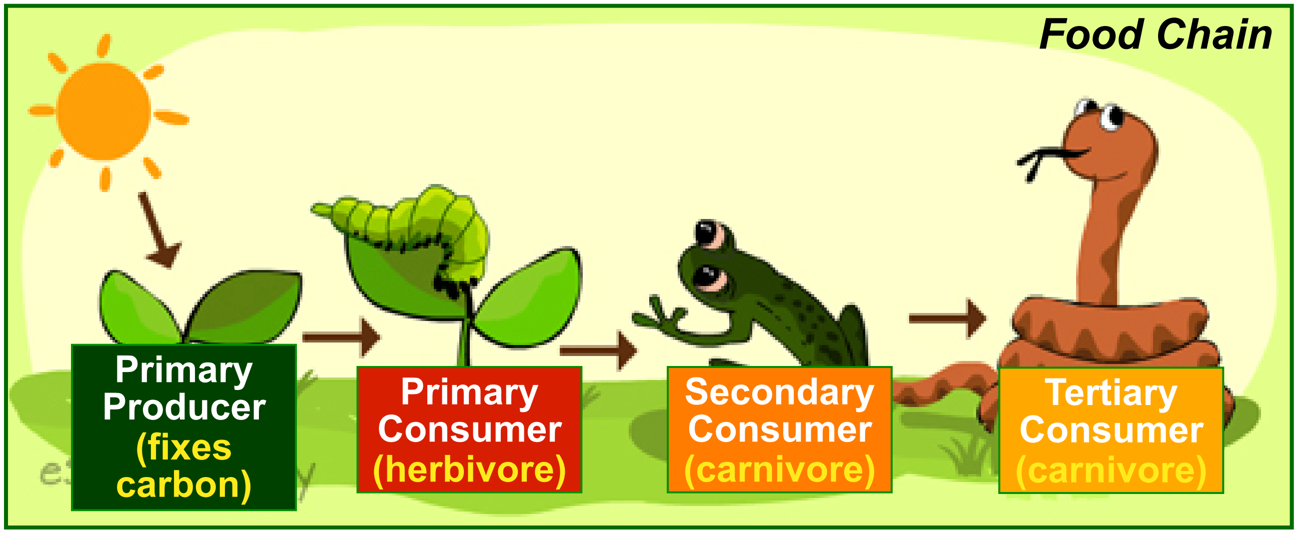
O_2 waste from photosynthesis, CO_2 waste from respiration, H_2O lost from stomates in plant leaves or evaporation from cyanobacteria & photosynthetic protists

- **Here, one blue arrow flows into primary producers but three flow out. For each arrow, describe an example of nutrient transfer that the arrow could represent, using specific organisms or components in your answer.**

Trophic Structures

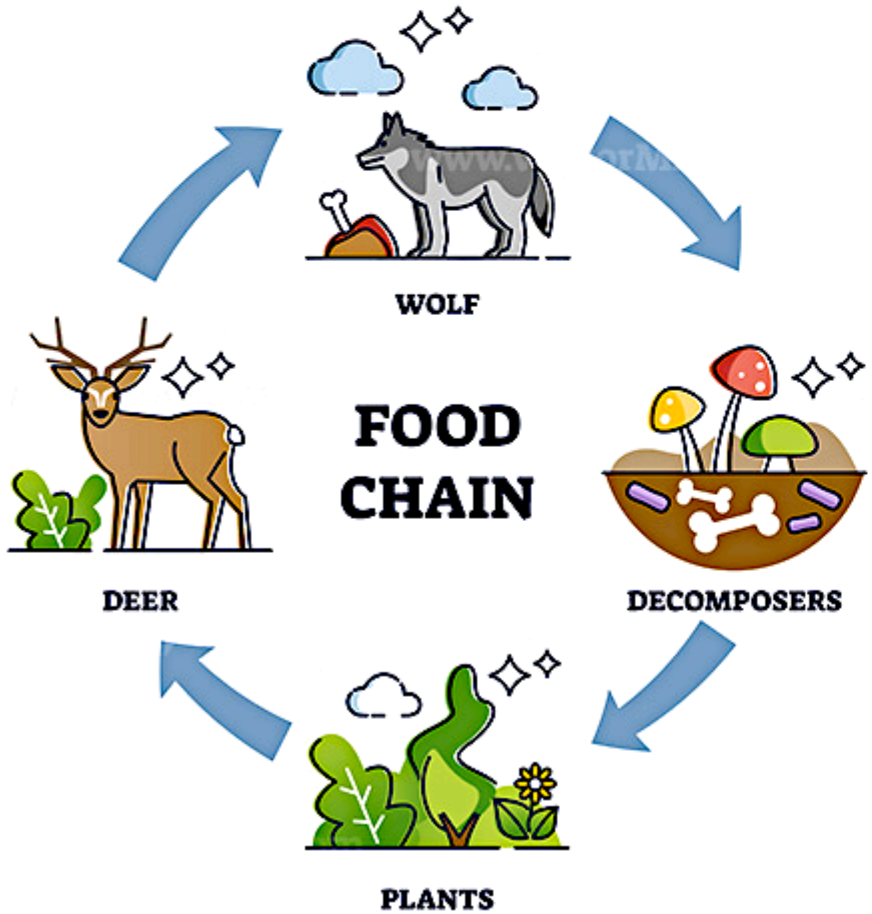
- **Trophic Structure = Feeding relationship between organisms in a community**
  - **Trophic structures can be visually represented as food chains & food webs**
    - **Food Chains = Show the transfer of energy from its source in photosynthetic organisms to decomposers**
    - **Food Webs = Show multiple food chains linked together** ***(a more realistic picture of energy transfer in communities)***
      - **Energy moves from the one eaten to the one doing the eating!**

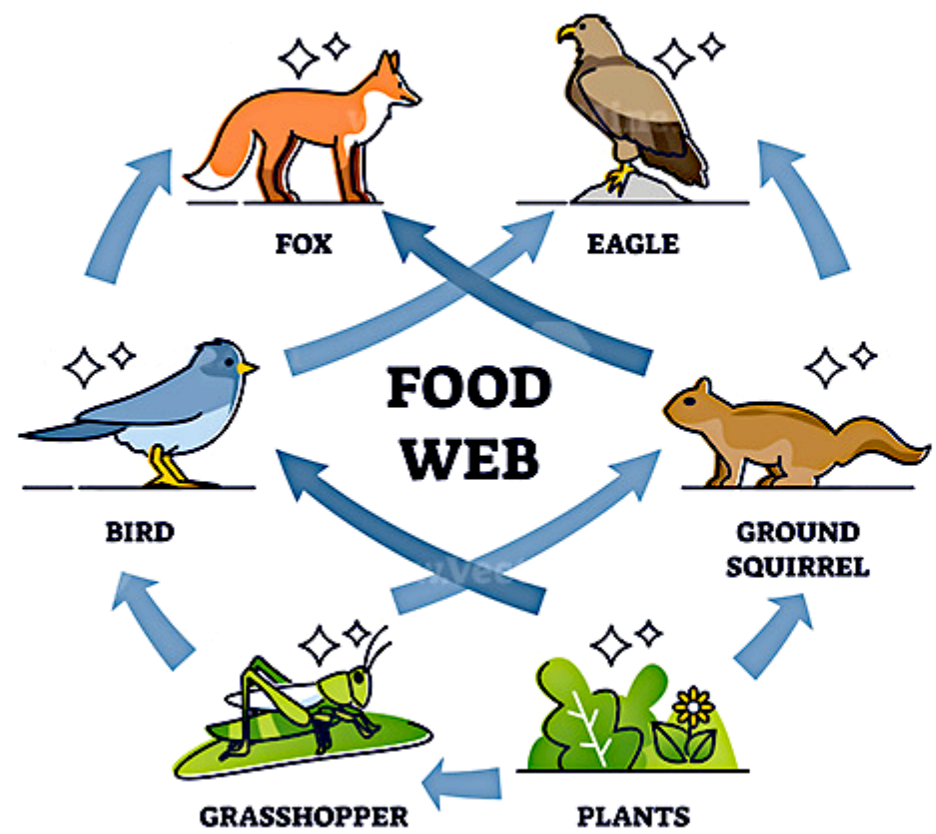
Arrows show the movement of energy!



Food Chain vs Food Web

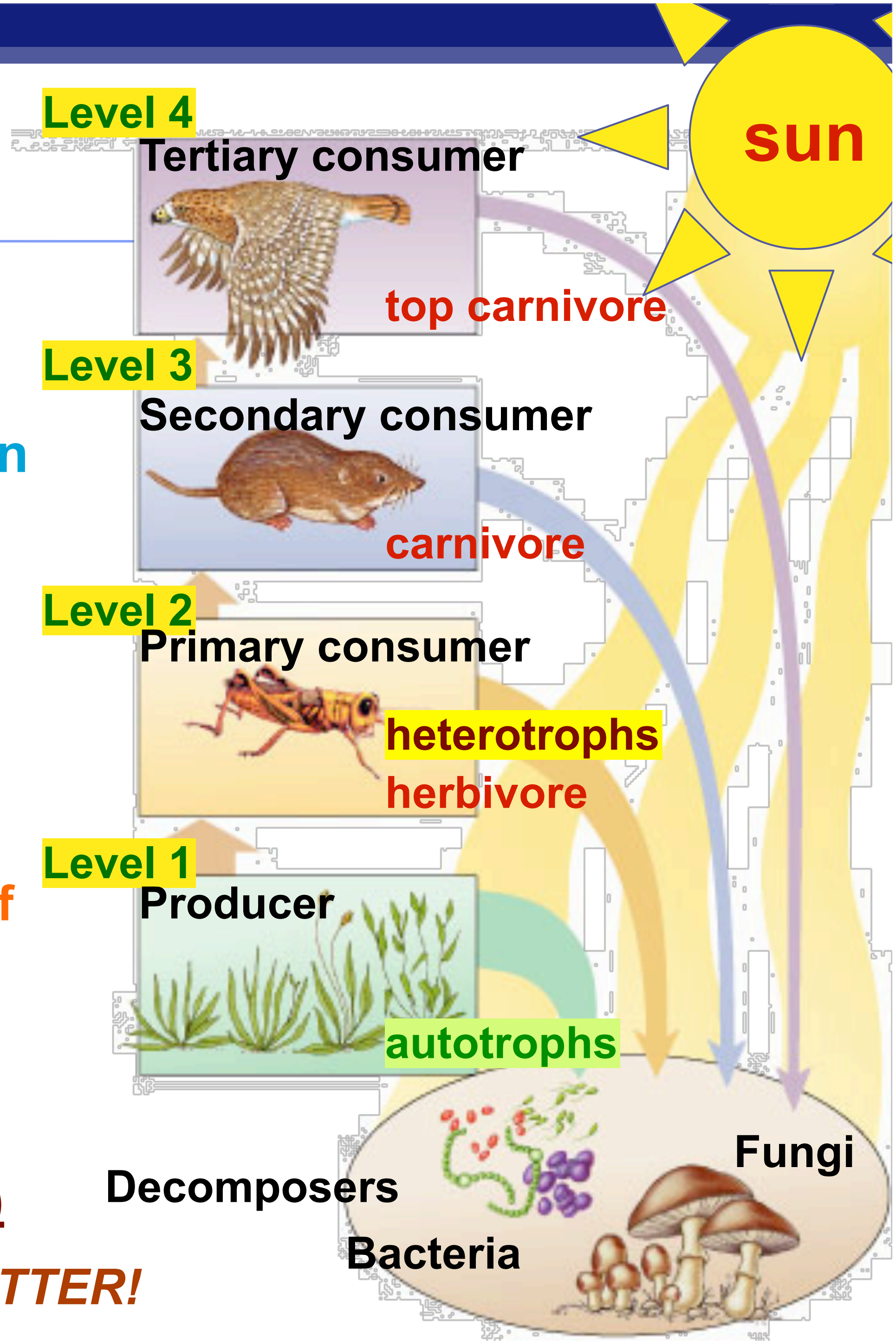
- **Arrows show <u>direction of energy flow</u> as high-energy organic molecules pass from organisms in one trophic level to those in the next.**
  - **In reality though, decomposers obtain energy from all trophic levels not just the top consumer (food chain below) and are a part of <u>every food web</u>!**





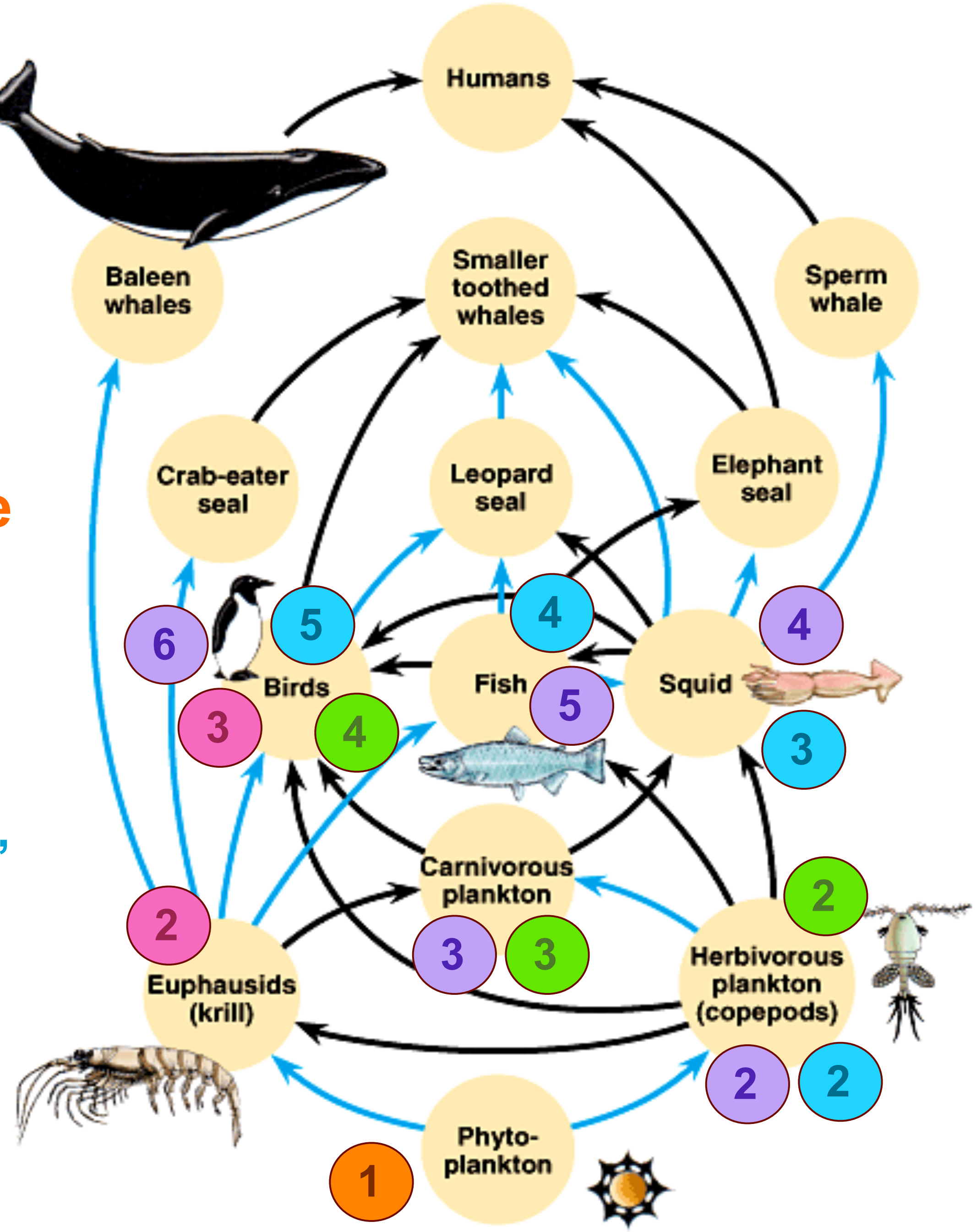
Food chains

- Trophic levels
  - feeding relationships
  - start with energy from the sun captured by plants, algae, & cyanobacteria
    - 1st level of all food chains
  - food chains usually go up only 4 or 5 levels!!!
    - Because of the inefficiency of energy transfer *(energy is lost as heat is lost along the way)*
  - ALL levels connect to decomposers (& detrivores)
    - ***REQUIRED TO RECYCLE MATTER!***



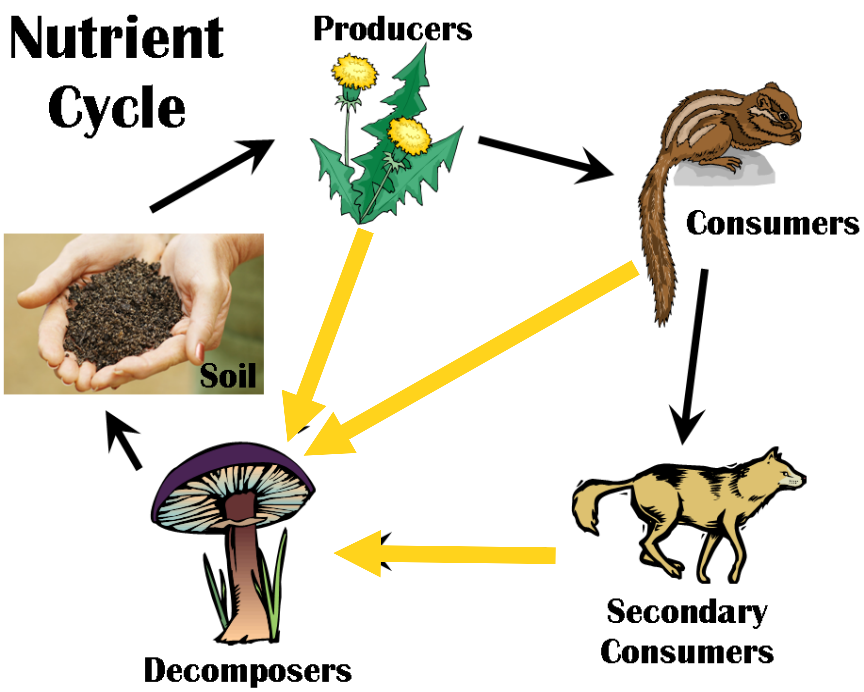
Food webs

- Food chains are linked together into **food webs**
- Who eats whom?
  - a species may weave into web at more than one level
    - think of bears
    - think of humans
      - eating meat, plants, or both?
        - In the example, the penguin occupies the 3*, 4*, 5*, & 6* trophic levels

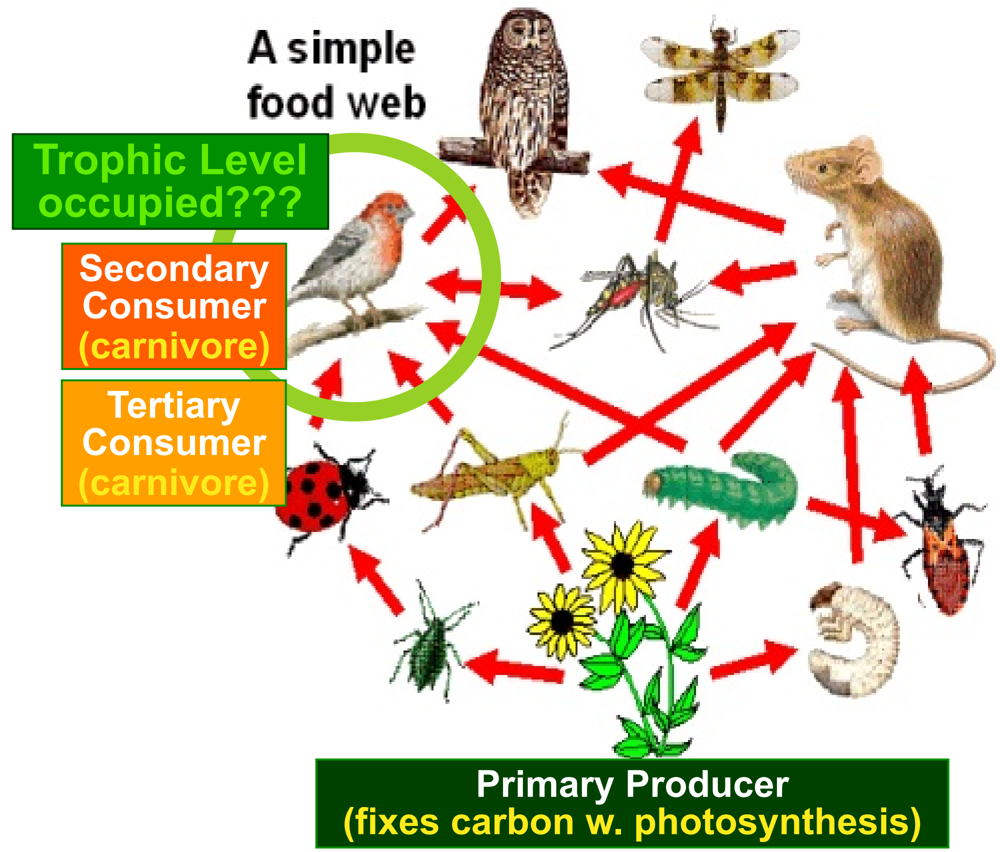


Trophic Structures

- <u>A species may occupy more than one trophic level</u>
  - Each food chain is only a few links long
    - <u>Most</u> have 5 or fewer trophic levels



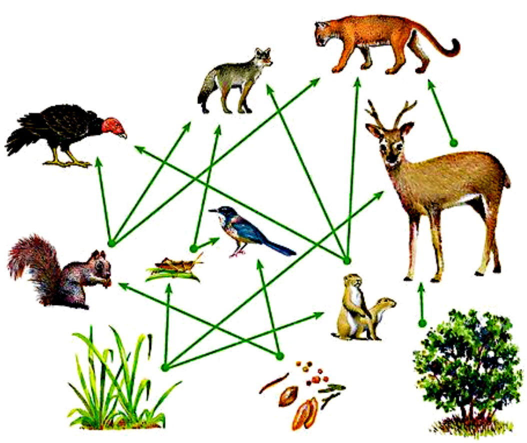
<u>Decomposers</u> obtain energy from ALL other trophic levels



Trophic Cascades

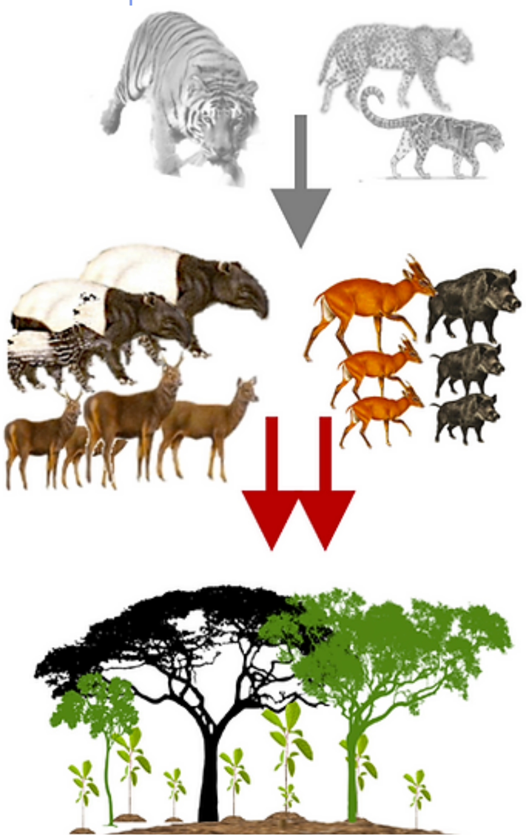
- Interactions and feeding relationships between species in the ecosystems keep the entire system in balance
  - Healthy ecosystems have both top-down and bottom-up process that help maintain species populations in a dynamic equilibrium.

- When an ecosystem trophic level (or a species within a trophic level) is reduced or removed, the consequences are felt at all trophic levels.
  - This loss of biodiversity due to changes in trophic level population sizes is caused by a trophic cascade.
    - Trophic cascades are commonly seen when keystone species are removed from the ecosystem, resulting in a loss of species richness (# of other species).
    - Trophic level 4 and 5 usually include apex predators that keep the lower trophic levels in check by controlling population sizes of trophic level 3 or 4.
      - This allows healthy population sizes of species in trophic levels 1 or 2
        - This is why apex predators are sometimes found to be keystone species.



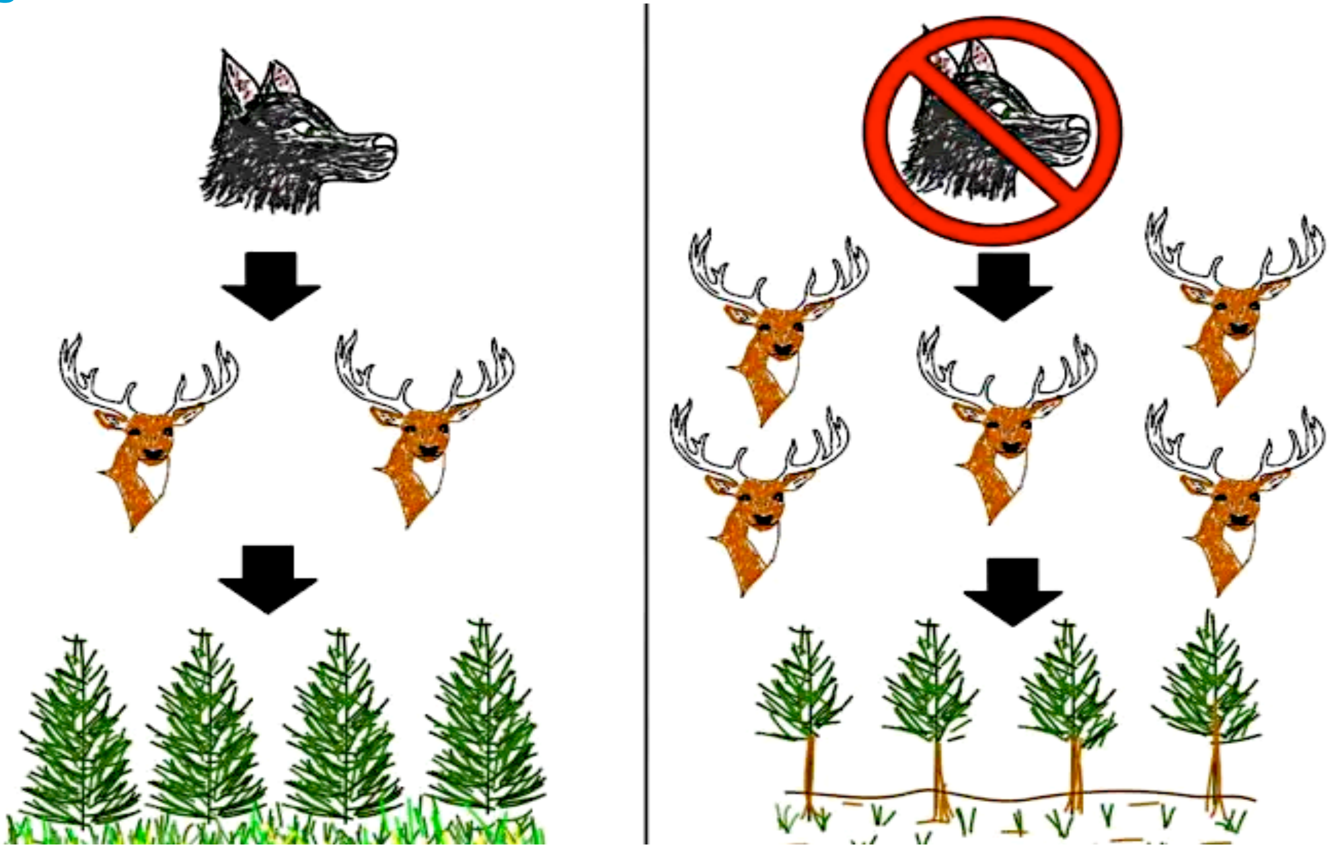
Top-Down Trophic Cascade

- **Top-Down Trophic Cascade**
  - **A top-down cascade occurs in ecosystems where the top consumer or apex predator controls population of the primary consumer (herbivore).**
    - **This, in turn, allows the population of the primary producer (plant species) to thrive.**
    - **Removal of the top predator can result in alteration throughout the food web:**
      1. **There can be a rise in primary consumers if apex predator fed on herbivores (leading to overpopulation)**
      2. **There would then also be an over-exploitation of the primary producers (loss of population size).**
      3. **Eventually, there are too few producers to sustai the increased amount of consumers.**
      4. **Increased fight over food, due increased competition, results alongside increased starvation and death.**



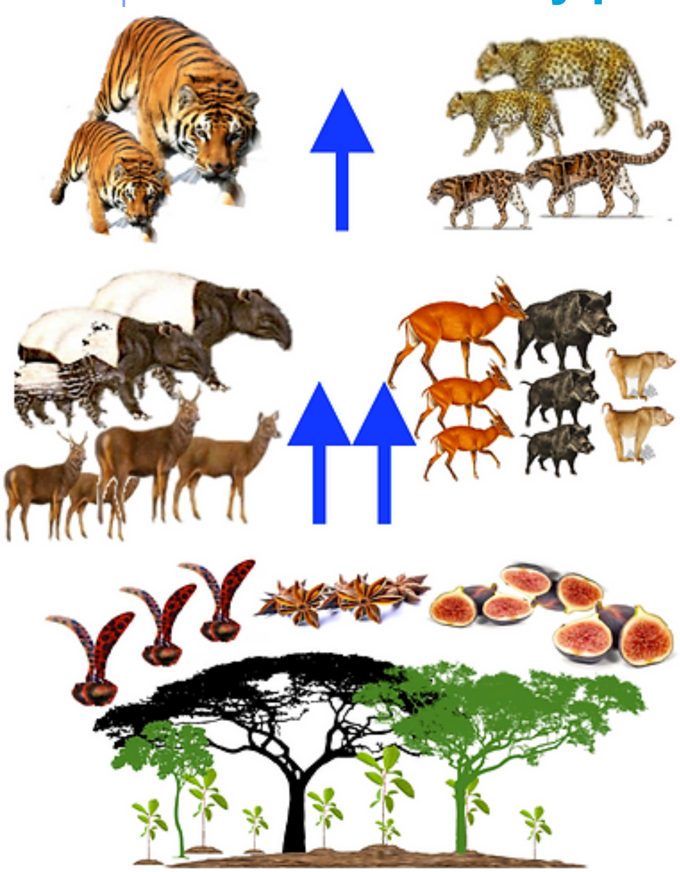
Top-Down Trophic Cascade

- **In a Top-Down Trophic Cascade, stability is dependent on competition and predation in higher trophic levels.**
  - **Invasive species can trigger this cascade by removing an existing apex predator, causing a drop in biodiversity of the primary producers or a trophic level near the bottom of the food chain.**
    - **Note: If the invasive species takes the place of the apex predator and exerts control of the trophic level below it, this change may not necessarily be negative.**



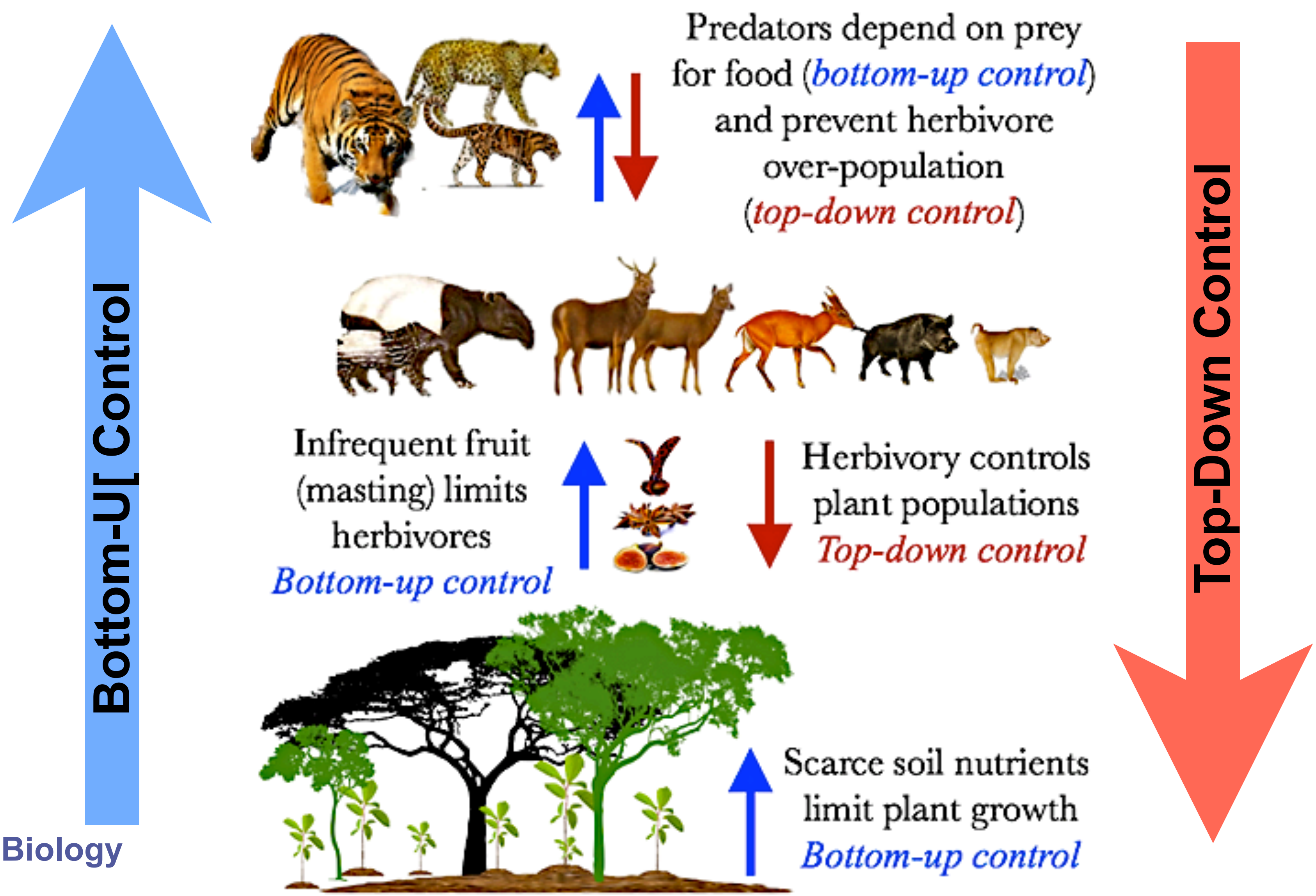
Bottom-Up Trophic Cascade

- Bottom-Up Trophic Cascade
  - The number of primary producers in the ecosystem controls the amount of energy carried to higher trophic levels
    - Primary producers store chemical energy and produce oxygen



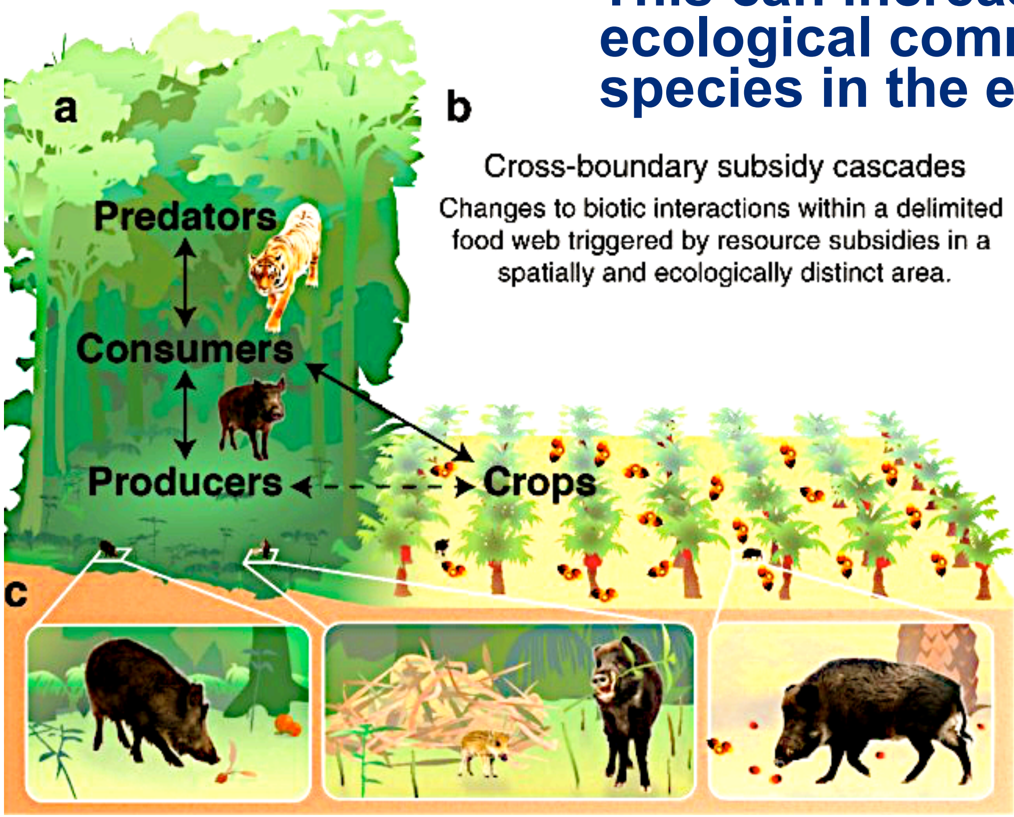
- Include plants, blue-green bacteria, and phytoplankton (aquatic photosynthetic protists and microorganisms)
  - The number of primary producers is altered by the amount of nutrients in the habitat (soil and water).
    - Removal of the primary producers causes negative effects throughout the food web:
      - Populations of all trophic levels will drop due to starvation (+ less energy availability)

Bottom-Up & Top-Down Controls



Subsidy Trophic Cascade

- Subsidy Trophic Cascade
  - The population of a particular species at specific trophic levels can be supported by an external food source.
    - Native animals can forage the resources that don't originate inside their same habitat
      - Ex: Native predator eating livestock passing by.
    -
      - This can increase the amount of predators in the ecological community, thus affecting other species in the ecosystem.

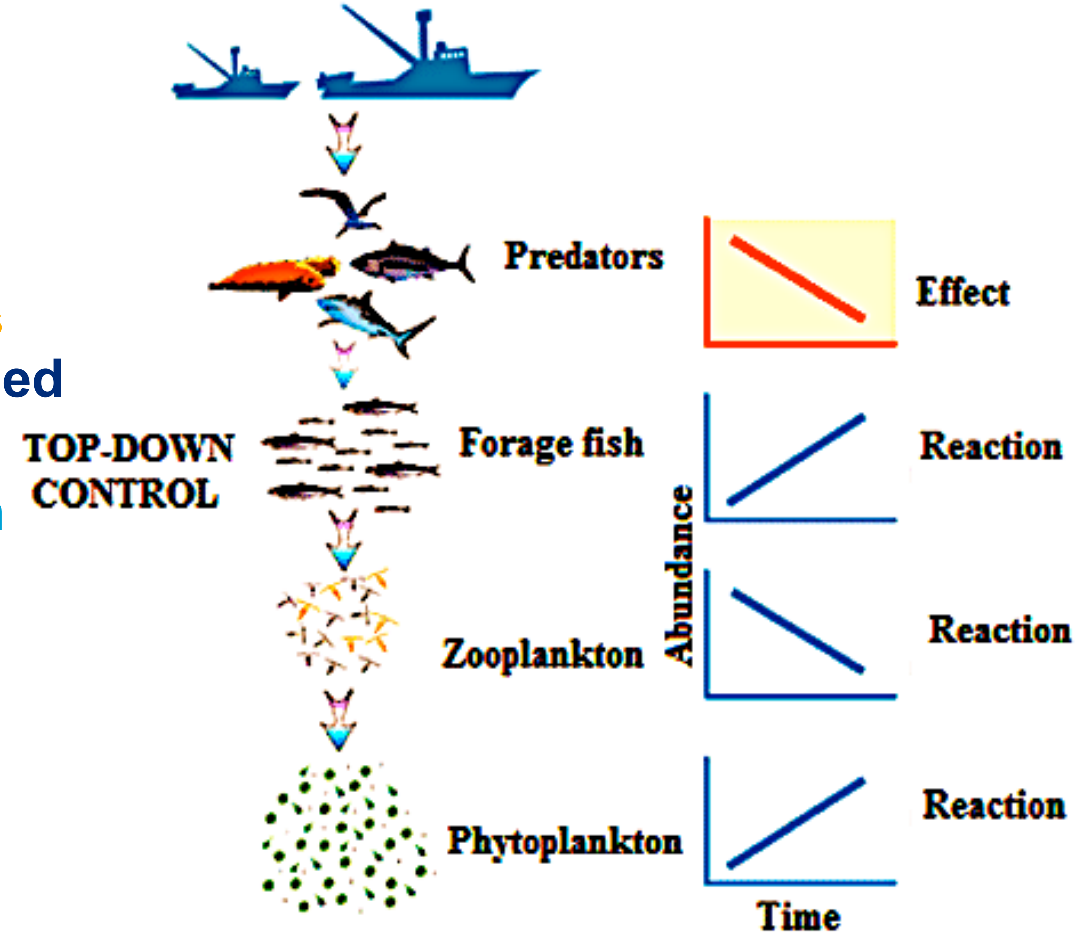


- This changes in one trophic level can result in an imbalance that may trigger a trophic cascade, triggering powerful secondary cascading effects on the food web.

Examples of Trophic Cascade

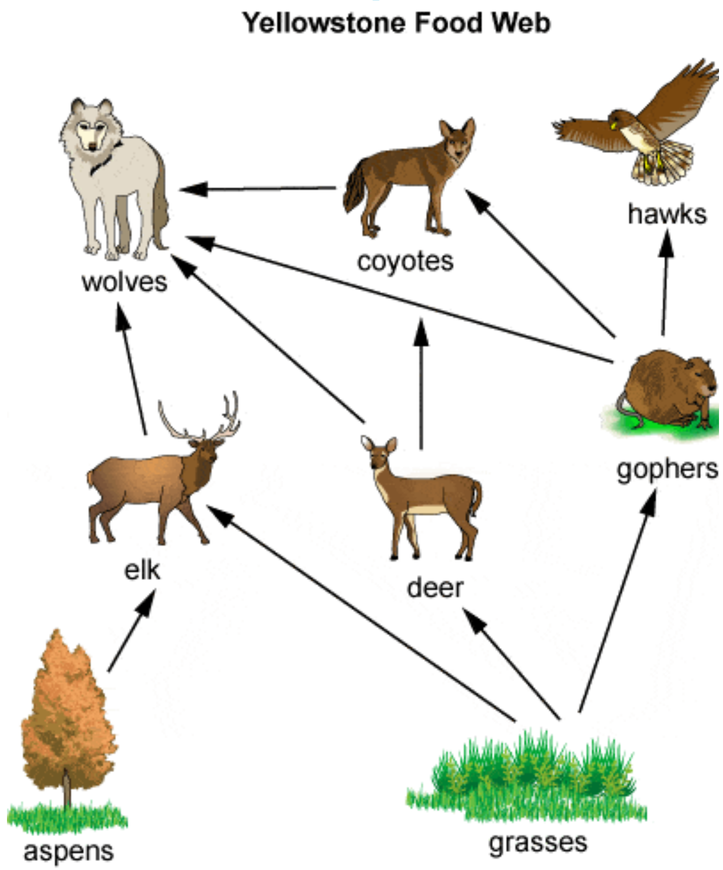
- **Trophic Cascade Effects on Marine Ecosystems**
  - Over-fishing of cod and other fish species commercially available in the North Atlantic Ocean has caused an increase in the smaller pelagic fish population, that would otherwise be eaten by cod.

- This led to a reduction in the population of herbivorous zooplankton (aquatic non-photosynthetic micro-organisms like protists), which is consumed by pelagic fishes
  - This led to an increase in the population of phytoplankton (aquatic photosynthetic micro-orgnisms like algae) due to reduced competition for nutrients from the water.



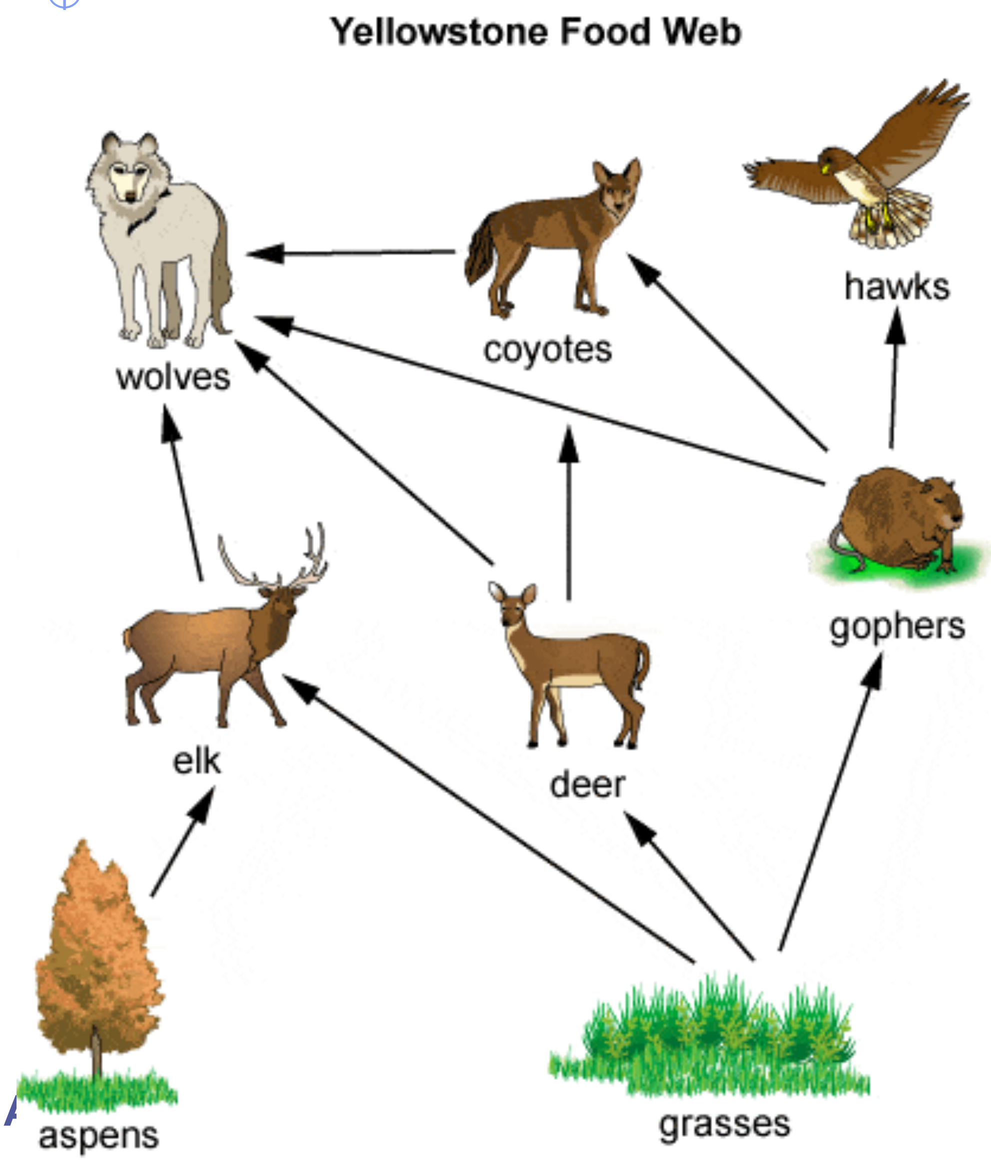
Examples of Trophic Cascade

- Trophic Cascade Effects on Terrestrial Ecosystems
  - **Wolves in Yellowstone National Park were reintroduced after an absence of 70 years.**
    - **A Top-down trophic cascade was initially observed when these species were removed from the Yellowstone national park.**



- **After reintroduction, positive effects of wolves have been identified in the ecosystem.**
  - **Elk were no longer scared of wolves. They've now learned to move faster and graze for shorter periods in a specific area, browsing on different species of vegetation and at different intensities.**
    - **This has allowed local vegetation to grow under much less pressure from grazing by elk and other grazers.**
    - **Stream bank vegetation has started to willow and aspen is growing again, for the first time after decades.**

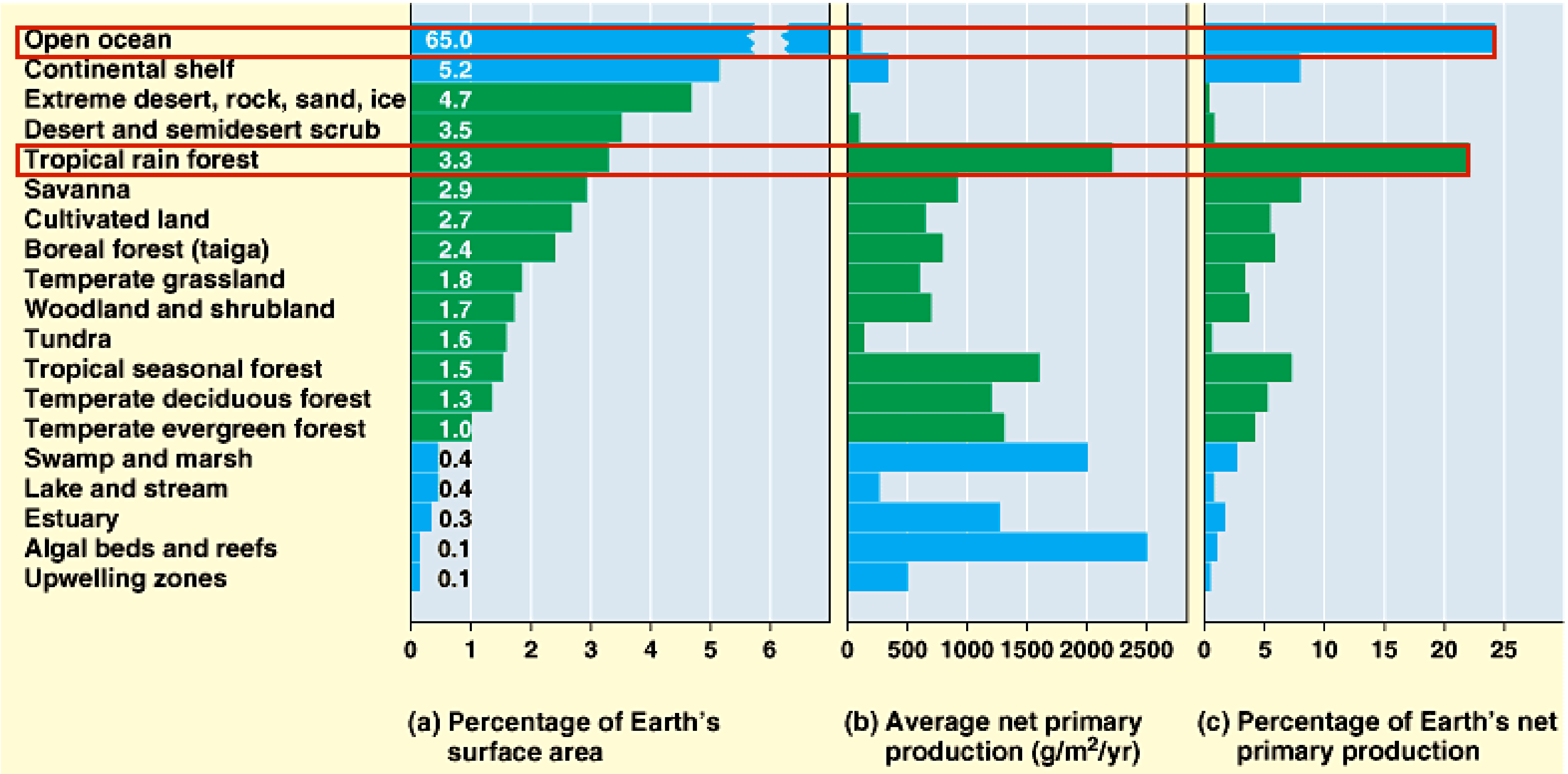
Examples of Trophic Cascade



- **Restoration of vegetation has allowed for the habitat of native birds, fish, and beaver and other species to flourish once again.**
- **Wolves have reduced the number of coyotes by 50% which is beneficial to the pronghorn, which has increased from 20% to a massive 70%.**

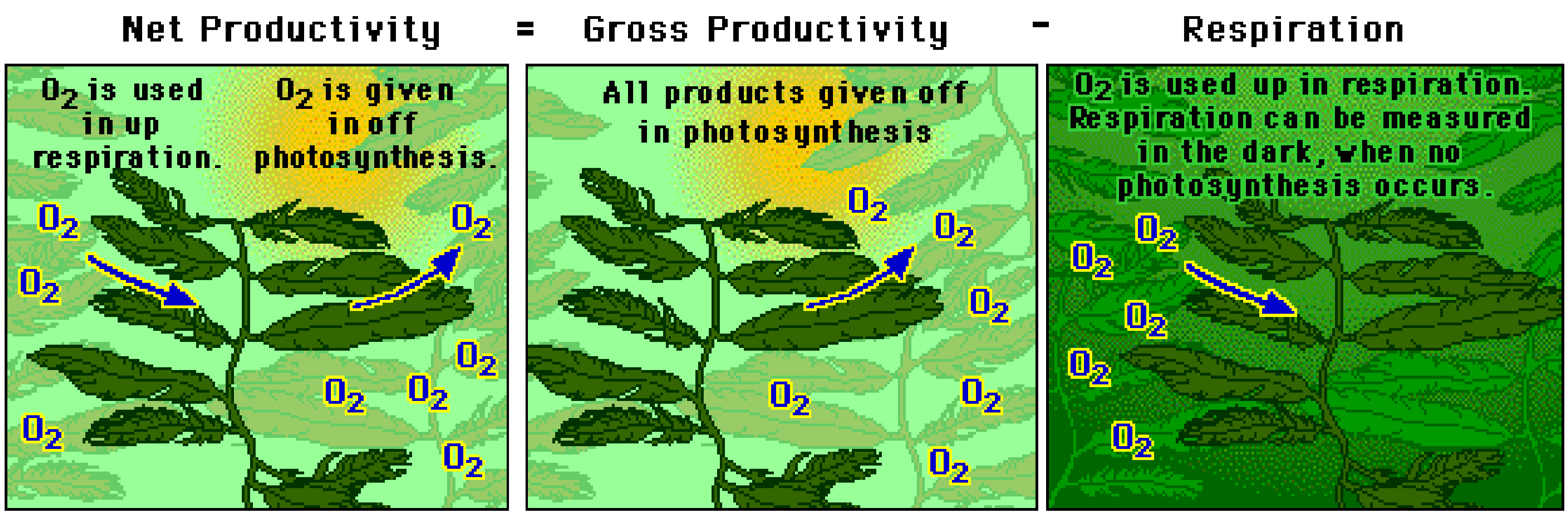
Ecosystem

- <u>Primary production</u> = the **rate** at which plants and other photosynthetic organisms produce organic compounds in an ecosystem *(ex. of unit: kcal/m²yr)*



Ecosystem

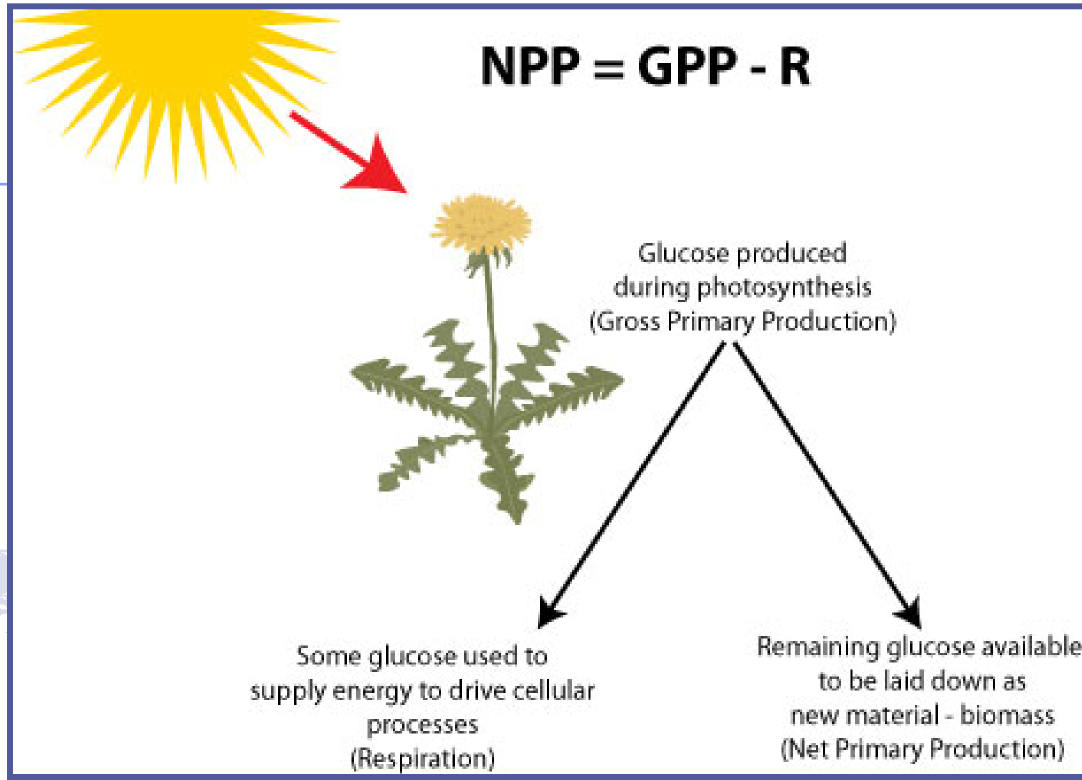
- There are two aspects of primary production:
  - (Gross) primary production (GPP) = the entire photosynthetic production of organic compounds in an ecosystem per unit of time.
    - *The rate at which solar energy is converted to chemical energy*
  - Net primary production (NPP) = the organic materials that remain after photosynthetic organisms have used some of these compounds for their cellular energy needs *(chemical energy extracted through cellular respiration for doing work).*

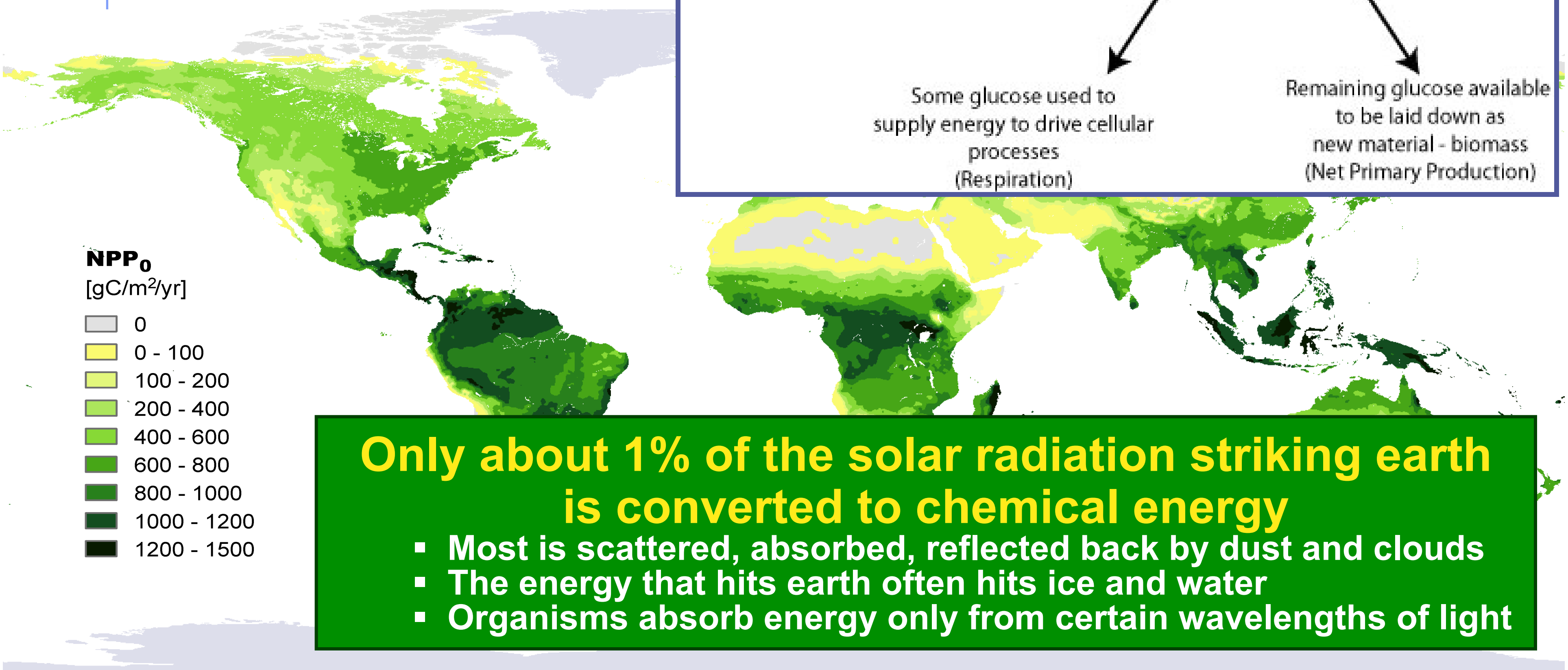


AP

Ecosystem

- ## NPP Worldwide
  - The tropics receive the greatest intensity of solar energy - ***most photosynthesis***





Only about 1% of the solar radiation striking earth is converted to chemical energy

- Most is scattered, absorbed, reflected back by dust and clouds
- The energy that hits earth often hits ice and water
- Organisms absorb energy only from certain wavelengths of light

Ecosystem

- NPP can also be expressed as the energy per unit are per unit time *(J/m^2yr)*
- NPP can also be expressed as the biomass (mass of vegetation) added to the ecosystem per unit of area per unit time *(g/m^2yr)*
  - *NPP is the amount of new biomass added in a certain period of time (BIOMASS IS A RATE)*
    - This is different from standing crop or standing crop biomass:
      - The total (often) dry mass (not rate) of photosynthetic autotrophs

Give it a try… "Primary Productivity"

Gross primary productivity is higher than net primary productivity. The difference between the two is

A. the amount of energy producers burn (lose) when they metabolize (perform cellular respiration & photosynthesis) and do work.

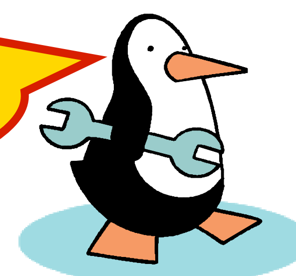
B. typically the ratio between the biomass of producers and the biomass of consumers.

C. an important measure of ecosystem productivity.

D. energy that is lost into outer space due to physiological inefficiencies.

E. untapped energy that is stored in plant roots.

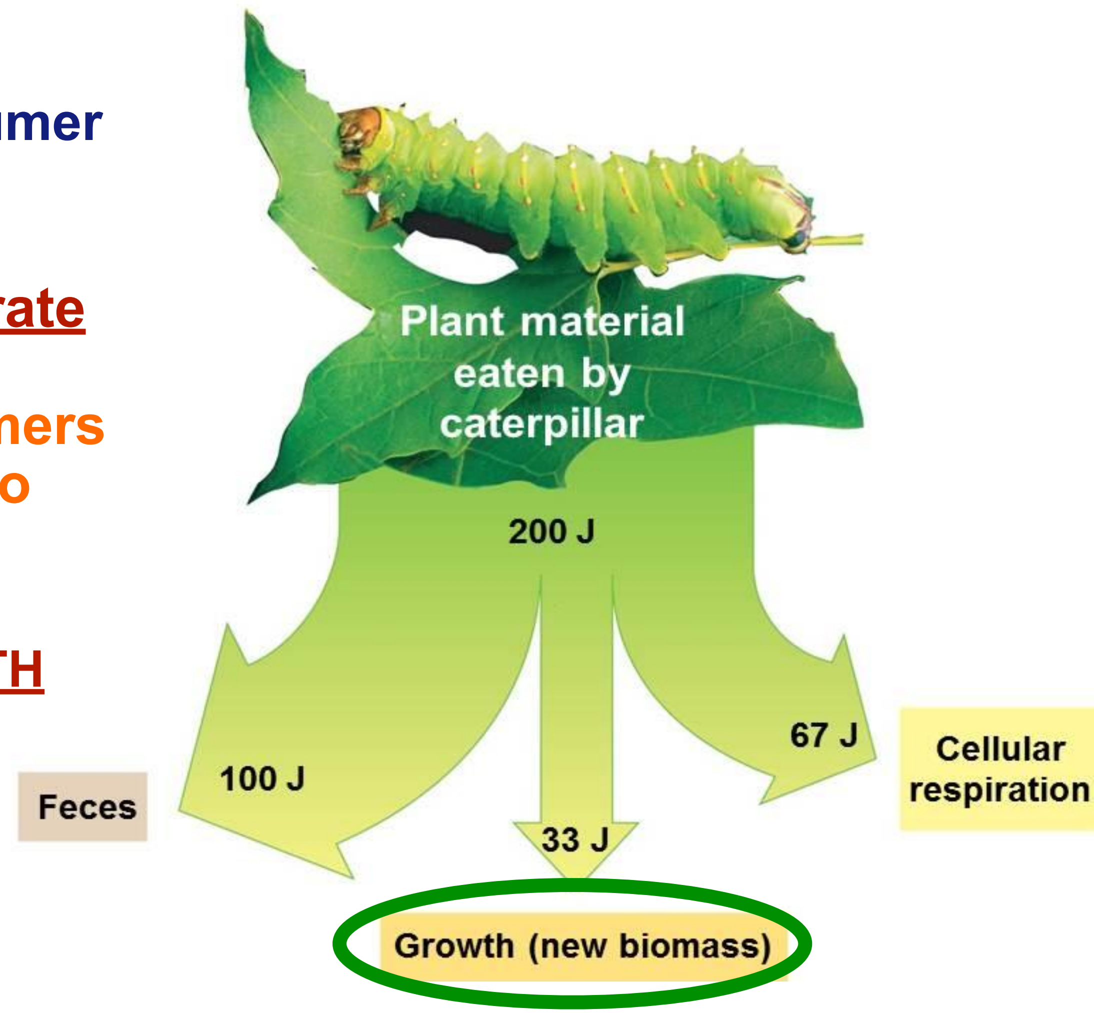
GPP = Amount chemical E stored through photosynthesis
NPP = Amount of chemical E available for the next trophic level.
NPP = GPP - Chemical E. lost due to Cellular Respiration



Inefficiency of energy transfer

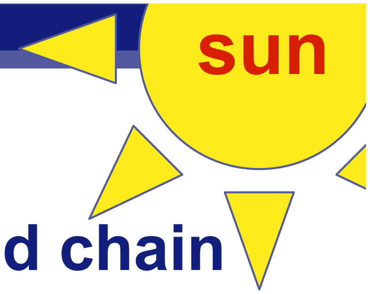
- Not all of the energy captured by primary producers (their gross primary production) passes on to the consumer and on.
  - **Secondary Productivity** = the **rate** at which chemical energy in a consumers food is converted to their own new biomass
    - Refers to **GROWTH**
      - Not the energy consumed by respiration

What happens to the energy a caterpillar consumes?

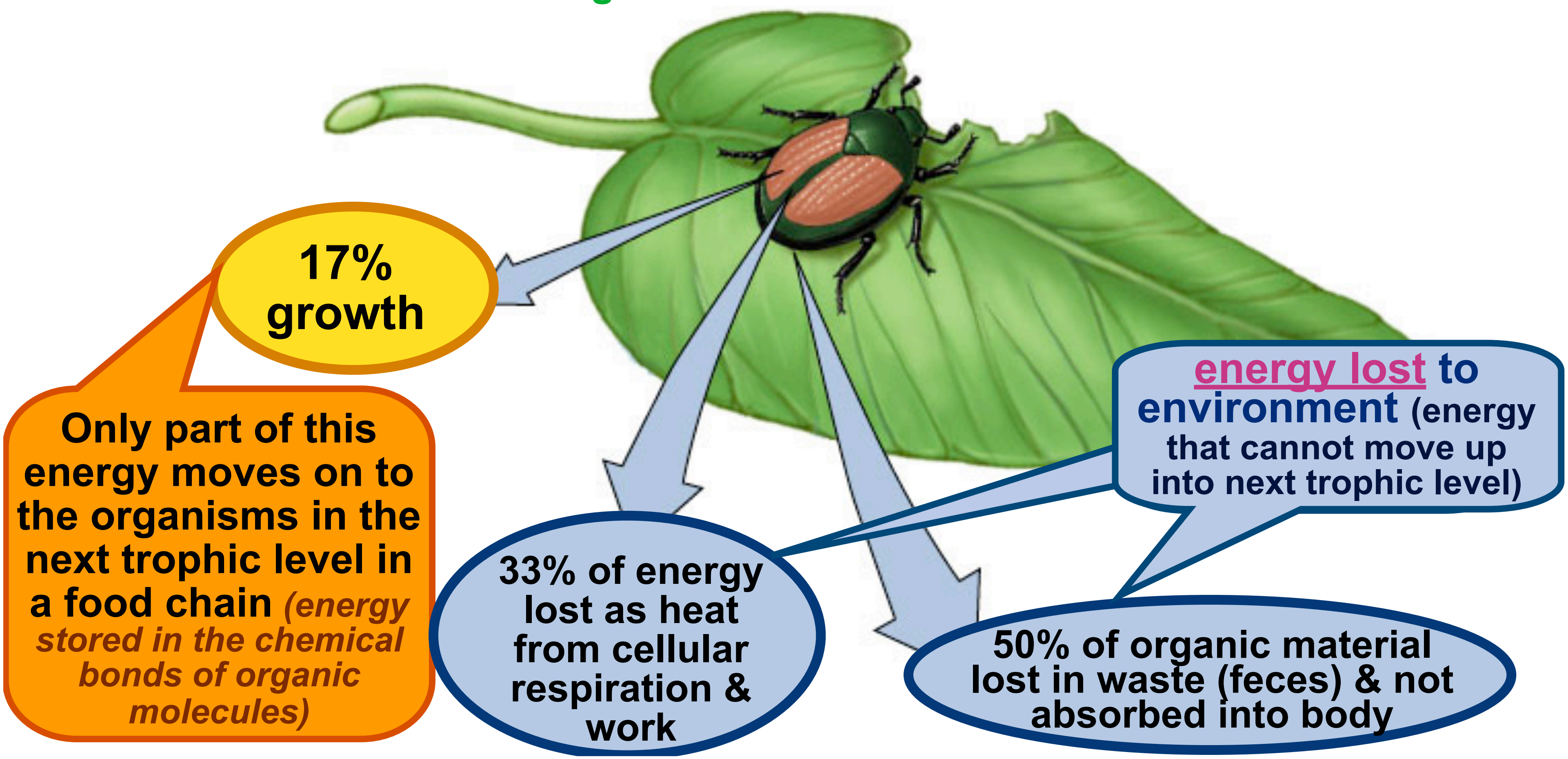


sun

Inefficiency of energy transfer



- There is a loss of energy between levels in a food chain
  - To where is the energy lost? To the environment in the form of a transfer of thermal energy (a.k.a. HEAT)
    - Heat lost cannot be harnessed for doing cellular work
      - The cost of living!



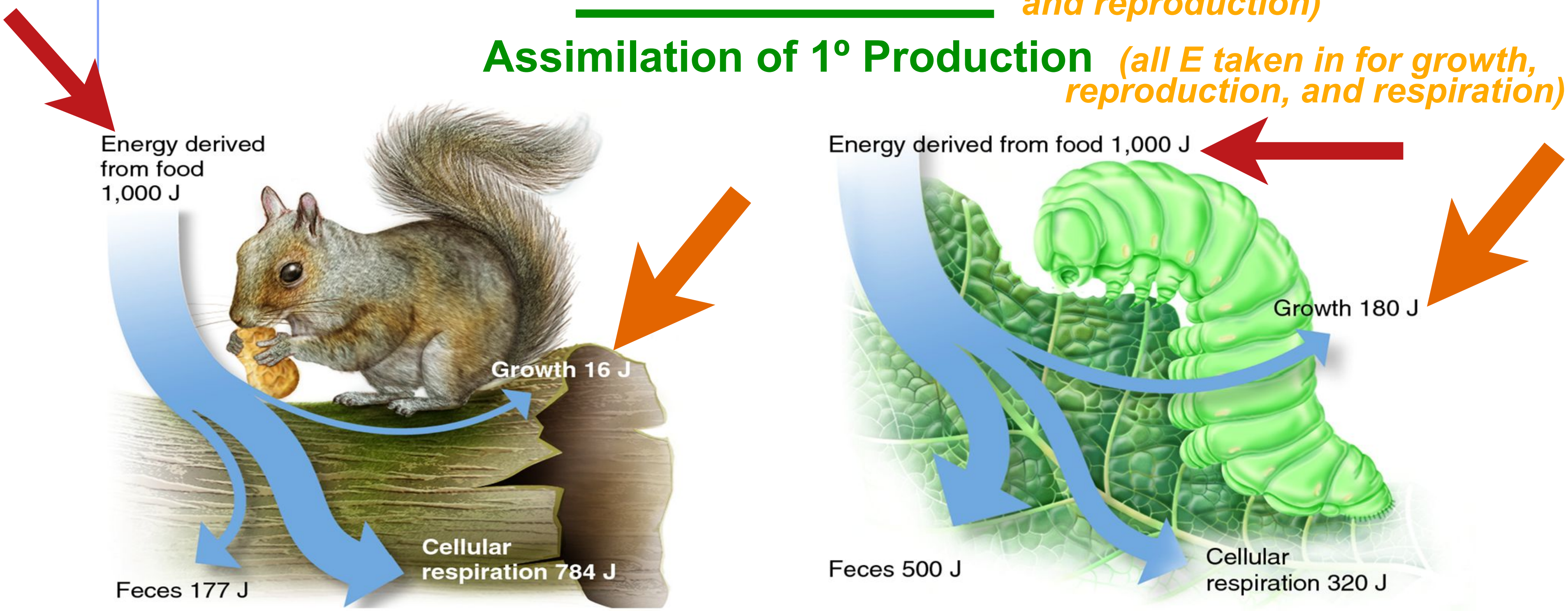
Production Efficiency Calculations

How efficient is a higher trophic level in using the energy in the biomass consumed from a lower trophic level for growth & reproduction?

Prod. Efficiency = $\dfrac{\text{Net } 2^{o} \text{ Production}}{\text{Assimilation of } 1^{o} \text{ Production}}$ x 100%

Net 2º Production *(E used for growth and reproduction)*

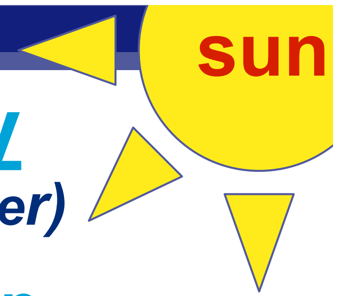
Assimilation of 1º Production *(all E taken in for growth, reproduction, and respiration)*



(b) Low production efficiency of a vertebrate

(a) High production efficiency of an invertebrate

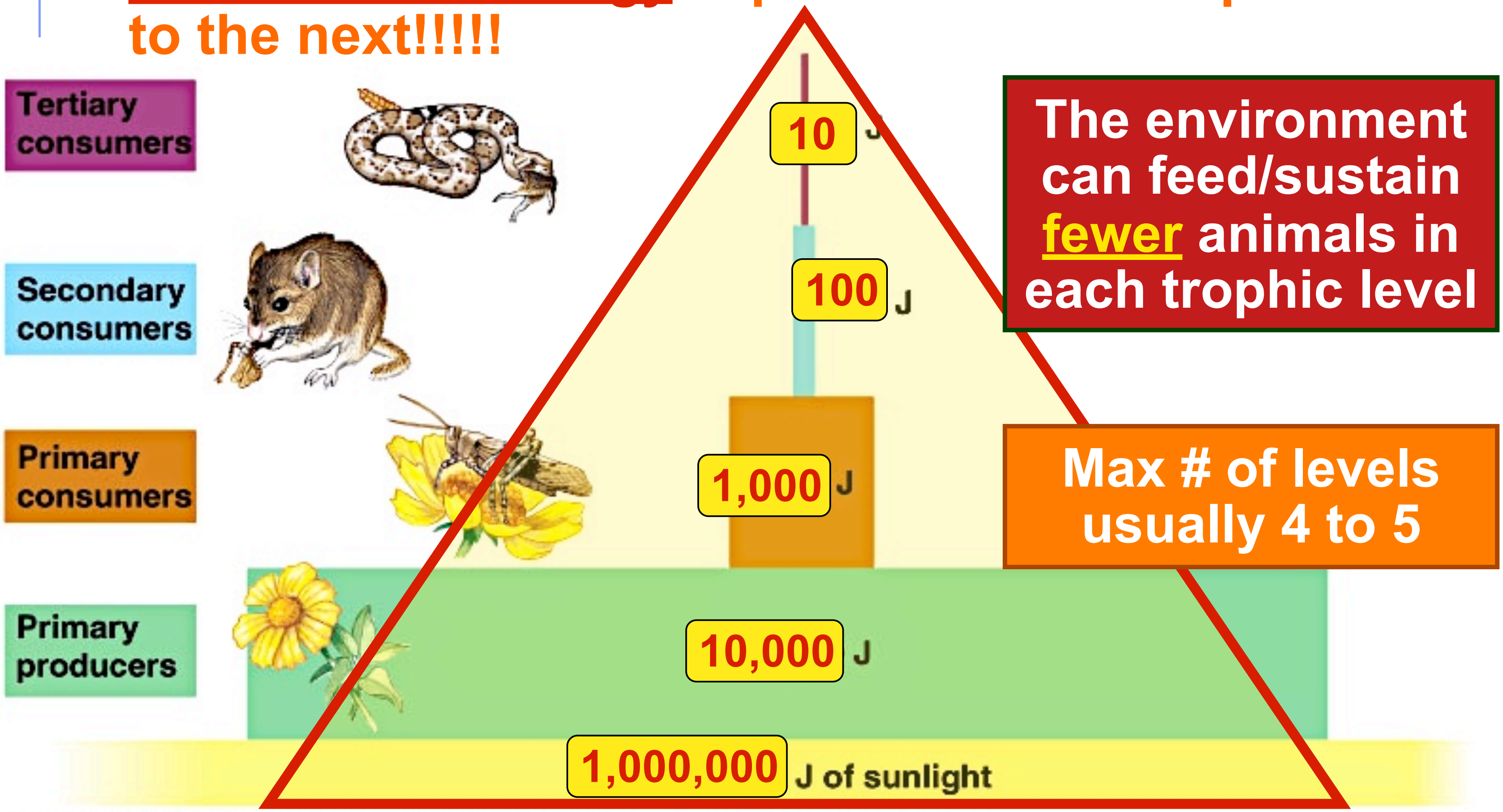
- **The production efficiency of endotherms** *("warm" blooded animals)* **is much lower than that of ectotherms** *("cold" blooded animals)*
  - **Birds & Mammals = 1-3% efficiency** (so much energy released via cellular respiration used to maintain high, constant body temp. and not for growth)
  - **Fish** (ectotherms) **= 10%**
  - **Insects & Microorganisms** (ectotherms) **= 40%**



Energy Pyramid & Trophic Efficiency

(= % of production transferred from one trophic level to another)

- Energy is lost between the levels of a food chain
  - *Only 1% of sun's energy is captured with photosynthesis*
- **ONLY 10% of energy** is passed from a trophic level to the next!!!!!



The environment can feed/sustain fewer animals in each trophic level

Max # of levels usually 4 to 5

Give it a try… "Energy in Ecosystems"

Why are big, fierce animals rare? Most big, fierce animals are tertiary consumers, which implies that

A. typically, they are highly territorial.

B. it's hard for an ecosystem to support many of them because so much energy is lost at each level of energy exchange.

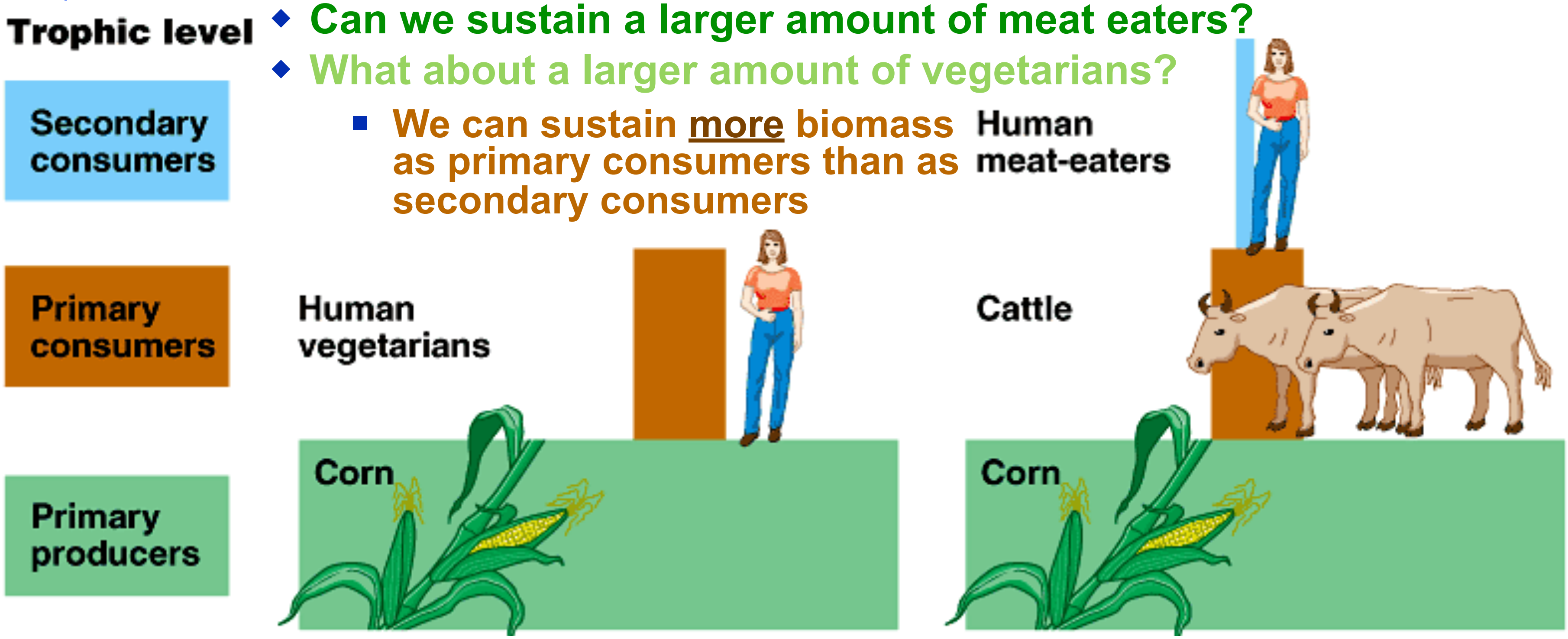
C. humans have caused most big, fierce animals to become extinct.

D. it takes a long time for big animals to evolve, and the K-T evidence for an ancient meteor strike eliminated dinosaurs and most other big, fierce animals.

E. it's hard for a big animal to move through dense vegetation.

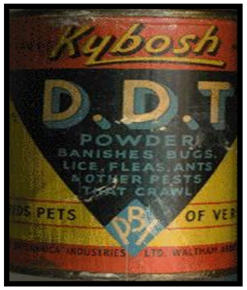
Humans in food chains

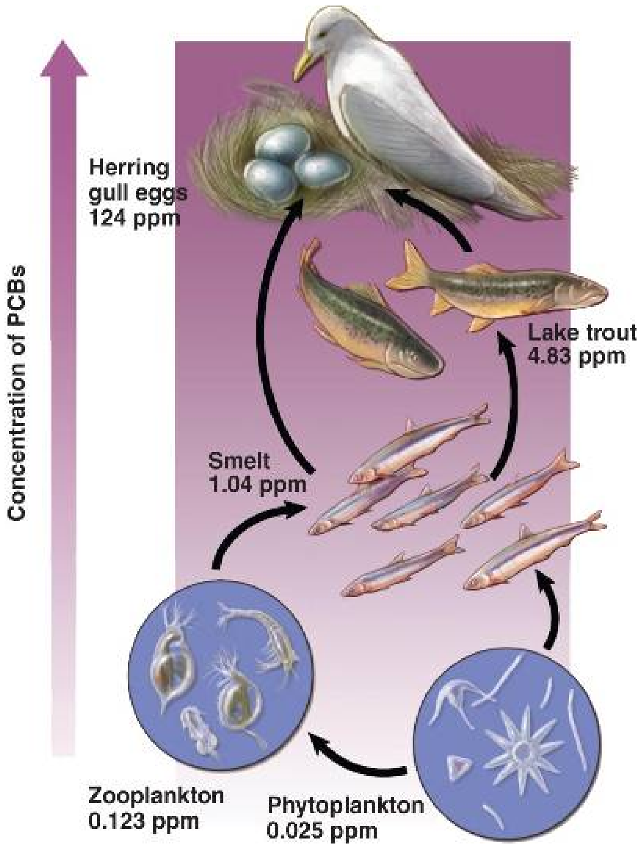
- **90% <u>less</u> total biomass makes up a higher trophic level compared to the trophic level right below it** *(since only <u>10%</u> of energy passes from one trophic level to the next through the organic molecules absorbed into the organisms of the next trophic level when they feed)*
  - These energy dynamics in ecosystems have important implications for human populations
    - How much energy does it take to feed humans?
  - Can we sustain a larger amount of meat eaters?
  - What about a larger amount of vegetarians?
    - We can sustain <u>more</u> biomass as primary consumers than as secondary consumers



Dangers of Biomagnification

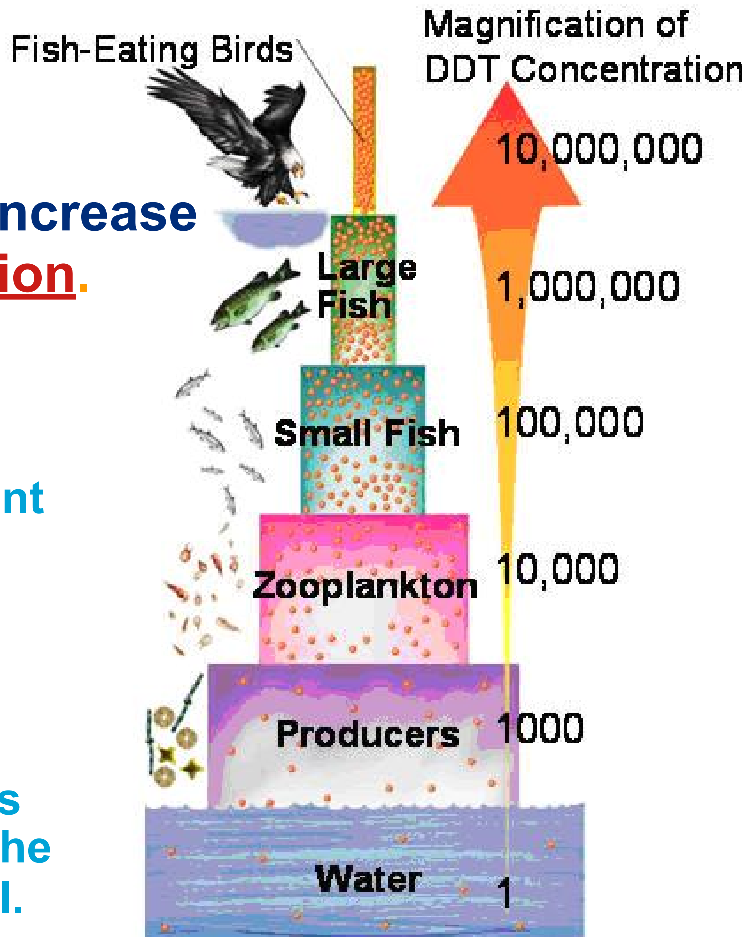
- Food webs make possible the transfer of energy and essential nutrients from producers to herbivores to carnivores and omnivores, and ultimately to the detrivores and decomposers that enrich the soil with organic waste.
  - But food webs are also an efficient conduit for the transfer of poisons
    - Biomagnification results when toxins and chemical pollutants build up in increasing concentrations in organisms higher up in the food chain.
  - Biomagnification chemicals must be:
    - Long-lived
    - Mobile
    - Soluble in fats
    - Biologically active
      - Ex: DDT, PCB, Mercury, Lead



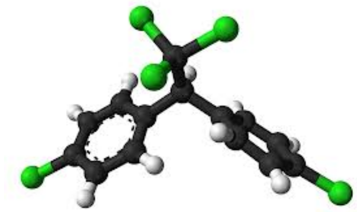


Dangers of Biomagnification

- Remember that only 10% of the energy in one trophic level is past to the next higher level.
  - So organisms in a higher trophic level must eat **MORE** biomass of the level below it just to get enough energy to survive.
    - Organisms in successively higher trophic levels thus experience an increase in contamination, or biomagnification.
      1. Small amounts of pollutants may stick to algae/plankton
      2. But by the time the toxin has passed to a small fish, the amount of pollutant in a single organism might be 100x what it was at the level of the algae.
      3. By the time the toxins have passed on to a few more levels in the food web, to the shark or human, they might be appearing in concentrations over 10,000x the original amount in the organisms of the lowest trophic level.



Dangers of Biomagnification



- DDT (dichlorodiphenyltrichloroethane), a mosquito and pest insecticide used widely after WWII, is one of the most prominent chemical pollutants throughout a food chain, not just in a specific organism
  - DDT was carried by water far from where it was used
    - Produces fertility and neurological problems in humans

Dangers of Biomagnification

- **DDT Caused sharp decline in pelican, osprey, & eagle populations**
  - **The chemical and breakdown products interfered with the ability of the bird to deposit calcium in eggshells properly.**
    - **Eggs have thinner shells that break easily when the parent tries to incubate the egg.**

Some eggs may not hatch at all.

  - **DDT banned in US in 1971**
    - **(Still sold to and used in some third world countries)**