ECOSYSTEM ECOLOGY

Ecosystem:

- **The organisms in a particular area and the physical environment with which they interact.**

- **All the biotic and abiotic factors in a community.**

(Abiotic factors: **energy**, water, carbon, nitrogen, phosphorous)

Functional attributes of ecosystem

- Energy flow
- Primary and secondary production
- Food chains, food web and trophic levels
- Ecosystem development and regulation
- Biogeochemical / nutrient cycles

Dynamics of Ecosystem

- The various components of the ecosystem constitute an interacting system. They are connected by energy, nutrients and minerals. The nutrients and minerals circulate and recirculate between the abiotic and biotic factors of the ecosystem several times. Whereas, the flow of energy is one way, once used by the ecosystem, it is lost. Thus the continuous survival of the ecosystem depends on the flow of energy and the circulation of nutrients and minerals in the ecosystem.
- The dynamics of an ecosystem involve two processes:

1. Energy flow and
2. Chemical cycling.

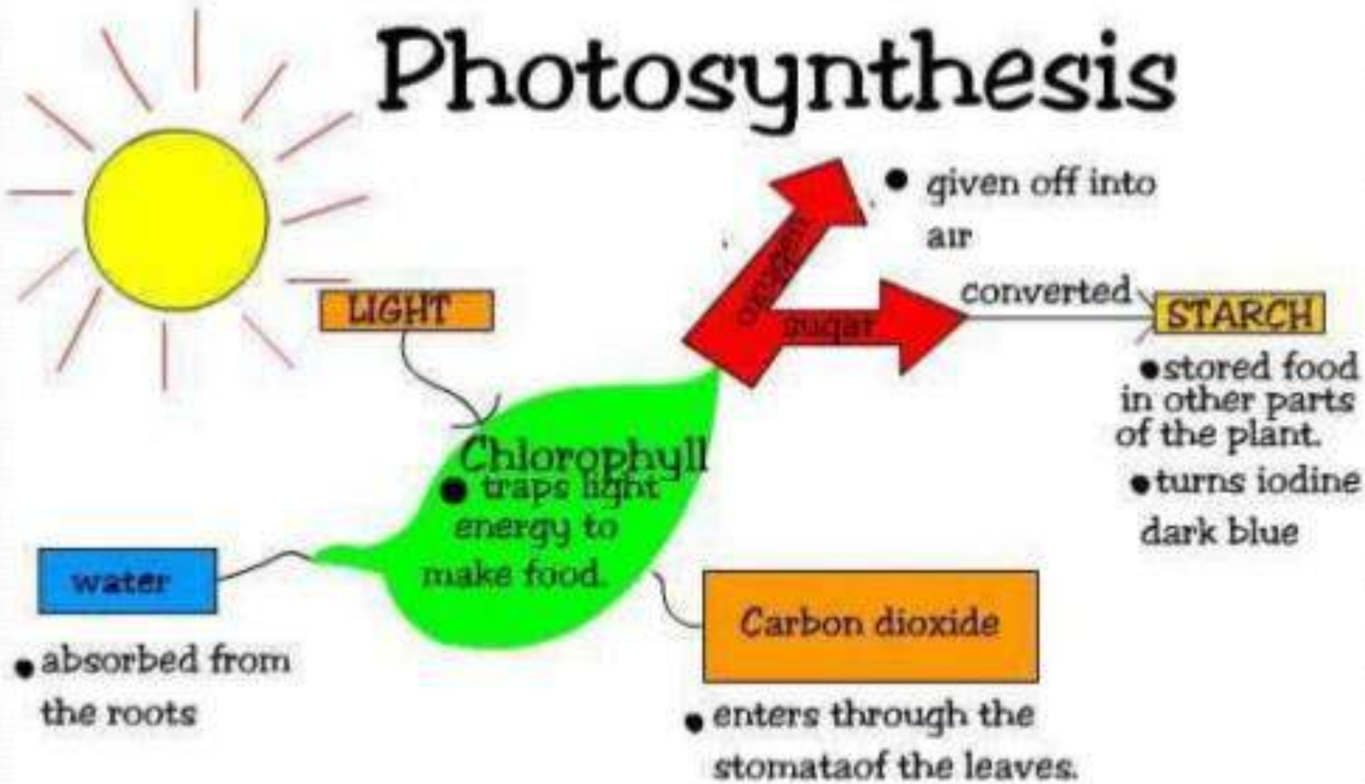
- Ecosystem ecologists view ecosystems as energy machines and matter processors.

Energy

- Energy is the ability to do work.
- The main source of energy for an ecosystem is the radiant energy or light energy derived from the sun.
- This light energy is converted into chemical energy in the form of sugar by plants by the process of photosynthesis. Plants utilize only 0.02% of Sun's light energy reaching the earth.

Energy flow

- Solar energy is trapped by the green plants, and converted into chemical energy and stored as carbohydrates. This happens during photosynthesis.
- A part of this chemical energy is used up by the green plants themselves. The major portion of the energy is consumed in the form of food by the consumers at different trophic level.
- Thus there is energy flow through the biotic components in an ecosystem.
- The transfer of energy from one trophic level to another trophic level is called energy flow.
- The flow of energy in an ecosystem is unidirectional. That is, it flows from the producer level to the consumer level and never in the reverse direction. Hence the energy can be used only once in the ecosystem.
- But the minerals circulate and re circulate many times in the ecosystem.
- A large amount of energy is lost at each trophic level. It is estimated that 80% to 90% of the energy is lost when it is transferred from one trophic level to another.



$$6CO_2 + 6H_2O + \text{sunlight \& chlorophyll} \rightarrow C_6H_{12}O_6 + 6O_2$$

The Global Energy Budget

- Every day, Earth is bombarded by large amounts of solar radiation.
- Much of this radiation lands on the water and land that either reflect or absorb it.
- Of the visible light that reaches photosynthetic organisms, about only 1% is converted to chemical energy.
- Although this is a small amount, primary producers are capable of producing about 170 billion tons of organic material per year.

Energy Flow through Ecosystems

- **Energy flows through ecosystems as organisms capture and store energy, then transfer it to organisms that eat them.**

- **These organisms are grouped into trophic levels.**

Trophic level

- Each food chain contains many steps like producers, herbivores, primary carnivores and so on. Each step of the food chain is called trophic level. The number of trophic levels in a food chain is always restricted to 4 or 5. But very often the chains are very much complicated with many trophic levels.

1st Trophic level

2nd Trophic level

3rd Trophic level

Food chain: is a linear network starting from producer organisms (such as grass or trees which use radiation from the sun to make their food) and ending at apex predator species (like grizzly bears or killer whales), detrivores (like earthworms or woodlice), or decomposer species (such as fungi or bacteria). A food chain also shows how the organisms are related with each other by the food they eat. Each level of a food chain represents a different trophic level.

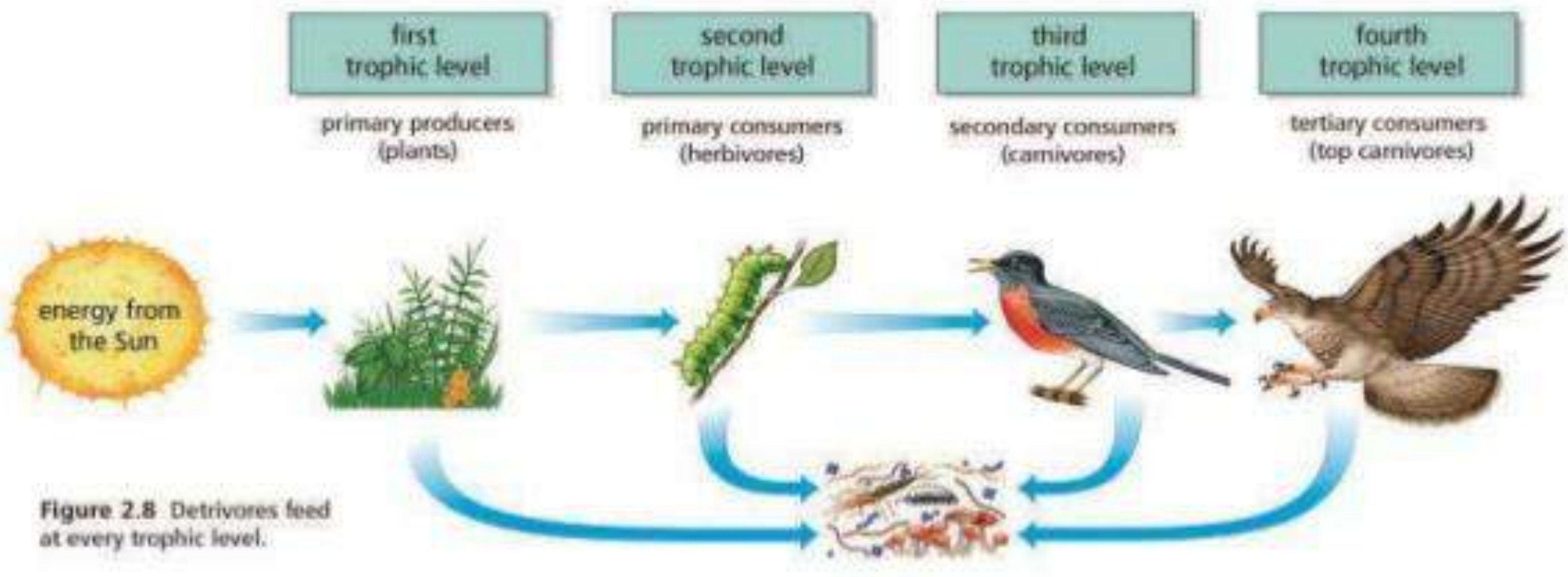
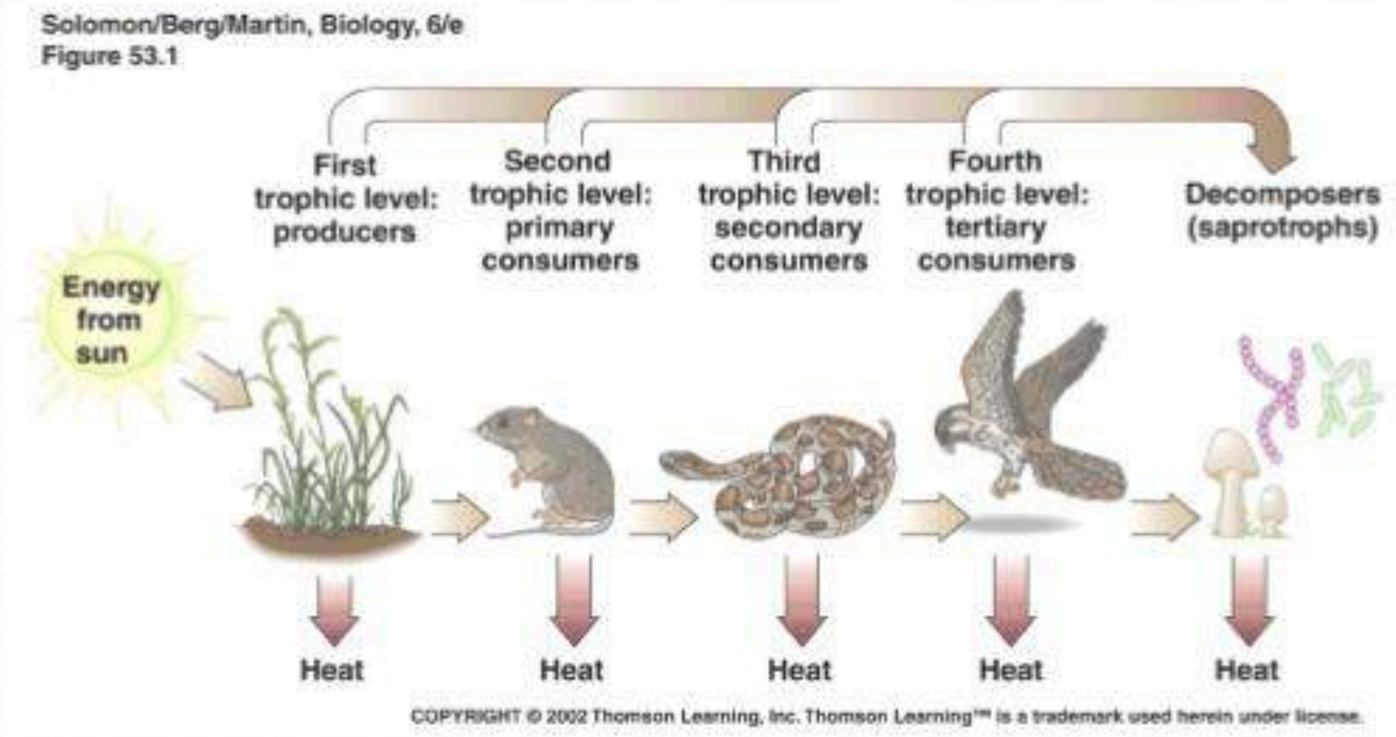
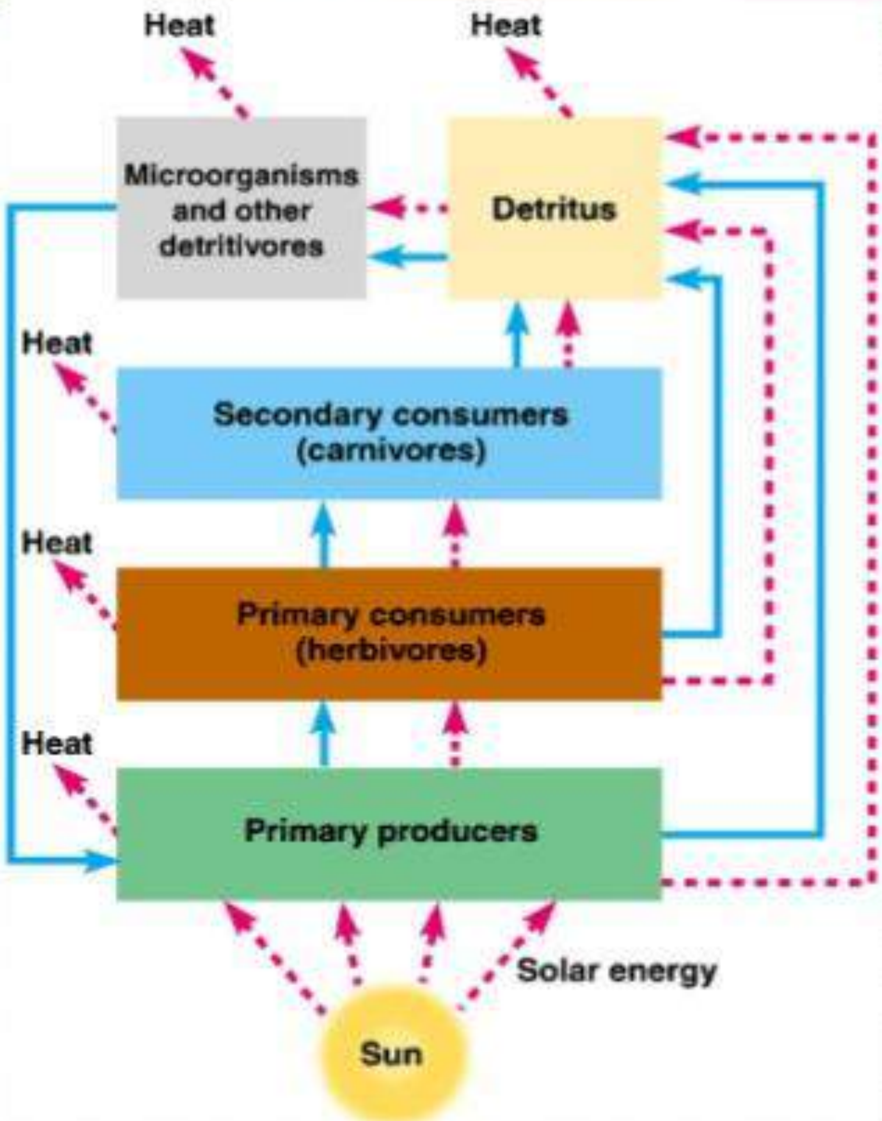
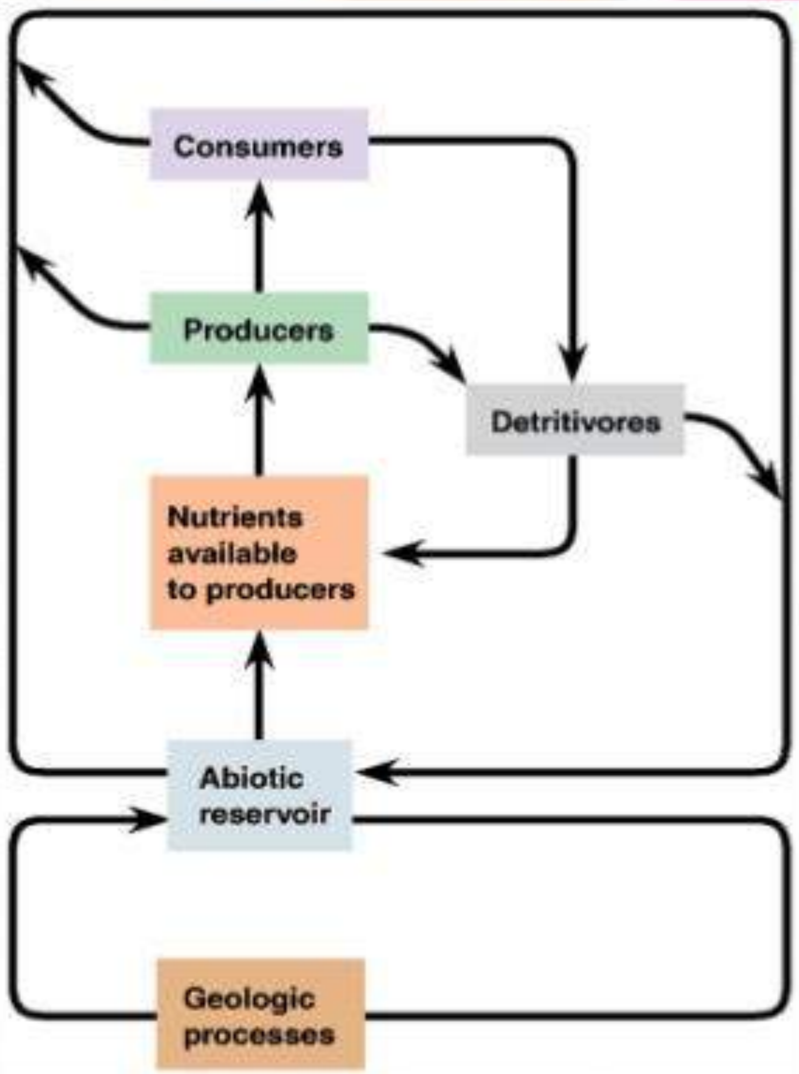


Figure 2.8 Detrivores feed at every trophic level.

Energy flow is unidirectional




Heat
Heat
Microorganisms and other detritivores
Detritus
Heat
Secondary consumers (carnivores)
Heat
Primary consumers (herbivores)
Heat
Primary producers
Solar energy
Sun


Consumers
Producers
Detritivores
Nutrients available to producers
Abiotic reservoir
Geologic processes

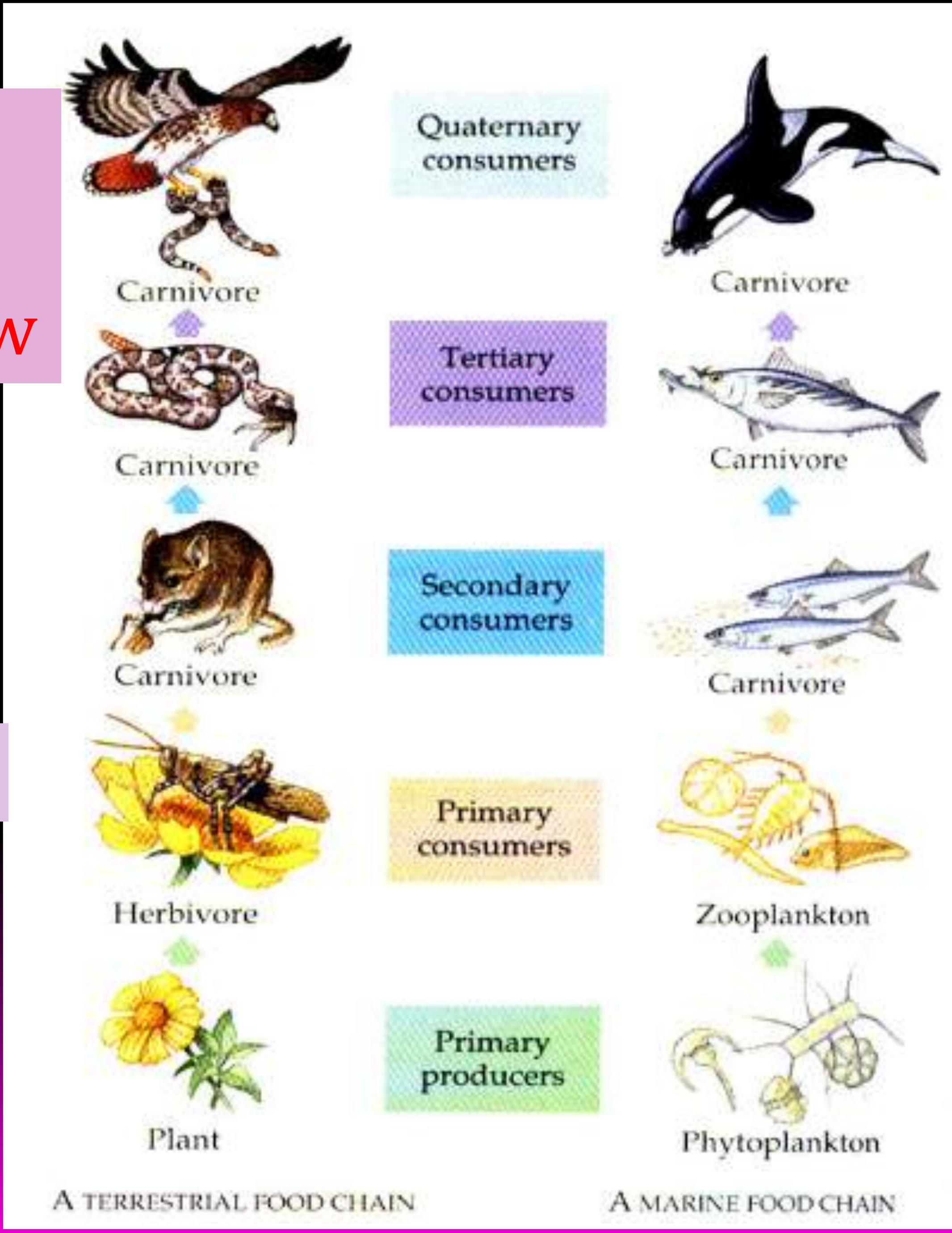
Trophic Levels:

Route of energy flow

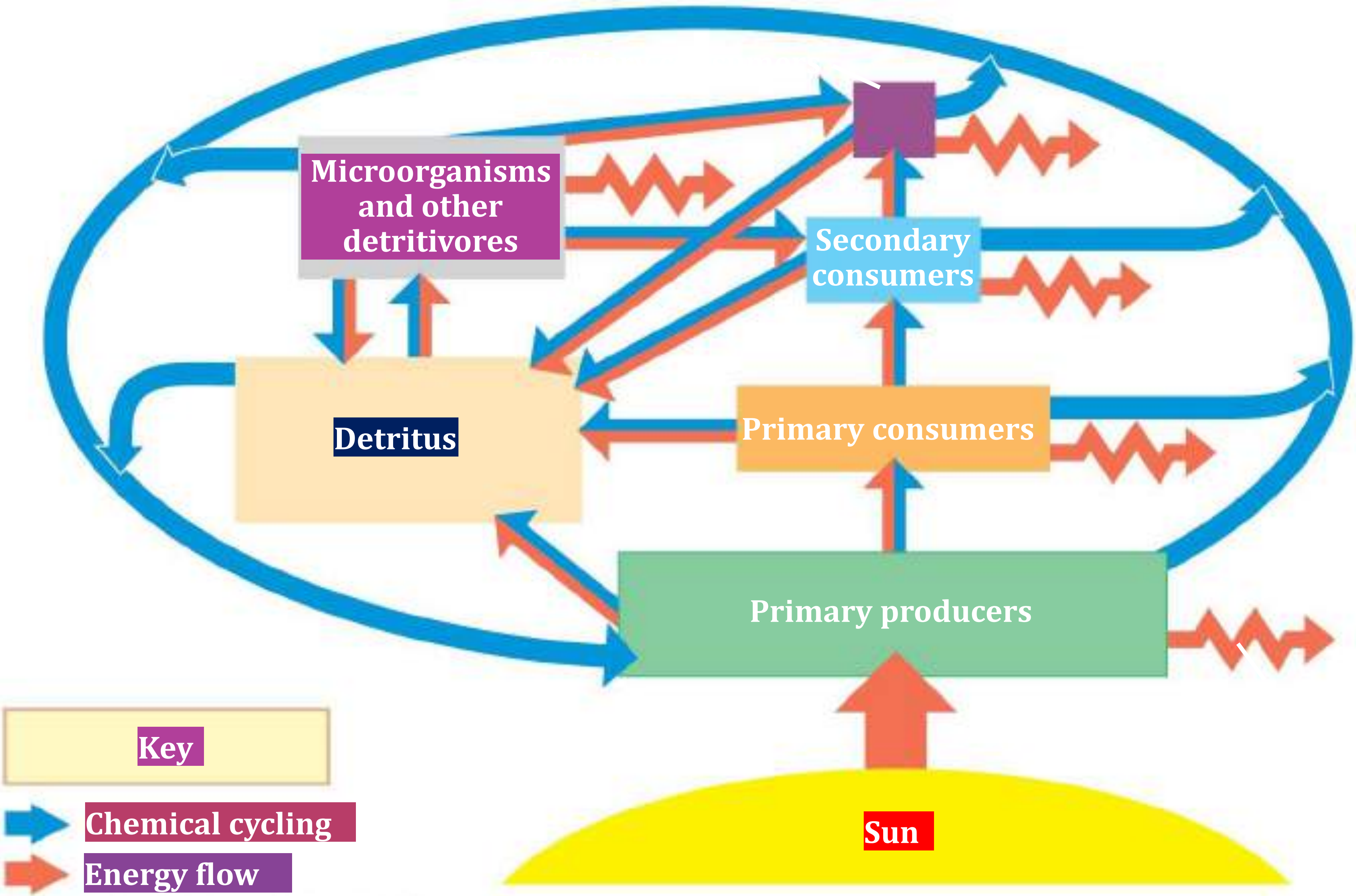
- food chain

- food web

- pyramid of numbers

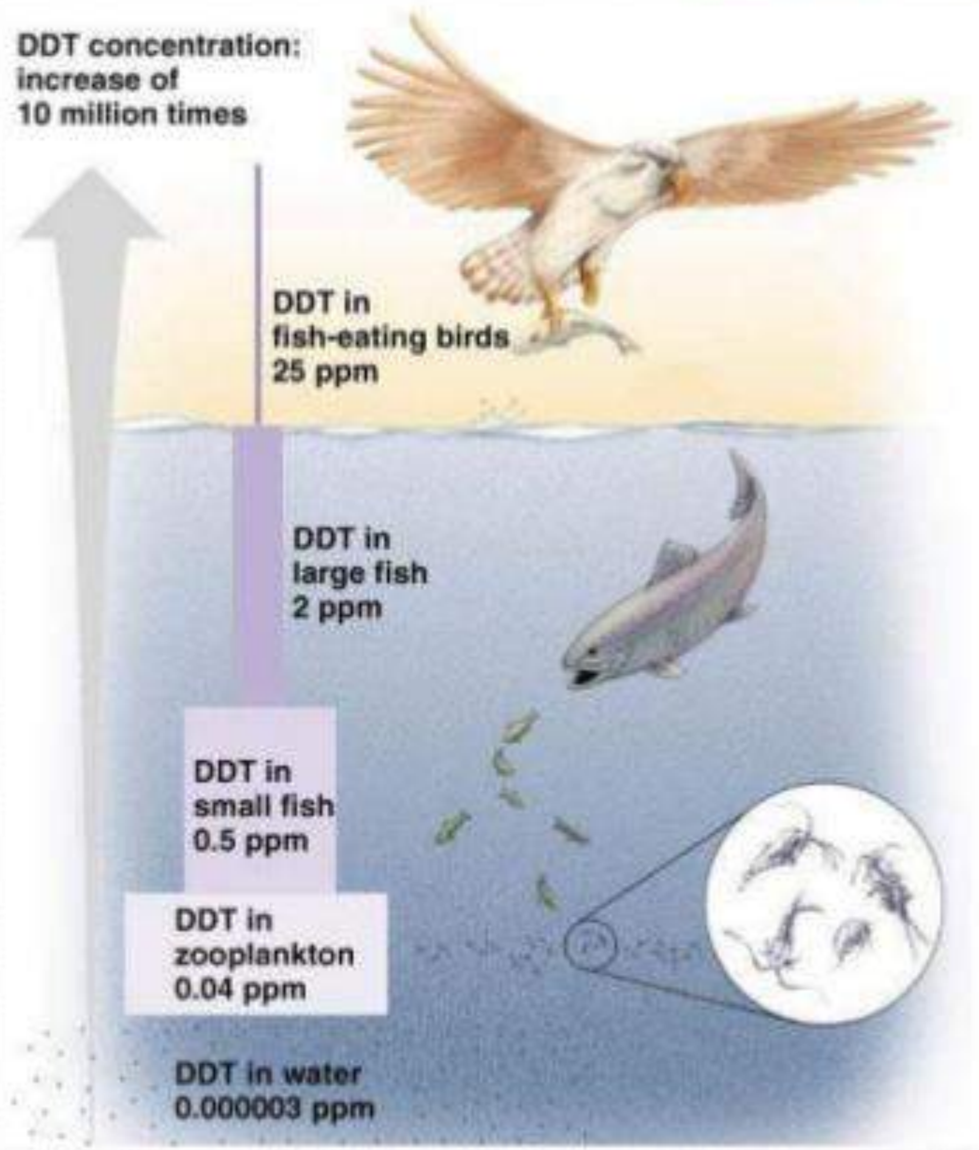


An overview of energy and nutrient dynamics in an ecosystem



Toxins can become concentrated in successive trophic levels of food webs

- Humans produce many toxic chemicals that are dumped into ecosystems.
- These substances are ingested and metabolized by the organisms in the ecosystems and can accumulate in the fatty tissues of animals.
- These toxins become more concentrated in successive trophic levels of a food web, a process called **biological magnification**.


DDT concentration:
increase of
10 million times
DDT in
fish-eating birds
25 ppm
DDT in
large fish
2 ppm
DDT in
small fish
0.5 ppm
DDT in
zooplankton
0.04 ppm
DDT in water
0.000003 ppm

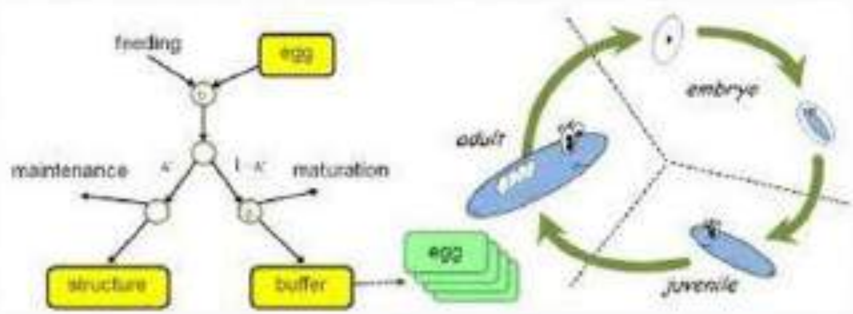
What is an energy budget?

Energy Budget:

- An account of an animal's total energy intake and how that energy is used and lost.
  - **Gross energy intake**: total energy lost a excretory energy, plus energy assimilated for existence and productive functions. (In short: this is the TOTAL amount of energy obtained from an organism's food)

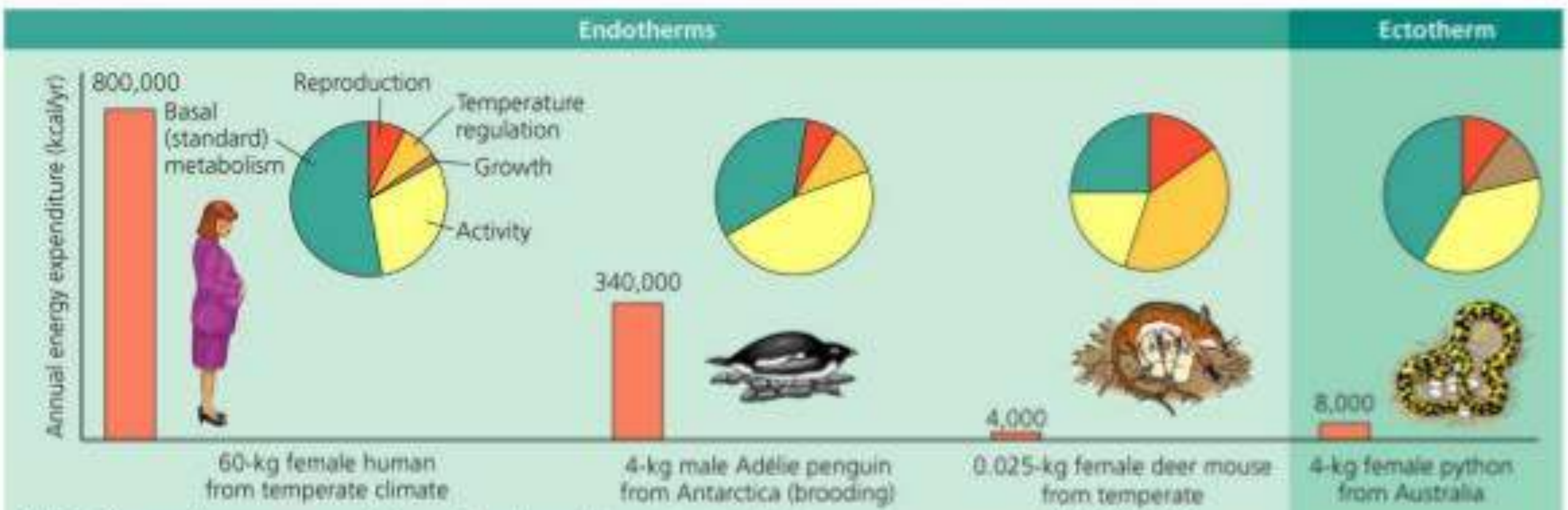
Ways Energy is Used/Lost

1. Excretory Energy
2. Existence Energy
3. Productive Energy



Energy Budgets

- For most animals – the majority of food energy goes to making ATP
  - Very little goes toward growth or reproduction
  - There is great variety in how animals "spend" their energy budget



(a) **Total annual energy expenditures.** The slices of the pie charts indicate energy expenditures for various functions.

A Body's Energy Budget

eat food → ATP

1. make energy
   - energy needed even at rest
   - activity
   - temperature control

2. synthesis (building)
   - growth
   - reproduction
   - repair

3. storage
   - glycogen (animal starch)
   - fat

Ecosystem Energy Budgets:

Primary Productivity (PP)
Secondary Productivity (SP1, SP2)

Primary Productivity (PP)

- **Rate at which energy or biomass is produced per unit area by plants (primary producers)**

- **Photosynthesis** powers primary productivity.

- **The annual productivity of an area is determined primarily by sunlight, temperature, and moisture.**

1. An ecosystem's energy budget depends on primary production

- Most primary producers use light energy to synthesize organic molecules, which can be broken down to produce ATP; there is an energy budget in an ecosystem.

37.15 Primary production sets the energy budget for ecosystems

- **Primary production**
  - is carried out by producers,
  - is the amount of solar energy converted to chemical energy by an ecosystem's producers for a given area and during a given time period, and
  - produces **biomass**, the amount of living organic material in an ecosystem.
- Different ecosystems vary in their
  - primary production and
  - contribution to the total production of the biosphere.

An ecosystem's energy budget depends on primary production

- Most primary producers use light energy to synthesize organic molecules, which can be broken down to produce ATP; there is an energy budget in an ecosystem.
- The producers are directly consumed by the herbivores that are eaten by the primary carnivores that in turn are consumed by the secondary carnivores. The consumers store some amount of energy in their tissues. This energy, stored by the consumers, is called secondary production. Only about 10 to 20% of the primary production is converted into secondary production.

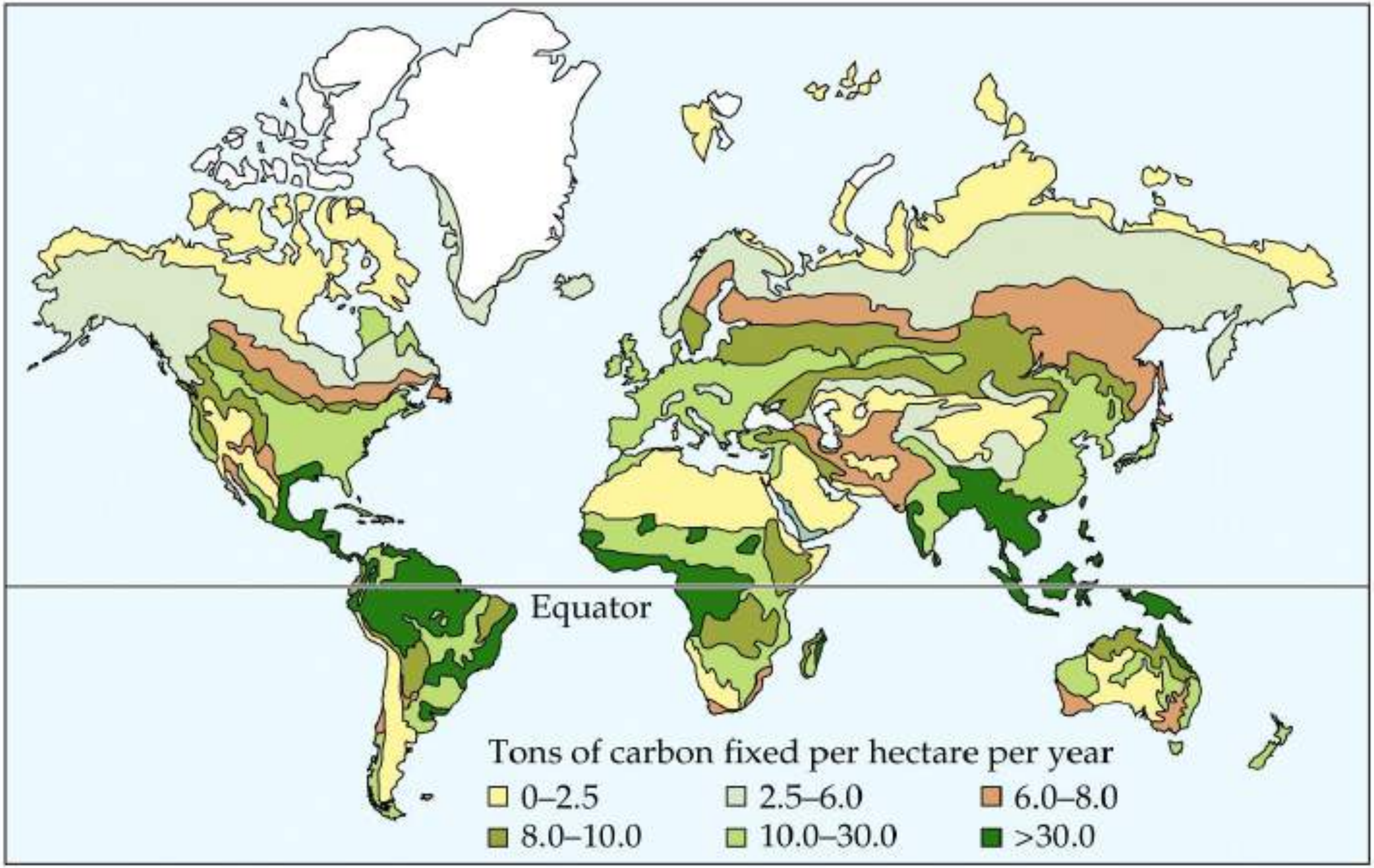
The Global Energy Budget

- The amount of solar radiation reaching the Earth's surface limits photosynthetic output of ecosystems
- Only a small fraction of solar energy actually strikes photosynthetic organisms, and even less is of a usable wavelength

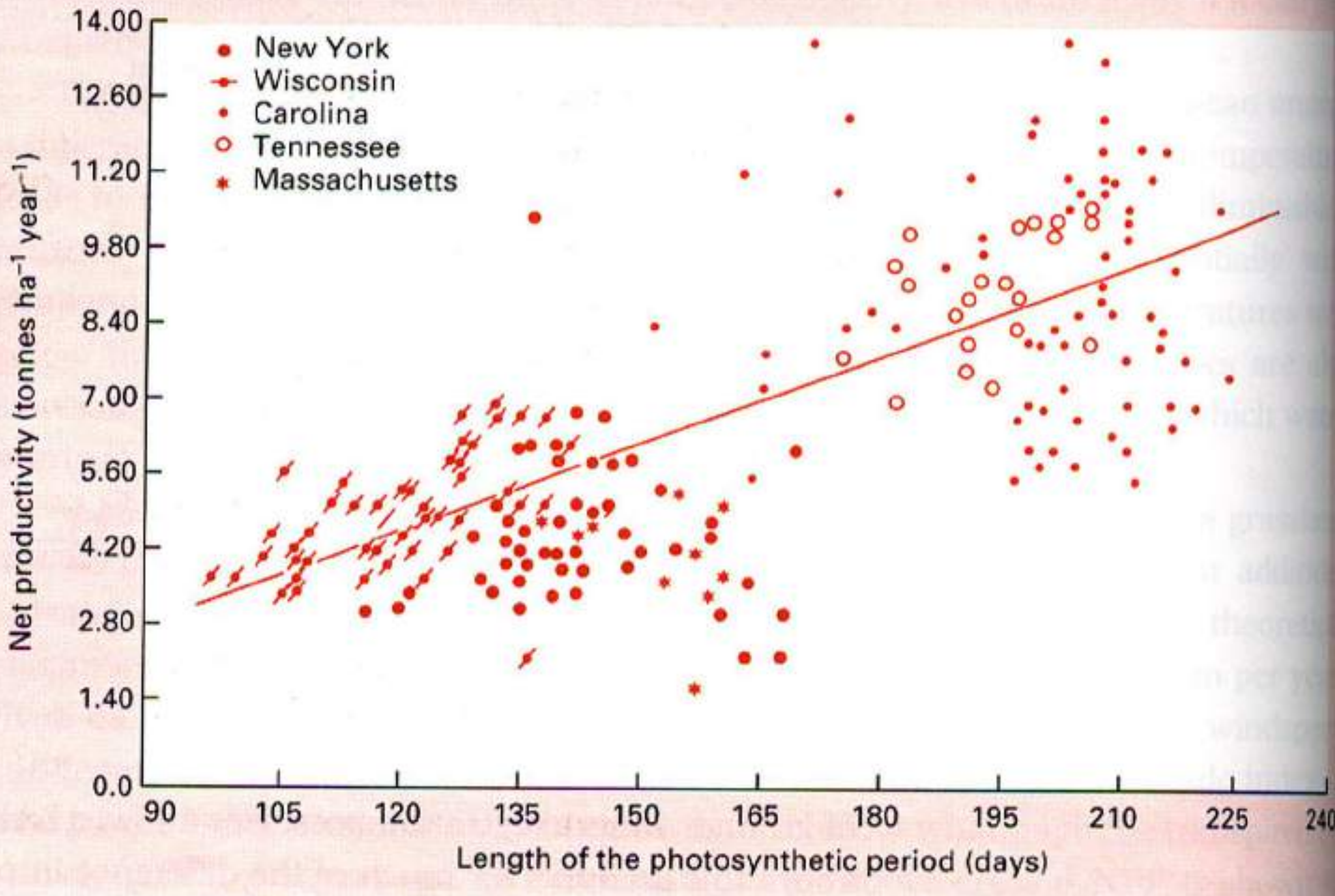
Energy and other limiting factors control primary production in ecosystems

- **In most ecosystems, primary production is the amount of light energy converted to chemical energy by autotrophs during a given time period**
- **In a few ecosystems, chemoautotrophs are the primary producers**

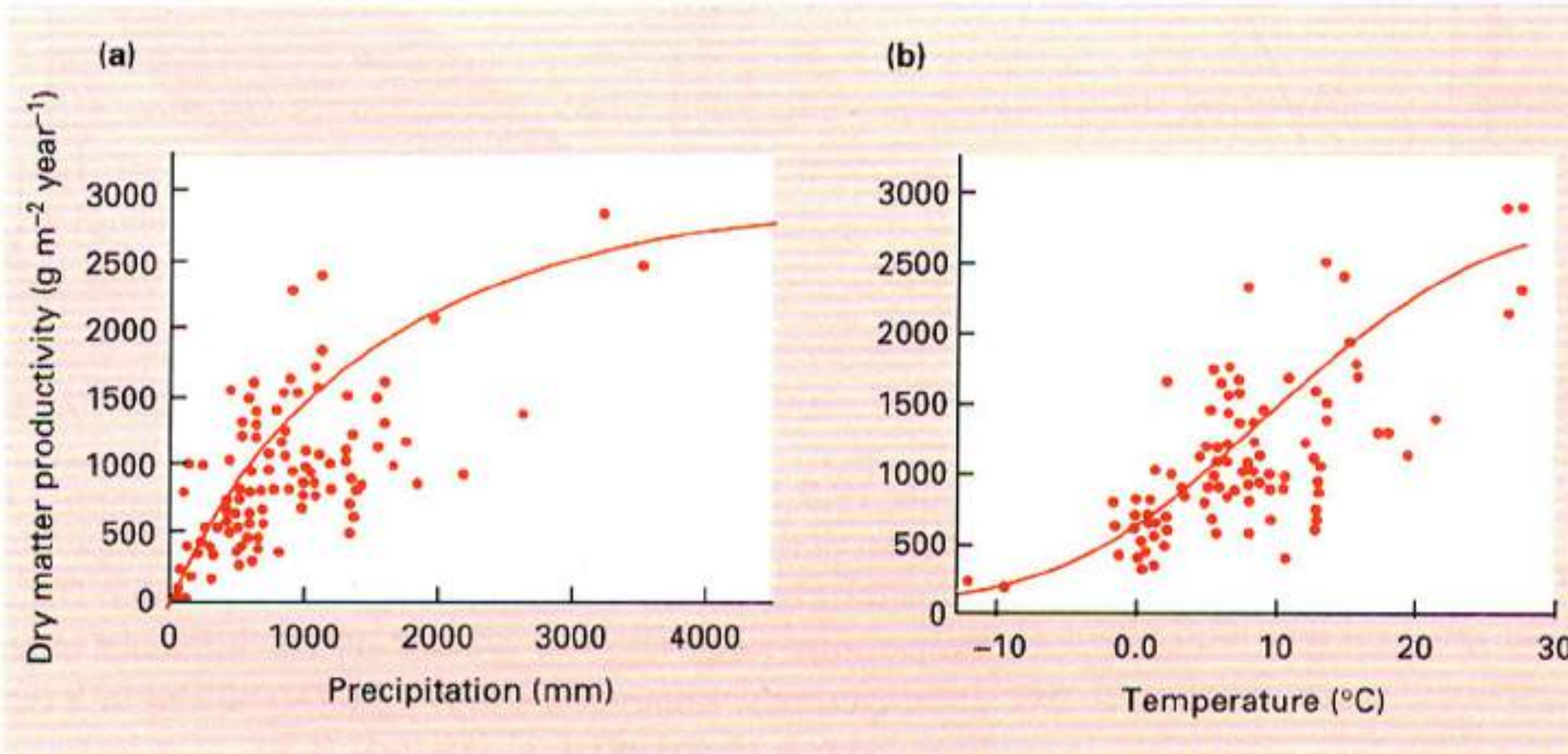
Distribution of Primary Production Worldwide



Positive Correlation Between Productivity and Sunlight



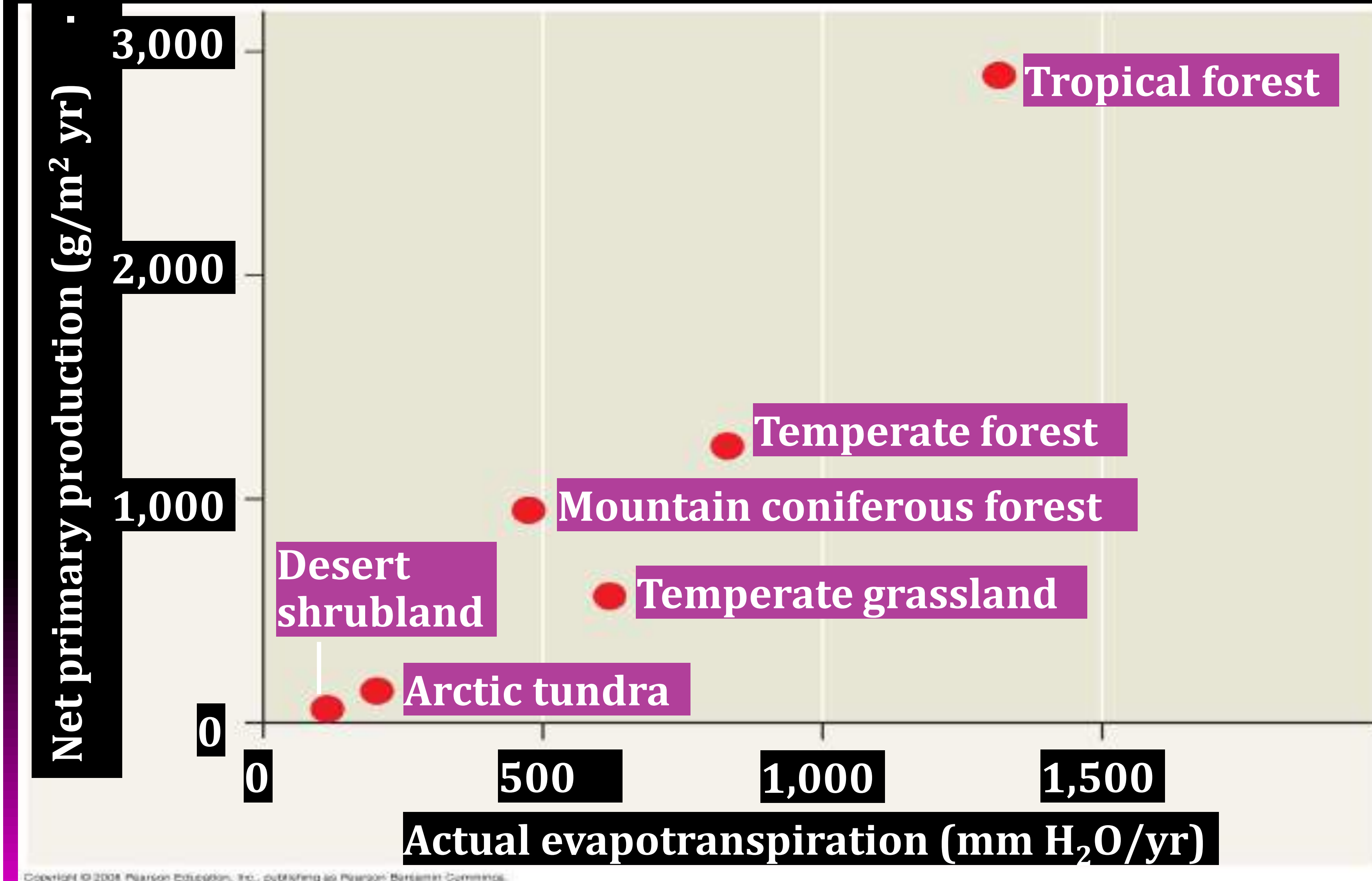
Positive Correlation Between Productivity and...



Precipitation

Temperature

Relationship between net primary production and actual evapotranspiration in six terrestrial ecosystems



Primary production

- The amount of light energy converted to chemical energy by plants during a given period of time per unit area is called primary productivity.
- It can be expressed in terms of energy per unit area per unit time, or as biomass of vegetation added to the ecosystem per unit area per unit time.

Secondary production

- The energy that is not used by producers can be passed on to organisms that cannot make their own energy.
- It's the energy flow through trophic levels
- grams m^{-2} $year^{-1}$ or grams m^{-2} $week^{-1}$

Gross and Net Primary Production

- Total primary production is known as gross primary production (GPP).This is the amount of light energy that is converted into chemical energy.
- The net primary production (NPP) is equal to gross primary production minus the energy used by the primary producers for respiration (R):

$$NPP = GPP - R$$

B. Energy Budget →Primary Production

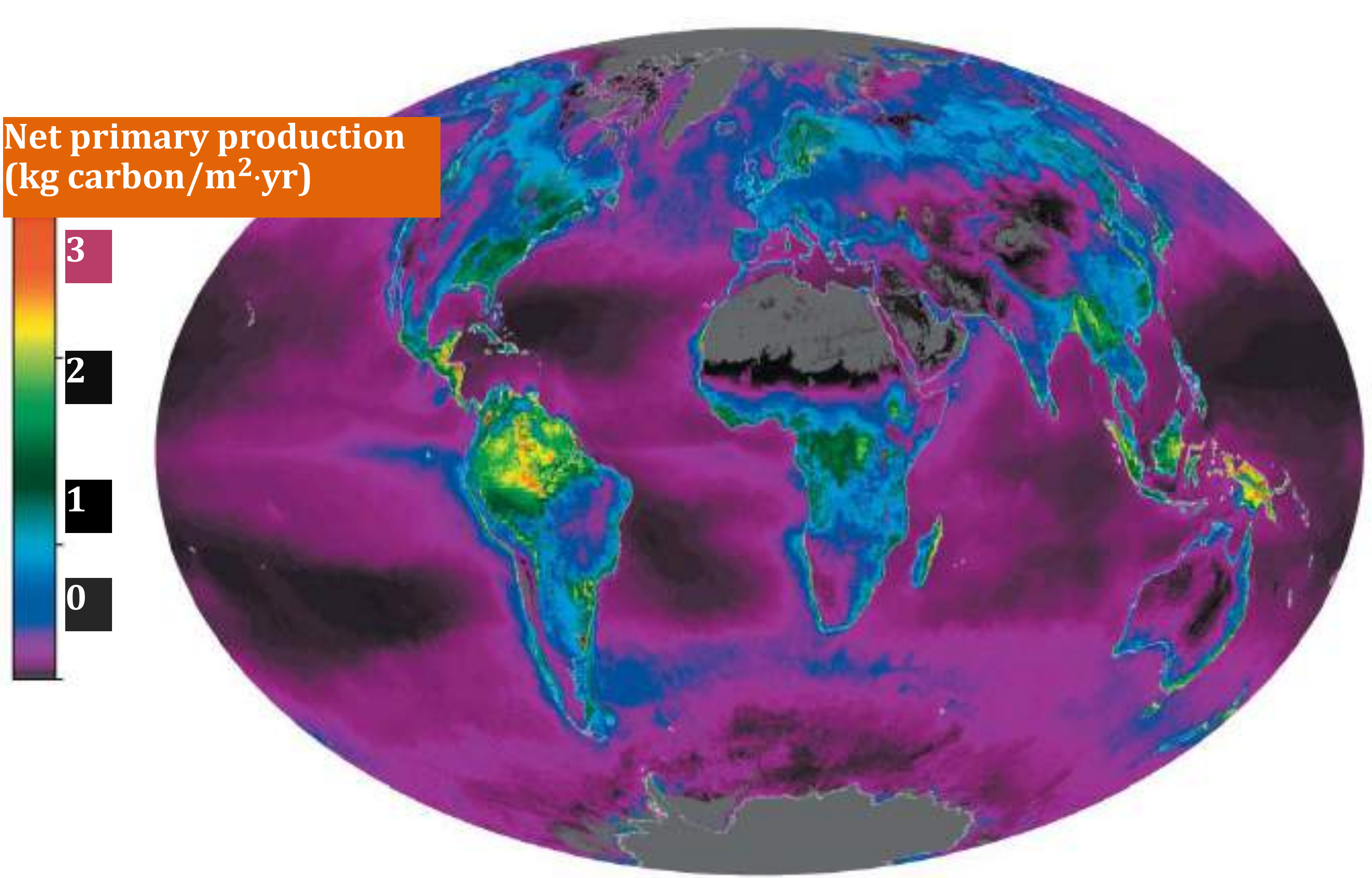
- Producers determine the energy budget for an ecosystem
  - GPP→ amount of solar energy converted into chemical energy→ all photsynthesis
  - NPP = GPP- Respiration (cost of staying alive)
  - PP → $J/m^2/y$ or biomass

Gross and Net Production

- Total primary production is known as the ecosystem's gross primary production (GPP)
- GPP is measured as the conversion of chemical energy from photosynthesis per unit time
- Net primary production (NPP) is GPP minus energy used by primary producers for respiration
- NPP is expressed as
  - Energy per unit area per unit time ($J/m^2 \cdot yr$), or
  - Biomass added per unit area per unit time ($g/m^2 \cdot yr$)

- NPP is the amount of new biomass added in a given time period
- Only NPP is available to consumers.
- Standing crop is the total biomass of photosynthetic autotrophs at a given time.
- Ecosystems vary greatly in NPP and contribution to the total NPP on Earth.
- Tropical rain forests, estuaries, and coral reefs are among the most productive ecosystems per unit area.
- Marine ecosystems are relatively unproductive per unit area, but contribute much to global net primary production because of their volume.

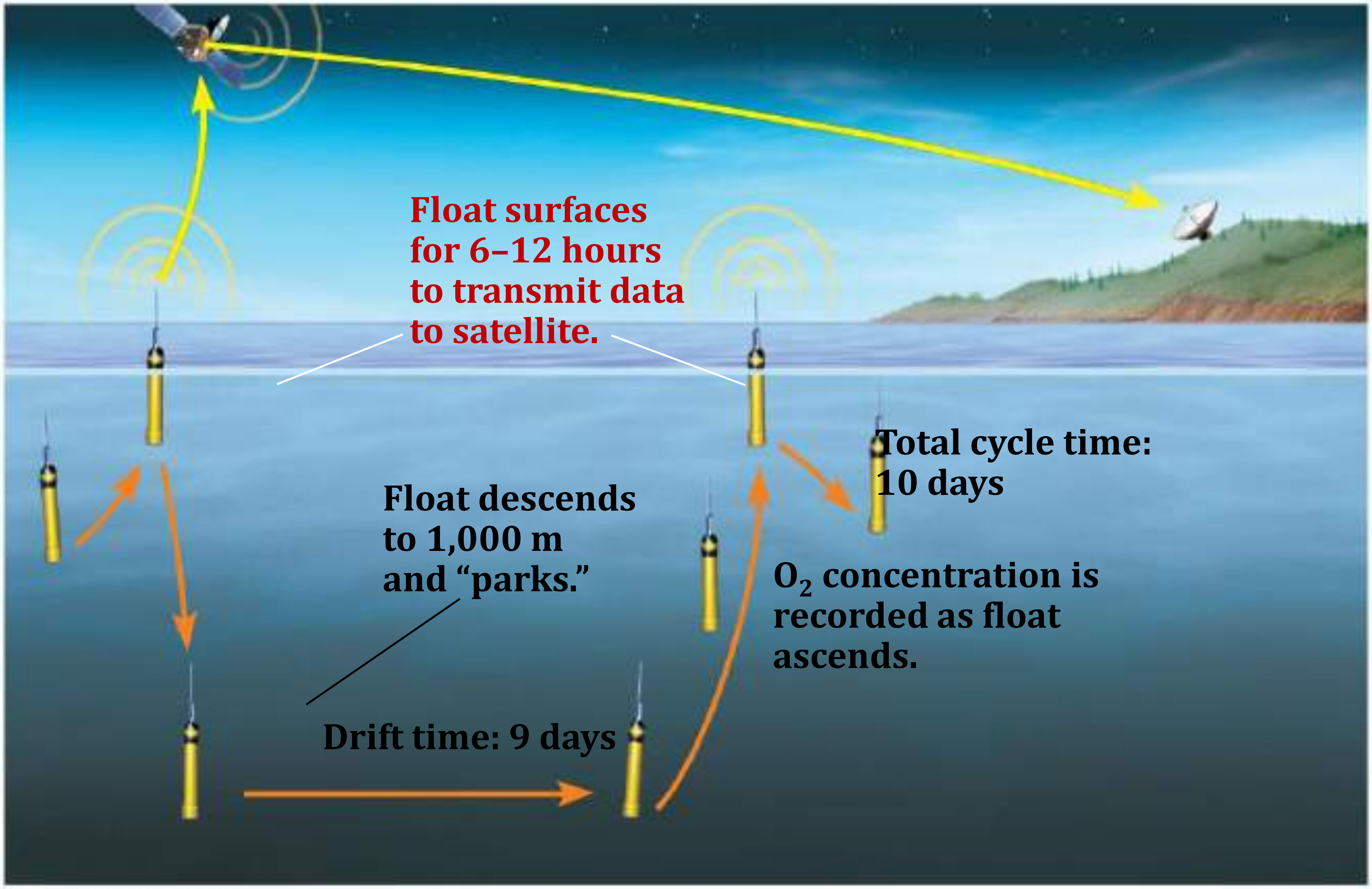
Figure 55.6



- **Net ecosystem production (NEP) is a measure of the total biomass accumulation during a given period**
- **NEP is gross primary production minus the total respiration of all organisms (producers and consumers) in an ecosystem**
- **NEP is estimated by comparing the net flux of CO_2 and O_2 in an ecosystem, two molecules connected by photosynthesis**
- **The release of O_2 by a system is an indication that it is also storing CO_2**

Figure 55.7

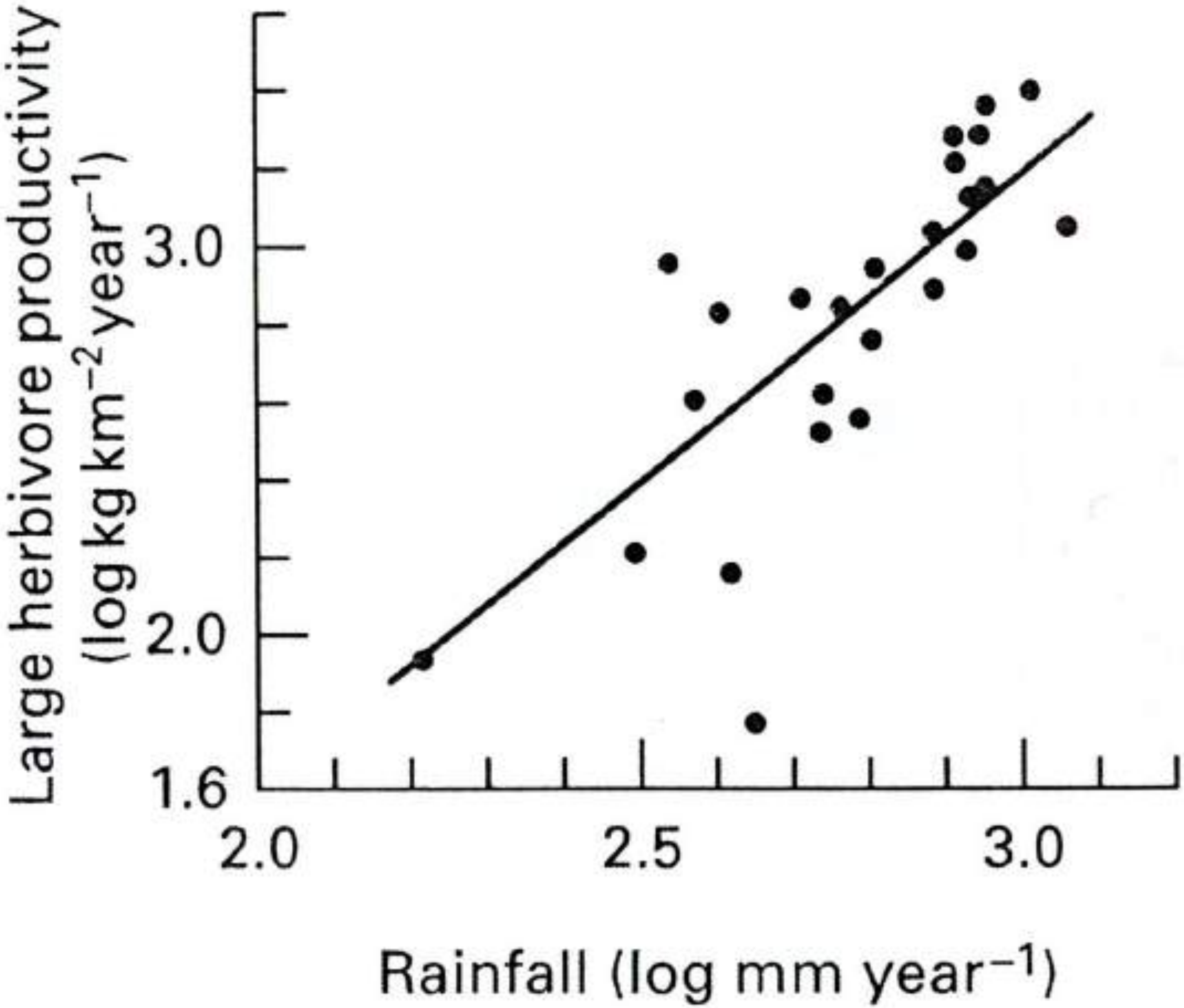
Ocean Production Revealed



Secondary Productivity (SP1, SP2…)

- Rate of production of new biomass from PP by heterotrophic organisms (primary and secondary consumers)

- Positively correlated with rainfall…

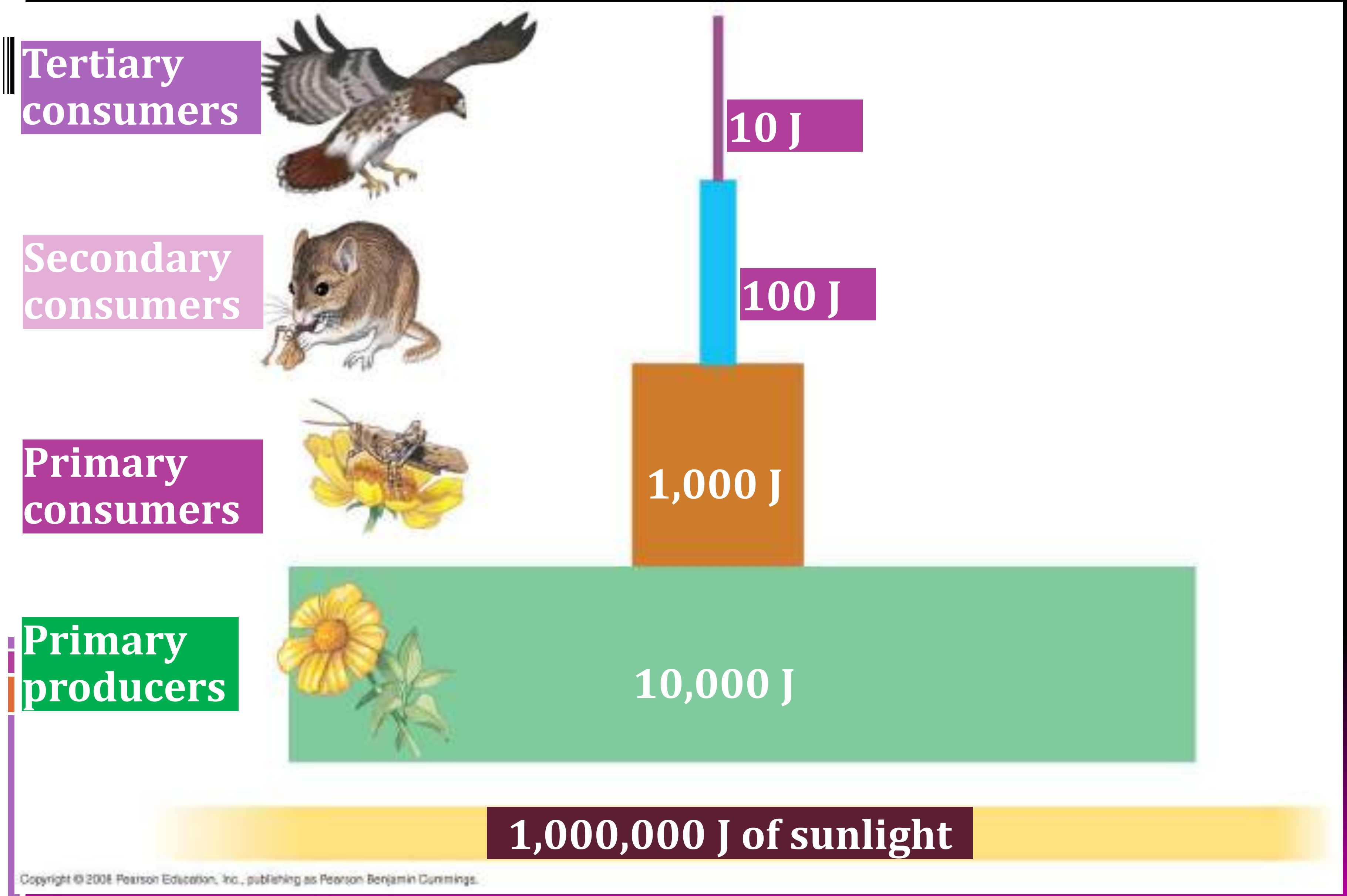


Increasing primary productivity

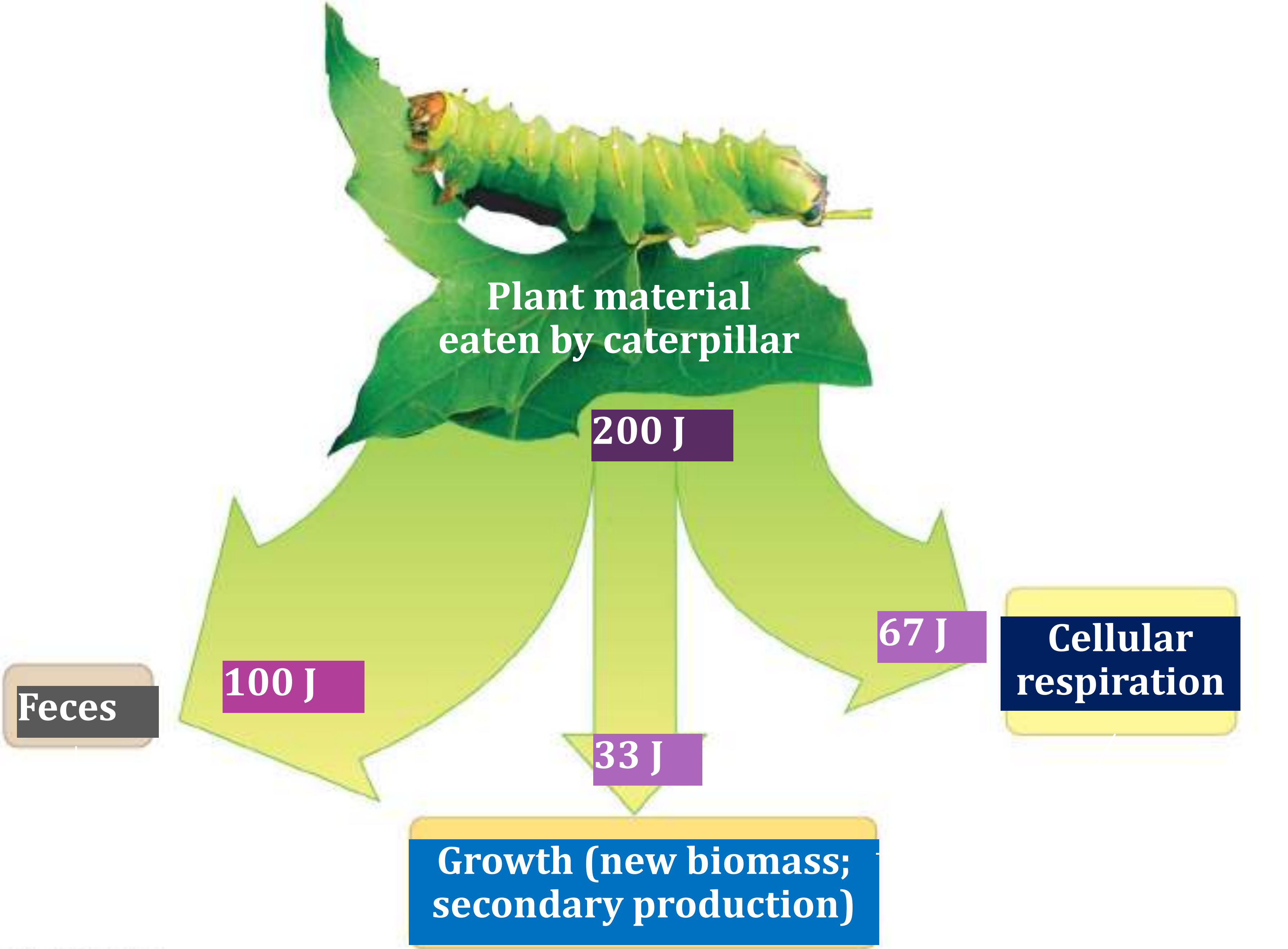
Energy transfer between trophic levels is typically only 10% efficient

- **Secondary production** of an ecosystem is the amount of chemical energy in food converted to new biomass during a given period of time

Fig. 55-10


Tertiary consumers
10 J
Secondary consumers
100 J
Primary consumers
1,000 J
Primary producers
10,000 J
1,000,000 J of sunlight
Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.

Where does all the energy go???


Plant material
eaten by caterpillar
200 J
100 J
Feces
33 J
67 J
Cellular
respiration
Growth (new biomass;
secondary production)

- **Birds and mammals have efficiencies in the range of 1–3% because of the high cost of endothermy**
- **Fishes have production efficiencies of around 10%**
- **Insects and microorganisms have efficiencies of 40% or more**

Ecological Efficiency:

Percent of energy <u>transferred</u> from one trophic level to the next.

Three categories of transfer efficiency are required to predict energy flow from PP to SP1 to SP2...

1) consumption efficiency

2) assimilation efficiency

3) production efficiency

1) consumption efficiency (CE)

% of total productivity at one trophic level that is consumed by the next highest level

(remainder not eaten)

2) assimilation efficiency (AE)

% of ingested food energy that is assimilated (i.e. digested), and thus potentially available for growth, reproduction

(remainder lost as feces)

3) production efficiency (PE)

% of assimilated energy that is incorporated into new biomass (growth, reproduction)

(remainder lost as respiratory heat)

Implications?

- SP1 is the % of PP that is incorporated at the next highest trophic level. (Ditto for SP2…)

This is NEVER 100%.

- Thus, energy loss at each trophic level limits the length of a food chain…

And that is why big fierce animals are rare!
Like: Whale, Ice beer, Elephant….etc.

Trophic Efficiency and Ecological Pyramids

- Trophic efficiency is the percentage of production transferred from one trophic level to the next
- It is usually about 10%, with a range of 5% to 20%
- Trophic efficiency is multiplied over the length of a food chain.

- **Approximately 0.1% of chemical energy fixed by photosynthesis reaches a tertiary consumer.**

- **A pyramid of net production represents the loss of energy with each transfer in a food chain**

Ecological Pyramids

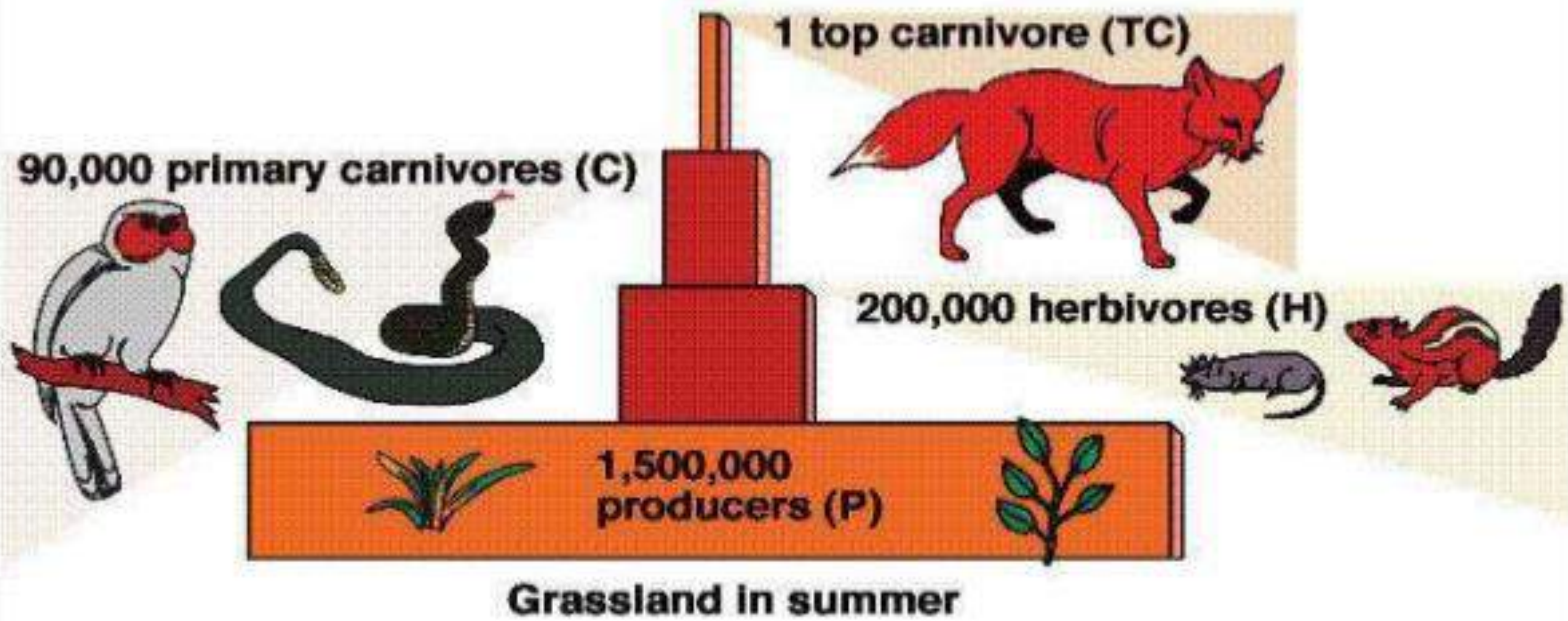
- The number, biomass, and energy of organisms gradually decrease from the producer to the consumer level. This can be represented by a pyramid called ecological pyramid.
- Ecological pyramid is the graphic representation of number, biomass, and energy of the successive trophic levels of an ecosystem.

Types of ecological pyramids

1. The pyramid of number
2. The pyramid of biomass
3. The pyramid of energy.

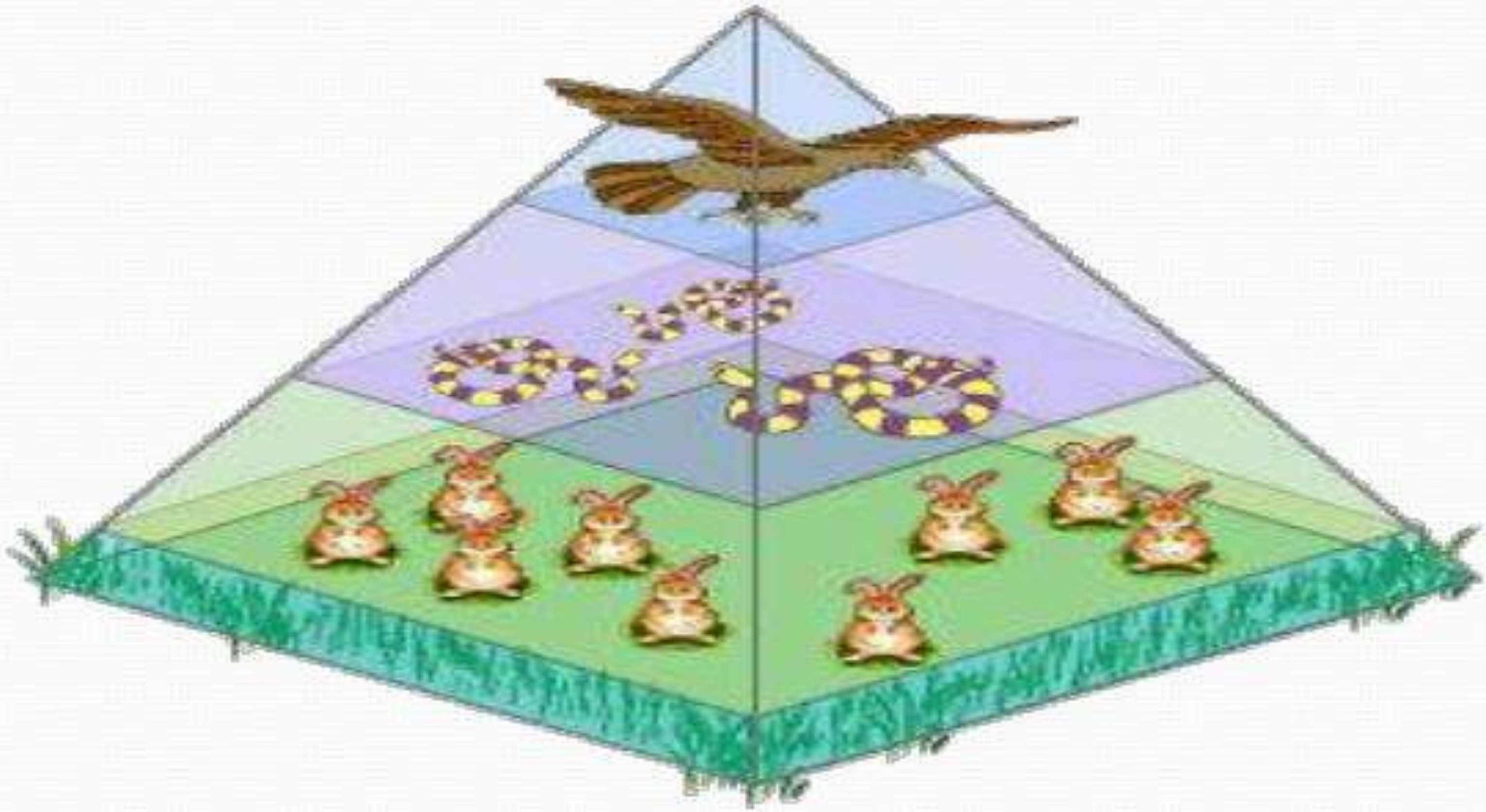
The pyramid of numbers

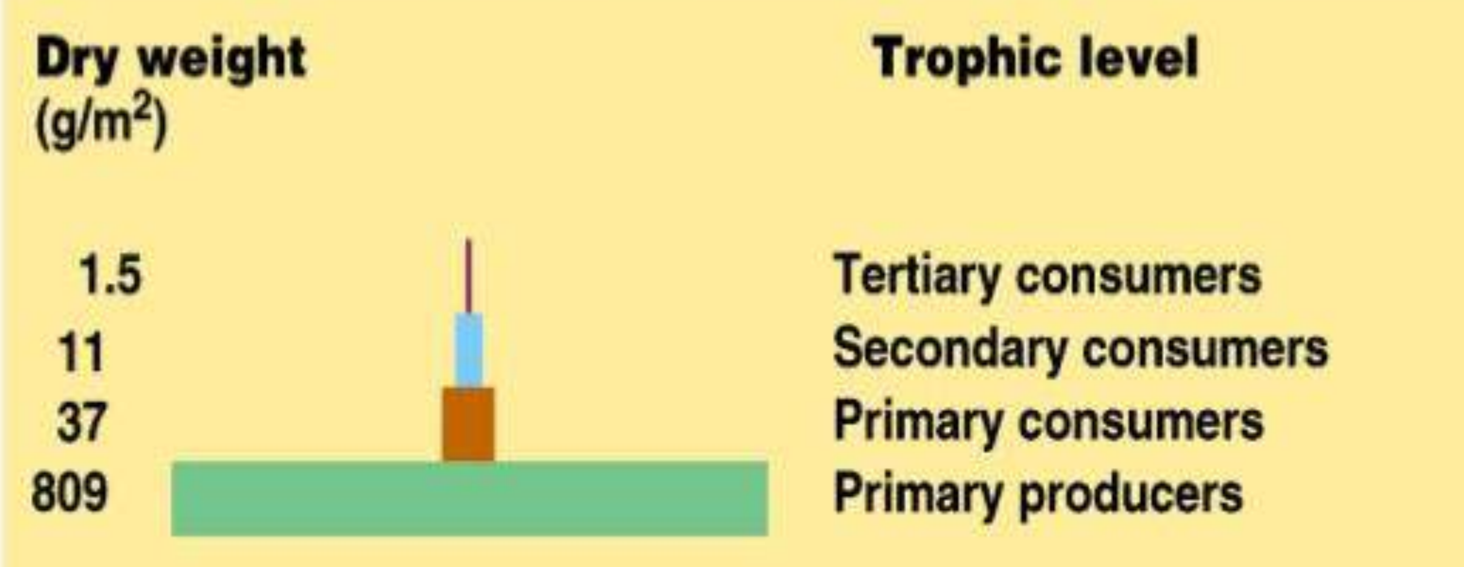
- The number of individuals at the trophic level decreases from the producer level to the consumer level.
- In any ecosystem the number of producers is far high. The number of herbivores is lesser than the producers. Similarly, the numbers of carnivores is lesser than the herbivores.


1 top carnivore (TC)
90,000 primary carnivores (C)
200,000 herbivores (H)
1,500,000
producers (P)
Grassland in summer

The pyramid of biomass

- Biomass: Biomass refers to the total weight of living matter per unit area.
- In an ecosystem the biomass decreases from the producer level to the consumer level.
- It represents the ecological consequence of low trophic efficiencies.
- Most biomass pyramids narrow sharply from primary producers to top-level carnivores because energy transfers are inefficient.

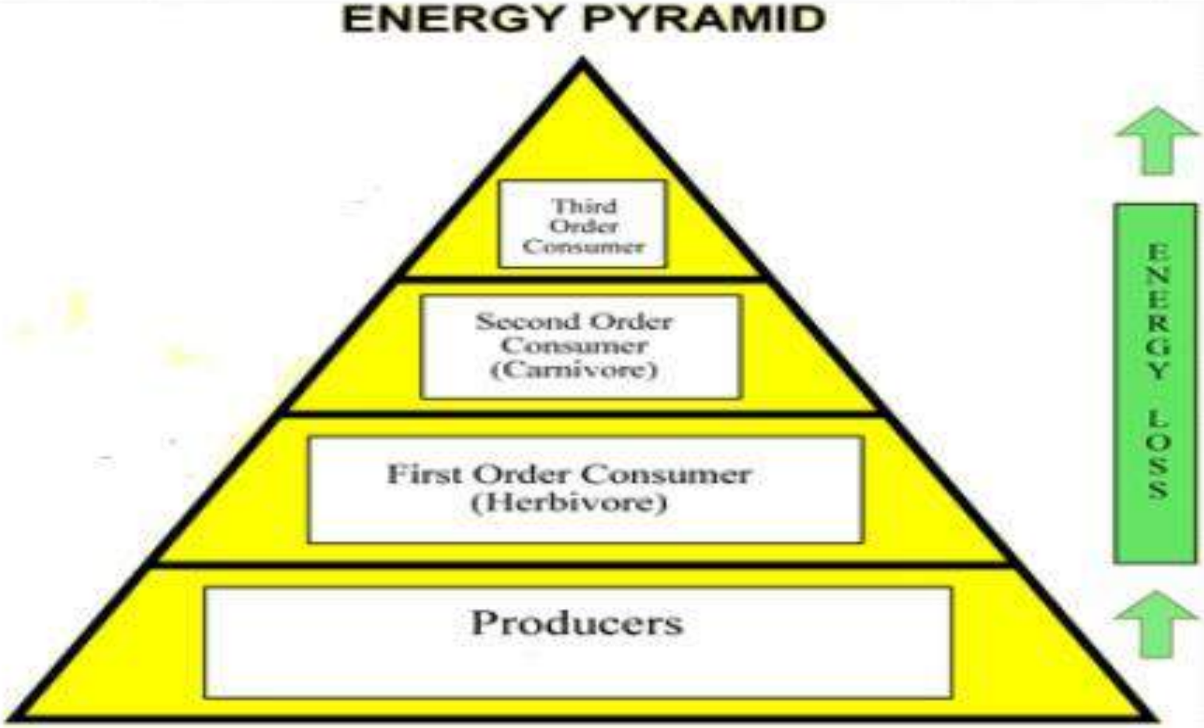


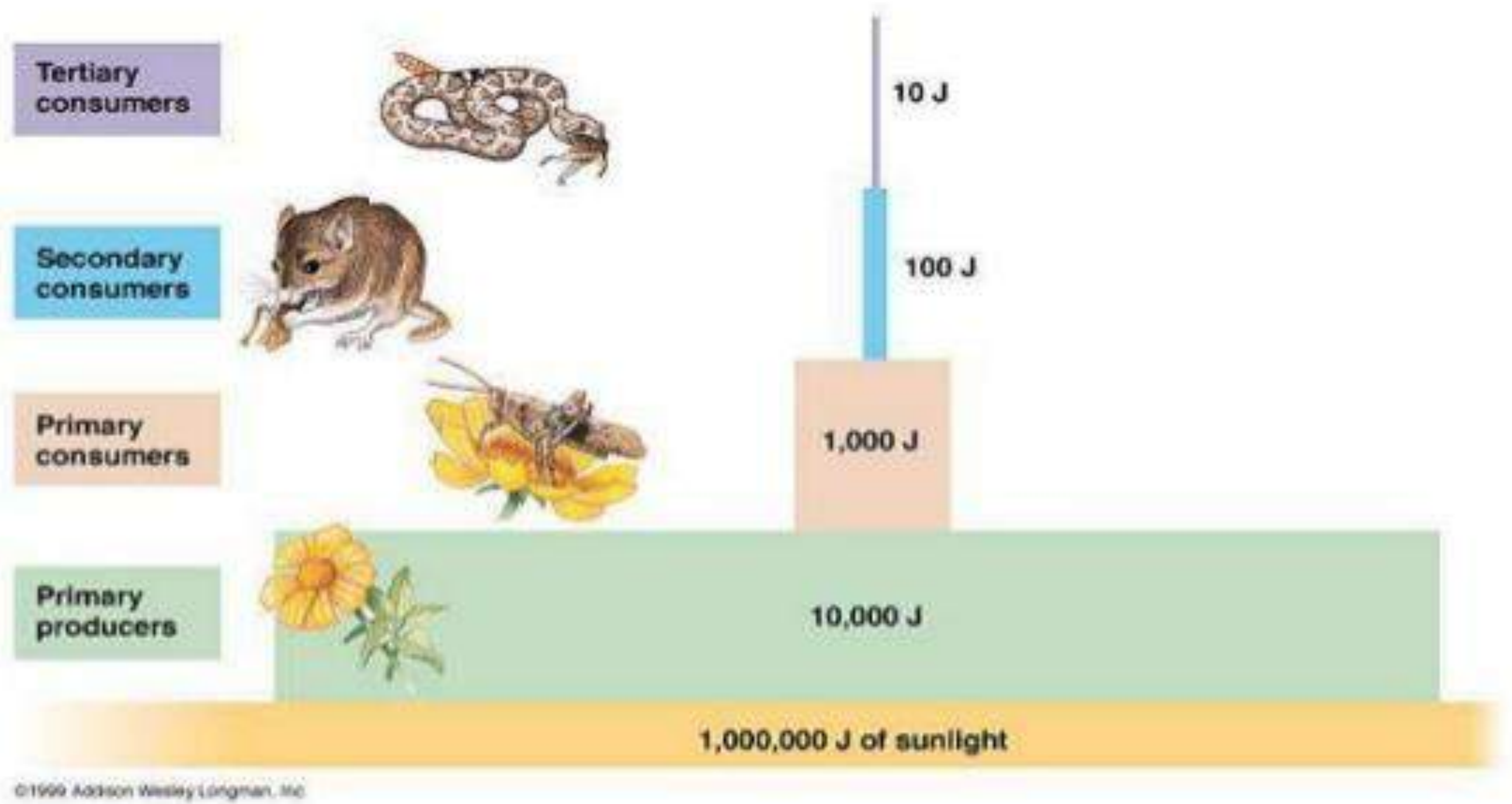


(a) Florida bog

Pyramid of energy

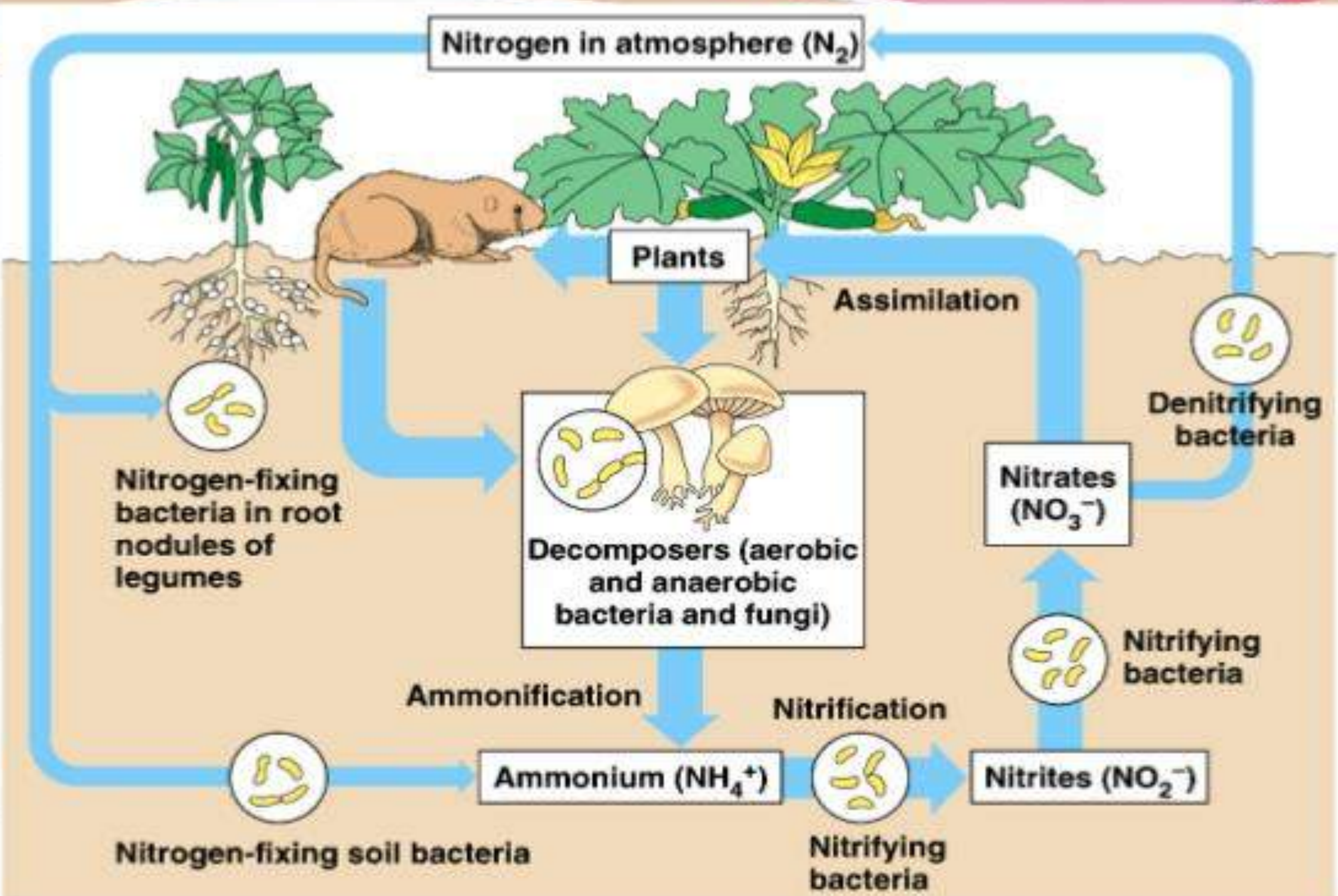
- The energy flows in an ecosystem from the producer level to the consumer level.
- Energy Pyramid shows the amounts of energy that moves from one level to the next
- At each trophic level 80% to 90% of energy is lost. Hence the amount of energy decreases from the producer level to the consumer level.


ENERGY PYRAMID
Third Order Consumer
Second Order Consumer (Carnivore)
First Order Consumer (Herbivore)
Producers
ENERGY LOSS


Tertiary consumers
Secondary consumers
Primary consumers
Primary producers
10 J
100 J
1,000 J
10,000 J
1,000,000 J of sunlight
©1999 Addison Wesley Longman, Inc

Nutrient cycles

- Nutrient cycling is strongly regulated by vegetation.
- Biological and geologic processes move nutrients between organic and inorganic compartments.
- Human activity intrudes in nutrient cycles by removing nutrients from one part of the biosphere and then adding them to another.
- Decomposition rates largely determine the rates of nutrient cycling.
- The rates at which nutrients cycle in ecosystems are extremely variable as a result of variable rates of decomposition.
- Decomposition can take up to 50 years in the tundra, while in the tropical forest, it can occur much faster. Contents of nutrients in the soil of different ecosystems vary also, depending on the rate of absorption by the plants.


Nitrogen in atmosphere (N_2)
Plants
Assimilation
Denitrifying bacteria
Nitrogen-fixing bacteria in root nodules of legumes
Decomposers (aerobic and anaerobic bacteria and fungi)
Nitrates (NO_3^-)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium (NH_4^+)
Nitrites (NO_2^-)
Nitrogen-fixing soil bacteria
Nitrifying bacteria

Nitrification :of Ammonia Occurs in two Steps

NH_3-N Ammonia N $\longrightarrow$ NO_2-N Nitrite N

Nitrosomonas

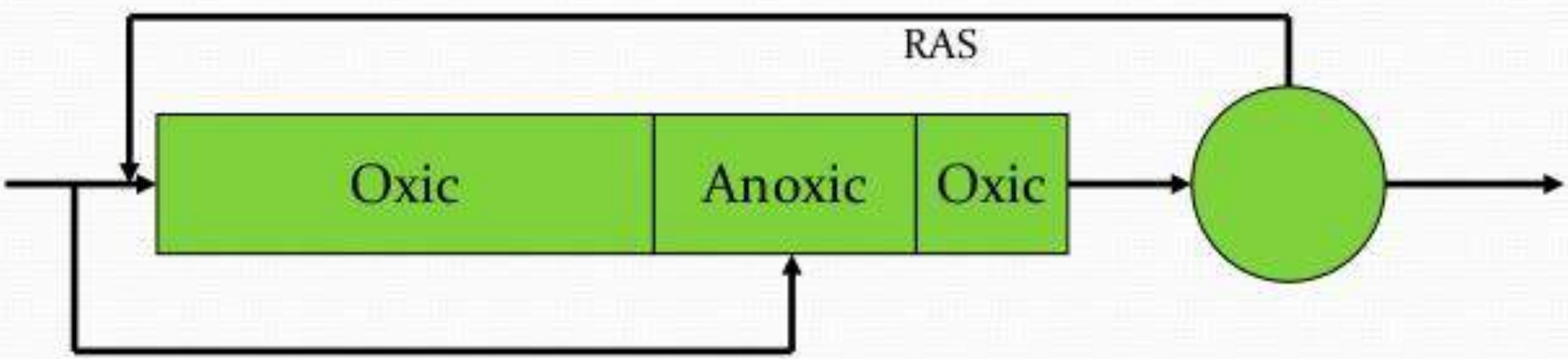
NO_2-N Nitrite N $\longrightarrow$ NO_3-N Nitrate N

Nitrobacter

DENITRIFICATION

$$NO_3 \xrightarrow[\text{Anoxic environment}]{\text{heterotrophic bacteria + BOD}} N_2 \uparrow$$

In an anoxic environment, heterotrophic bacteria will use the oxygen from nitrates as they assimilate BOD, producing nitrogen gas.



Critical load and nutrient cycles

- Recent studies indicate that human activities have approximately doubled the worldwide supply of fixed nitrogen, due to the use of fertilizers, cultivation of legumes, and burning.
- This may increase the amount of nitrogen oxides in the atmosphere and contribute to atmospheric warming, depletion of ozone and possibly acid rain.
- In some situations, the addition of nitrogen to ecosystems by human activity can be beneficial, but in others it can cause problems.
- The key issue is the critical load, the amount of added nitrogen that can be absorbed by plants without damaging the ecosystem.