Landscape Ecology

Landscape ecology [Chpt 23]

- Edges, ecotones and boundaries
- Corridors
- Island biogeography
- Patch dynamics
- Disturbance

LANDSCAPE ECOLOGY

A LANDSCAPE consists of *communities of varying sizes and compositions* embedded in a MATRIX

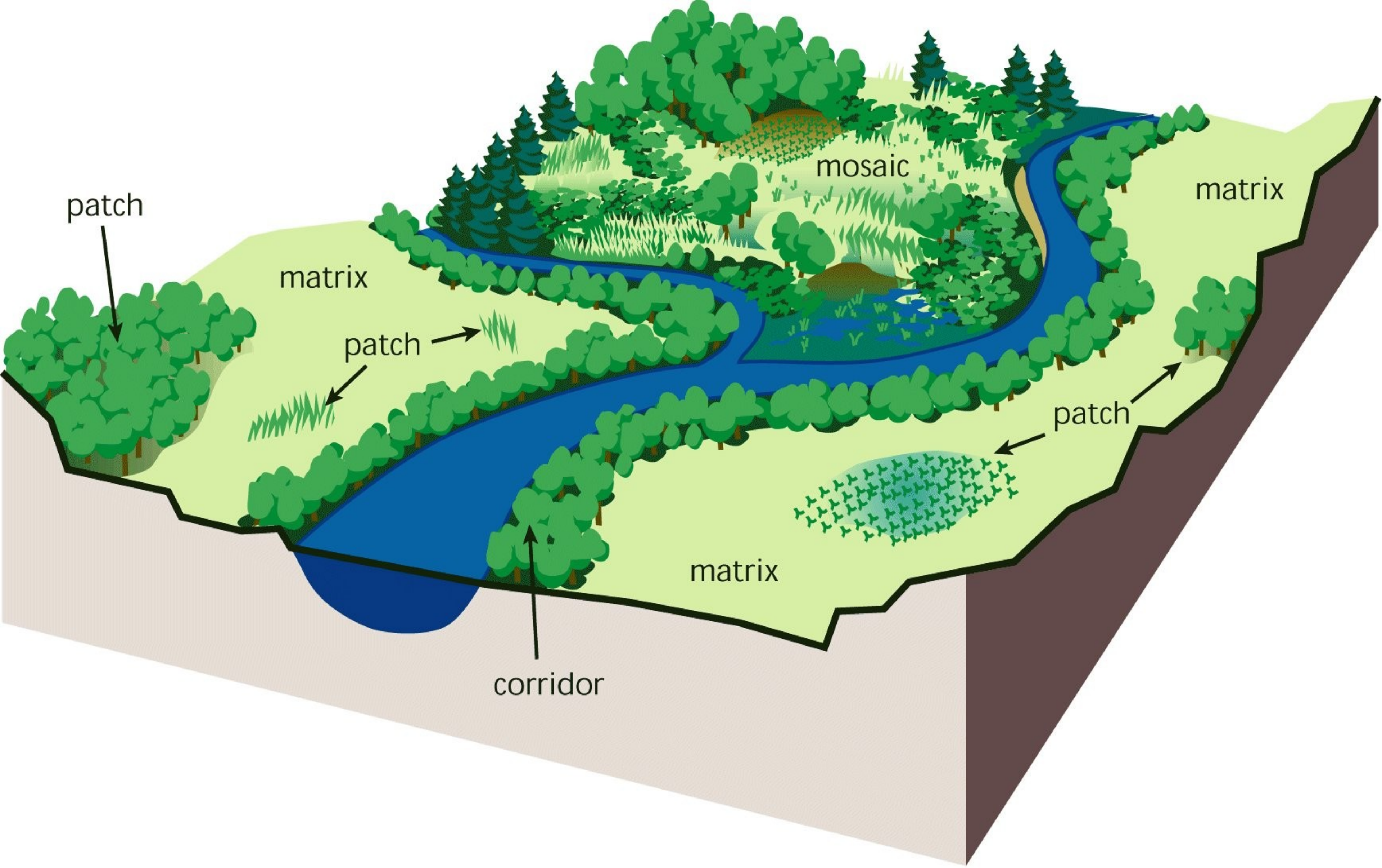
(=surrounding areas that differ in species structure or composition).

Natural patterns of PATCHES or landscape elements (distinct communities that make up the mosaic) within this landscape are affected by human disturbance

i.e. introduced patches (altered patches that often involve the elimination of natural ecosystems / the introduction of exotic species)
surround unmodified remnant patches (unmodified natural ecosystems).

The size, shape, area and orientation of **PATCHES** have an important influence on many physical and ecological processes.

e.g. flow of wind, the dispersal of seeds, and the movement of animals, and on their suitability as habitats for plants and animals.



Elements of the landscape: matrices, patches, and corridors.

The edge of one patch meets the edge of another patch at a BORDER

The ‘edge’ area s of two adjacent patches (plus border), is referred to as the BOUNDARY.

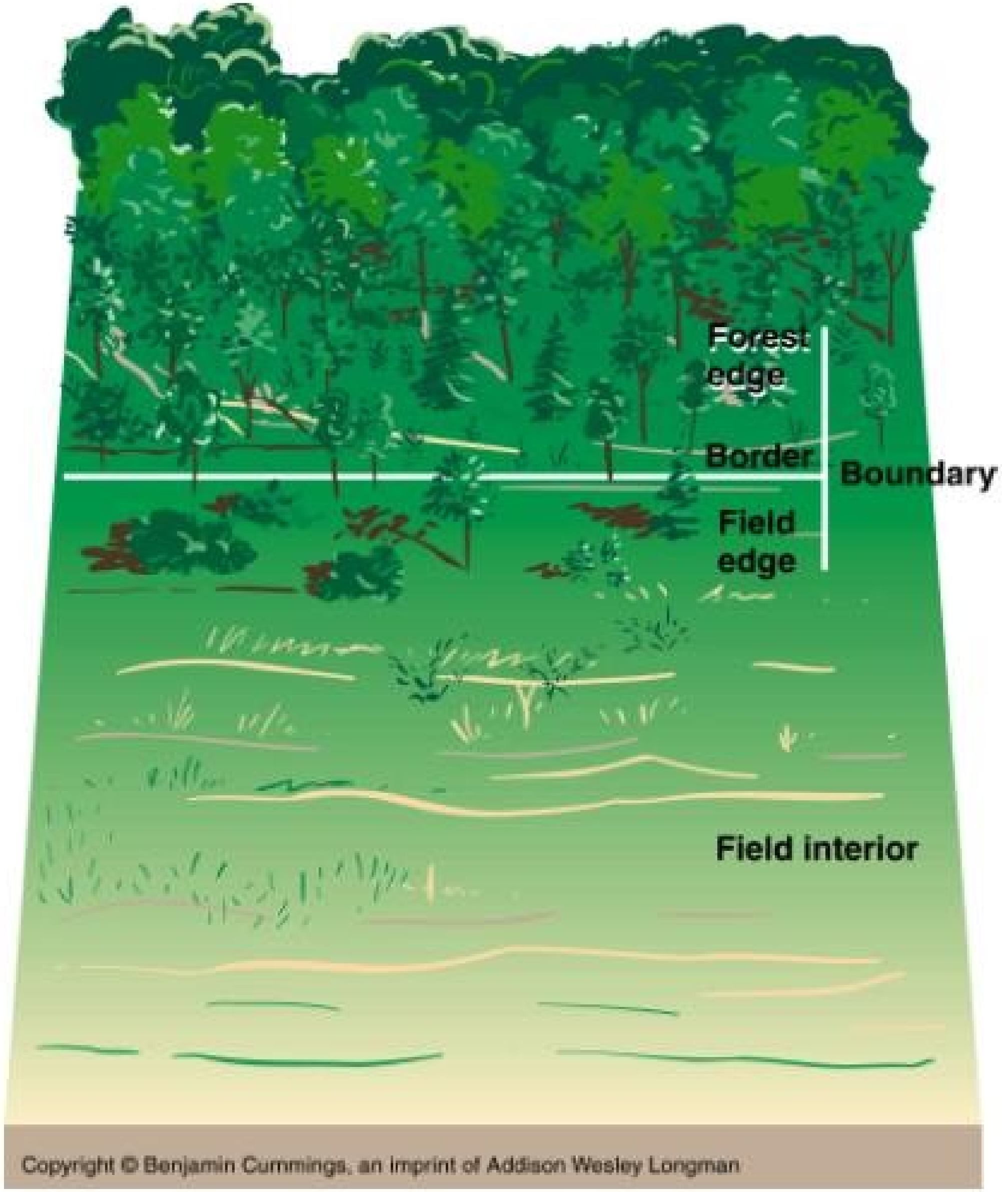
- Although some adjacent patches have boundaries that are abrupt, with sharp contrasts between the two patches;

- Some patches do not have distinct boundaries and intergrade / blend into other patches in areas of community overlap, or ECOTONES.

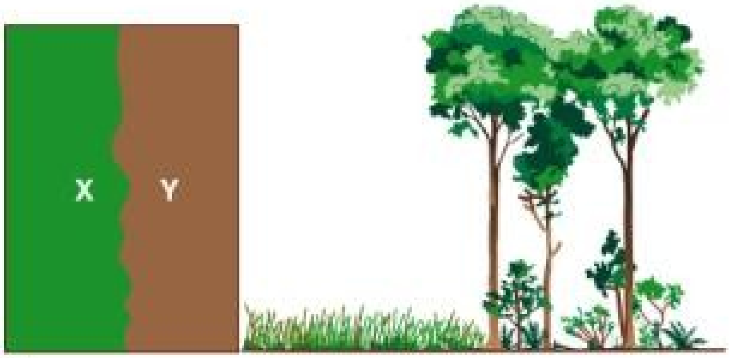
In the ecotone, species common to each community mingle with species common to the edge, often resulting in a highly diverse and unique community in the boundary

- EDGES

Spatial relationships of border, boundary, edge, and interior in a landscape.

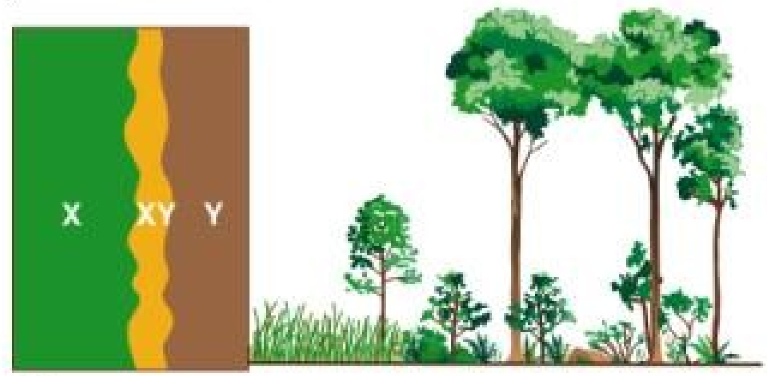


Types of ecotones: (a) Abrupt, narrow edge with no development of an ecotone. (b) Narrow ecotone developed by advancement of community Y into community X. (c) Community X advances into community Y to produce ecotone XY. (d) Ideal ecotone development in which plants from both communities invade each other to create a wide ecotone X^2Y^2.



(a)

(b)



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(d)

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o inherent edges are stable, long-term features of a landscape.
o induced edges are maintained by periodic disturbances.

o The EDGE EFFECT refers to ecotones and edges being environmentally diverse and composed of species from each patch as well as species unique to the edge itself;

oconsequently, species richness is often higher along community edges and ecotones.

EDGES

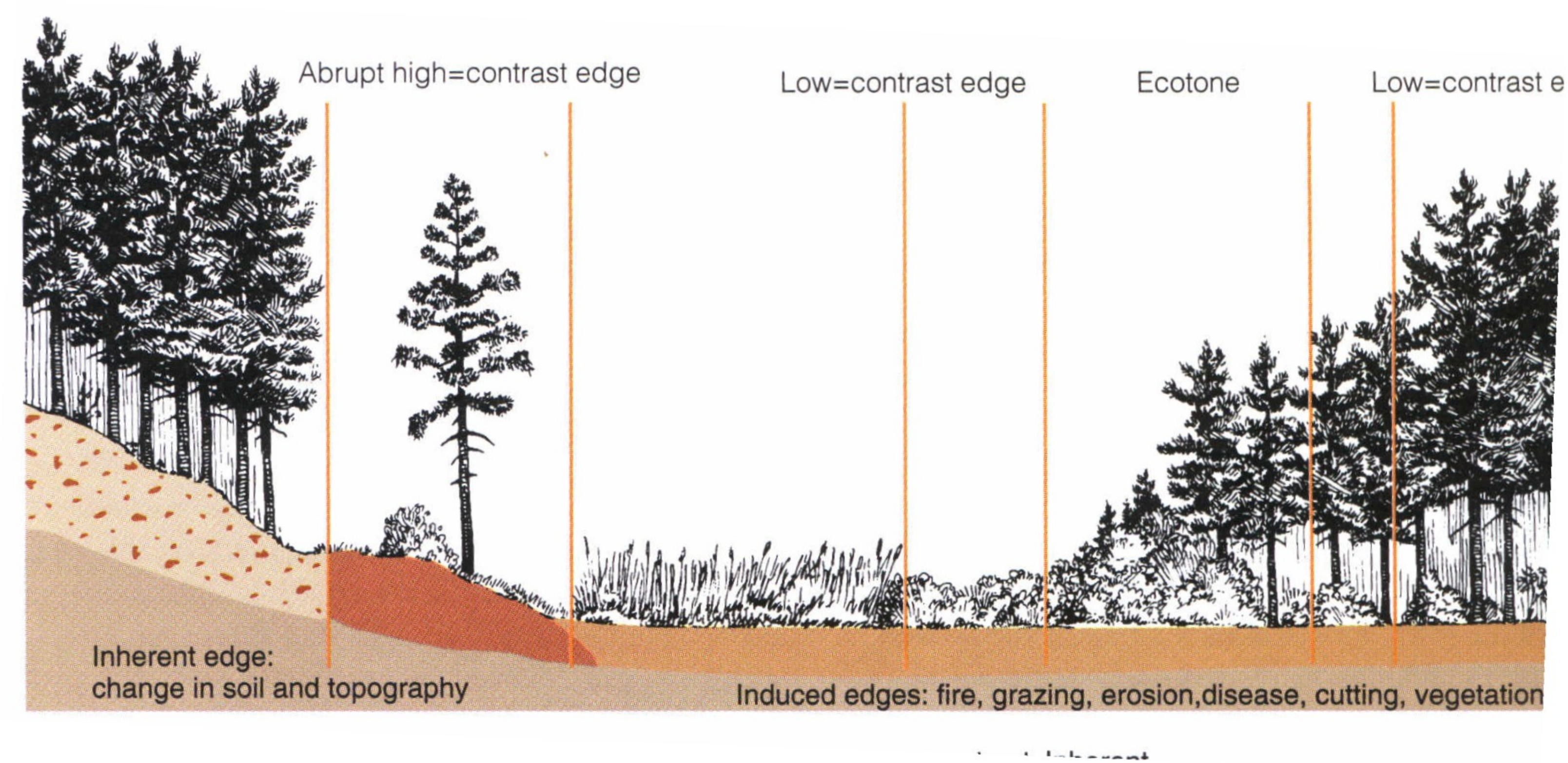
- Some edges result from abrupt changes in soil type, topography, geomorphic features (such as rock outcrops), and microclimate.
- Under such conditions, long-term natural features of the physical environment determine adjoining vegetation types.
- Such edges, referred to as INHERENT, are usually stable and permanent.

EDGES

- Other edges result from such natural disturbances as fire, storms, and floods
- or from such human-induced disturbances as livestock grazing, timber harvesting, agriculture, and suburban development.
- Such edges, maintained by periodic disturbances, are called INDUCED EDGES.
- Unless maintained, these disturbed areas will tend to revert to their original state – e.g. succession

- **Edge development**

Types of edges: inherent and induced, high contrast and low contrast. Inherent edges are most abrupt. Edges of high contrast exist between widely different adjacent communities, such as shrub and mature forest. Edges of low contrast involve two closely related successional communities, such as shrubs and sapling growth.



- Successional process that occur in edge communities arises because environmental conditions in the newly formed edge are different from those of the adjacent vegetation communities, especially in the case of forests.

- Environmentally, such edges reflect steep gradients of wind flow, moisture, temperature, and solar radiation.

- Wind velocity is greater at the forest's edge than within the forest, creating higher rates of evaporation and xeric conditions in and around the edge.

- With increased temperatures - transpiration increases, placing greater demands on soil moisture by plants.

- Because changes in the penetration of solar radiation are influenced by aspect, north-facing and south-facing edges will differ in environmental conditions.
- In the Northern Hemisphere, a south-facing edge may receive 3 – 10 x more hours of sunshine a month during midsummer than a north-facing edge, making it much warmer and drier.
- Although the depth to which sunlight penetrates the vertical edge of the forest depends on a variety of factors, including solar angle, edge aspect, density and height of vegetation, latitude, season and time of day, in general the edge effect extends about 50 m into the forest.

CORRIDORS are strips of vegetation linking one patch with another.

The vegetation of the corridor is similar to the patches it connects but different from the surrounding landscape in which they are set.

- **Narrow-line corridors** **include windbreaks, hedgerows, roads and roadside strips, and drainage ditches.**
- **Strip corridors** **(have both interior and edge environments) include strips of woodlands, power line rights-of-way & stream riparian (bank vegetation) zones.**

Corridors provide both *unique habitat and passages* between habitat patches.

Often, corridors originate from human disturbance or development and are remnants of largely undisturbed land between agricultural fields and developments.

- **Corridors act as filters, providing dispersal routes for some species but not others—the filter effect.**

- **Corridors have both positive effects**

  (i.e., promotion of gene flow)

and negative effects

  (i.e., spread of disease, road-kill)

Island Biogeography Theory

The various patches that form the vegetation patterns across the landscape suggest ISLANDS of different sizes.

The size of the patches and their distances from each other have a pronounced influence on the nature and diversity of the life they hold.

- **Darlington's rule of thumb (1957):**

"a tenfold increase in area leads to a doubling of the number of species."

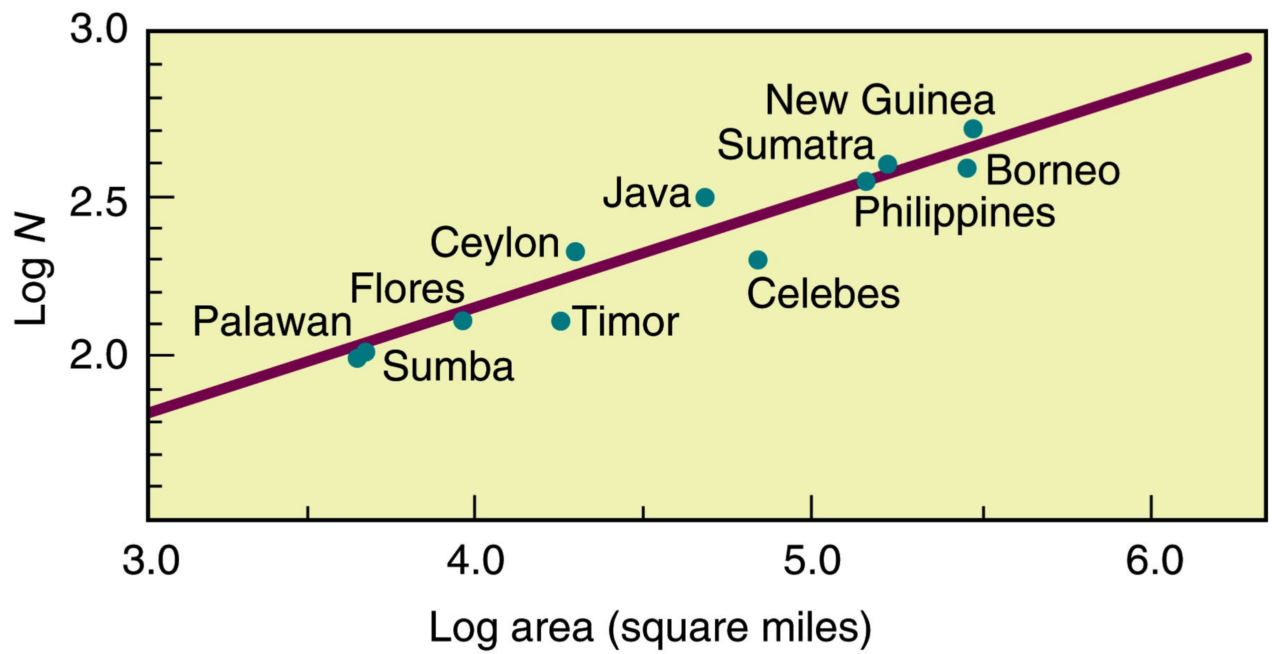
F.W. Preston (1962) formalized the relationship between the area of an island and the number of species present.

When the two values are plotted as logarithms, the number of species varies linearly with island size.

The steeper the slope of the line, the larger the increases in species richness per unit increase in island size.

▪ ISLAND BIOGEOGRAPHY THEORY

Number of bird species on various islands of the East Indies in relation to area. The abscissa gives areas of the islands. The ordinate is the number of bird species breeding on each island. The number of species varies linearly with island size:
log S = log c + zlogA, where S is the number of species, A is the area of the island, c is a constant measuring the number of species per unit area, and z is a constant measuring the slope of the line relating S and A.



The theory of island biogeography (MacArthur and Wilson 1963) states that the number of species of a given taxon established on an island represents a dynamic equilibrium between:

- the rate of immigration of new colonizing species and
- the rate of extinction of previously established ones.
- The rate at which one species is lost and a replacement gained is called the TURNOVER RATE.

o There are a number of limitations to this theory:

- It examines species richness only.
- It makes no assumptions about species composition—all species are treated as equivalents.
- It does not address limitations related to the life history or habitat requirements of the species involved.
- It assumes that the probabilities of extinctions and immigrations are the same for all species.

Immigrations and extinctions may not be independent.

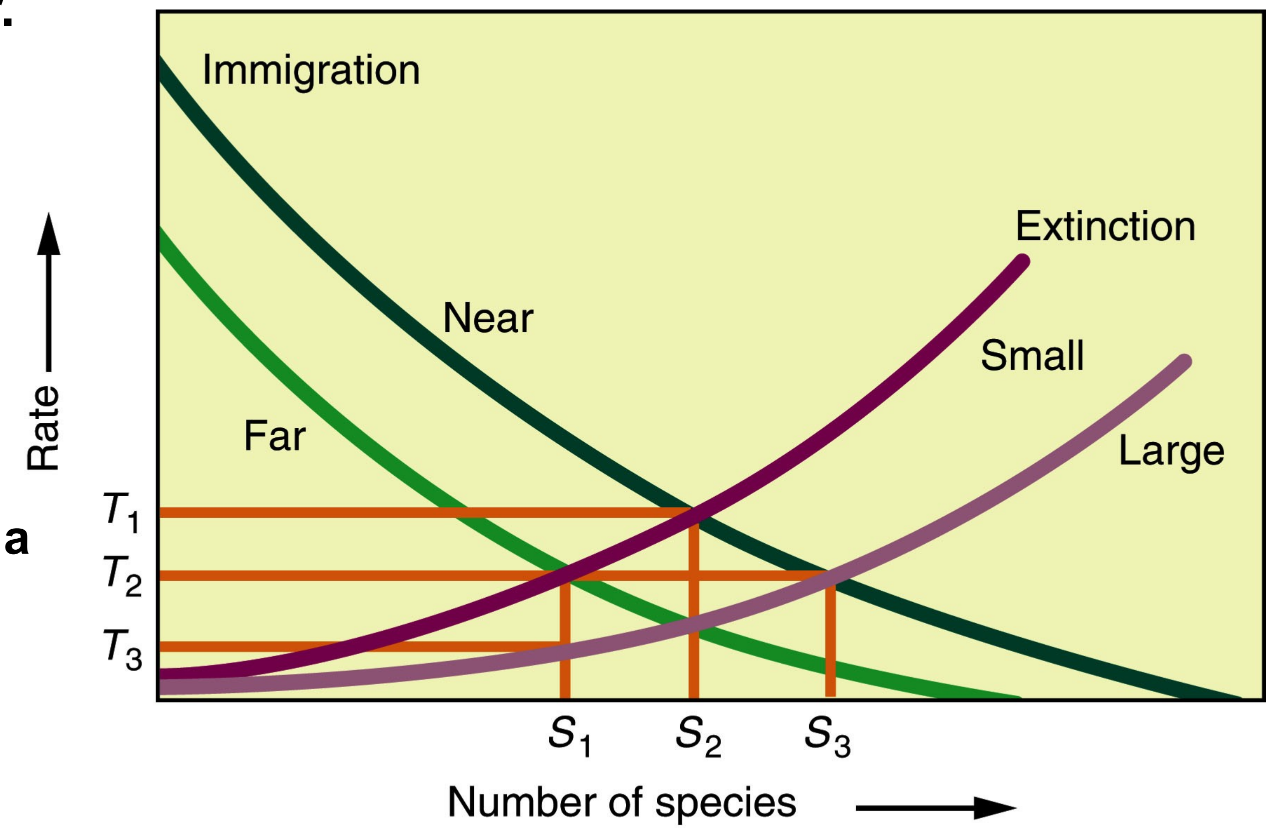
For example:
extinction of a dwindling population may be slowed or prevented by an influx of immigrants

= the rescue effect.

Graphical representation of the island biogeography theory, involving both distance and area. Equilibrium species densities are labeled by corresponding value of S. Immigration rates decrease with increasing distance from a source area. Thus distant islands attain species equilibrium with fewer species than near islands, all else being equal. Extinction rates increase as the size of the island becomes smaller.

[S_3>S_2 for large islands; S_2>S_1 for small islands.]

T=the rate at which a species is lost and another is gained.



- An alternative approach to island biography is the HABITAT DIVERSITY THEORY.

The habitat diversity theory states that it is the diversity of habitats that supports species richness, not the area per se.

Larger islands may have lower extinction rates and support more species than smaller islands because they have more diverse habitats.

  - There is considerable evidence that habitat heterogeneity can override the influence of island size

  - with smaller islands with high habitat heterogeneity supporting greater species richness than large, more homogeneous islands.

Patch Dynamics

Patches are dynamic systems affected by both natural processes and human disturbances.

The impact of fragmentation is related to the scale at which it occurs.

- **The probability of occurrence of interior species**

—those whose habitat begins some distance within the habitat patch—

increases with patch size.

- **Some species are area-sensitive because they require large territories or foraging areas.**

- **Area-insensitive species are found in small or large habitat units.**

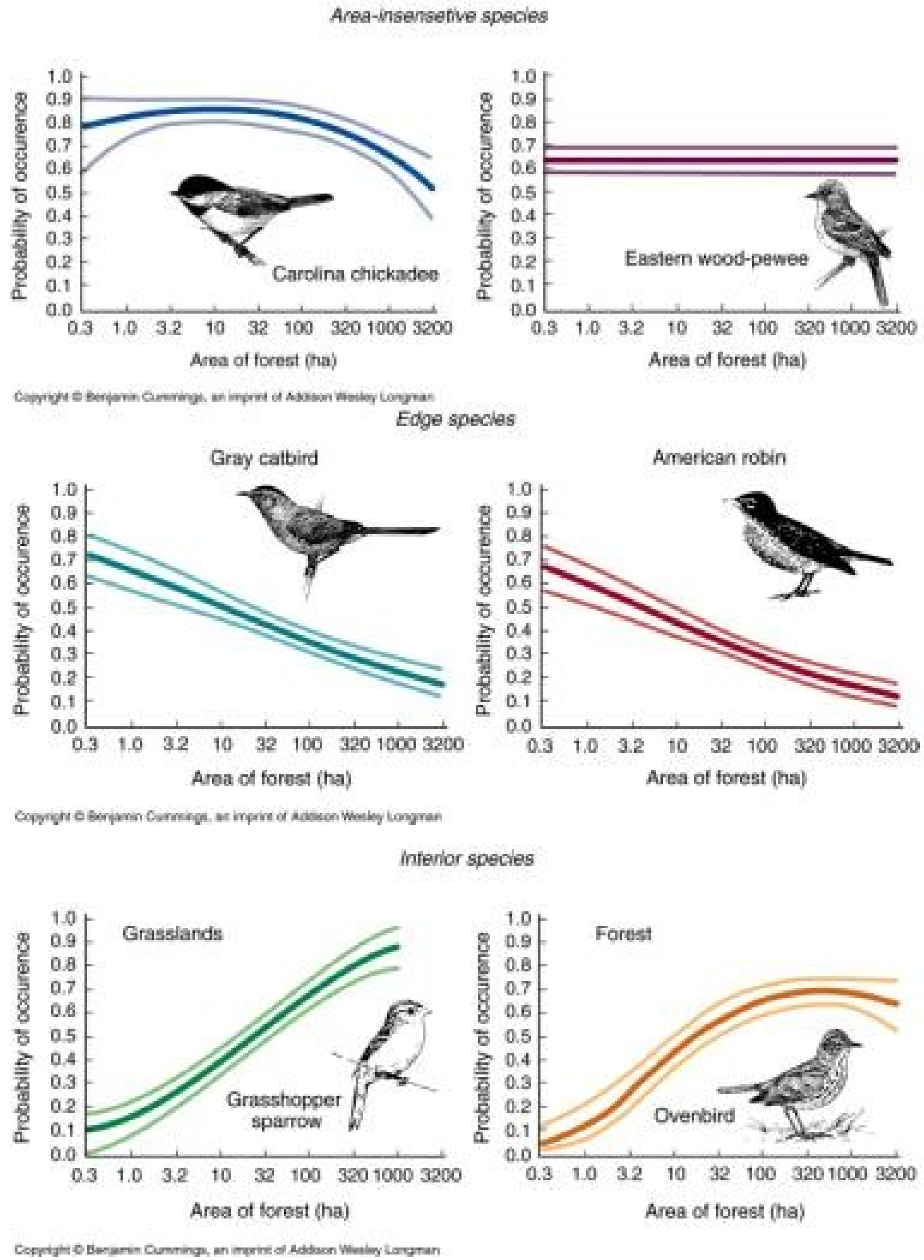
As fragmentation continues and patch area is reduced –

- area-sensitive species go extinct

- while edge and area-insensitive species increase in numbers.

As fragmentation continues, species numbers follow a downward trend.

Differences in habitat responses among edge, area-insensitive, and area-sensitive for interior bird species. The graphs indicate the probability of detecting these species from a random point in forests and grasslands of various sizes. The dotted lines indicate 95 percent confidence intervals for the predicted probabilities.



- The minimum size of habitat needed to maintain interior species differs between plants and animals.
- For plants, patch size, per se, is not as important in species persistence and extinction as environmental conditions.
- For many shade-tolerant plant species found in the forest interior, the minimum area depends on the patch size required to allow for appropriate moisture and light conditions.
- If the stand is too small or too open, the interior environment becomes so xeric that mesic species, both herbaceous and woody, cannot survive and reproduce.

Theoretically, although maximum diversity is achieved with patches of intermediate size

- many species that require large patches are excluded.

Also, fragmentation of larger patches may not result in a significant decline in species *diversity*

- but it may eliminate many species from the landscape.

Although species diversity is related to area, it also is a function of the ratio of edge (or perimeter) to area.

The length of perimeter is directly proportional to the square root of the area.

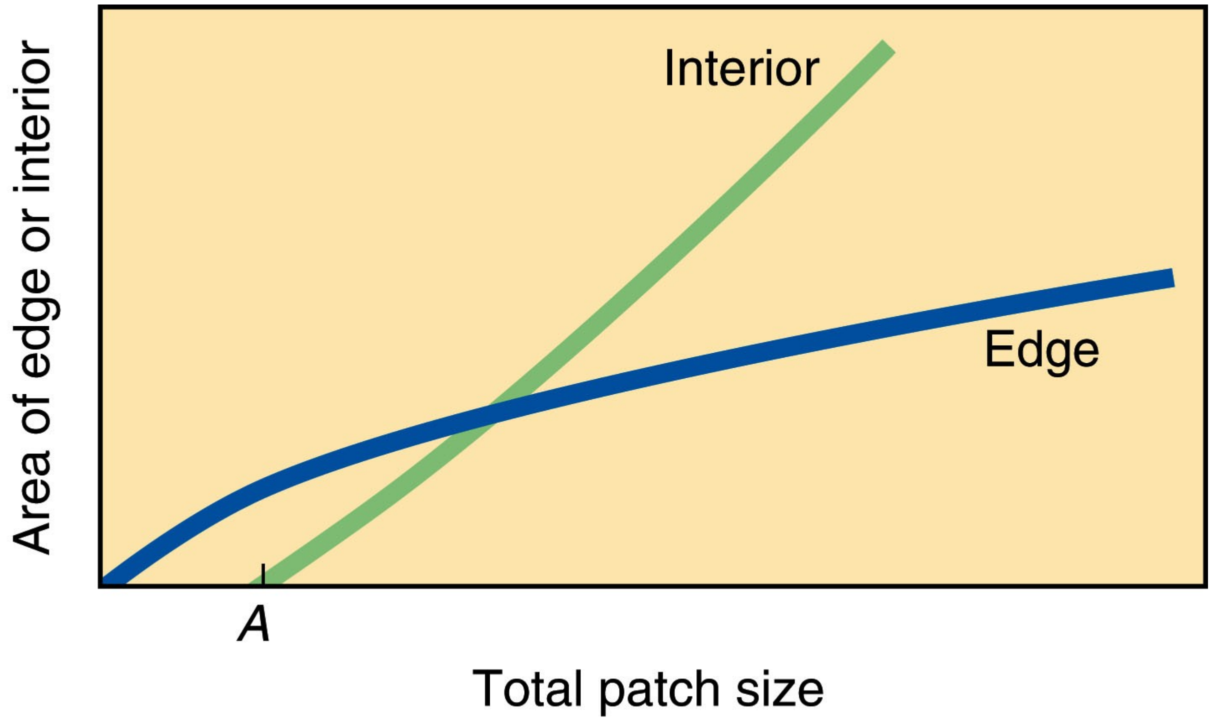
At some small size, territorial islands are all edge.

If the depth of the edge remains constant as area increases, the ratio of edge to interior decreases as the habitat island size increases.

Configuration or shape of the island is also important.

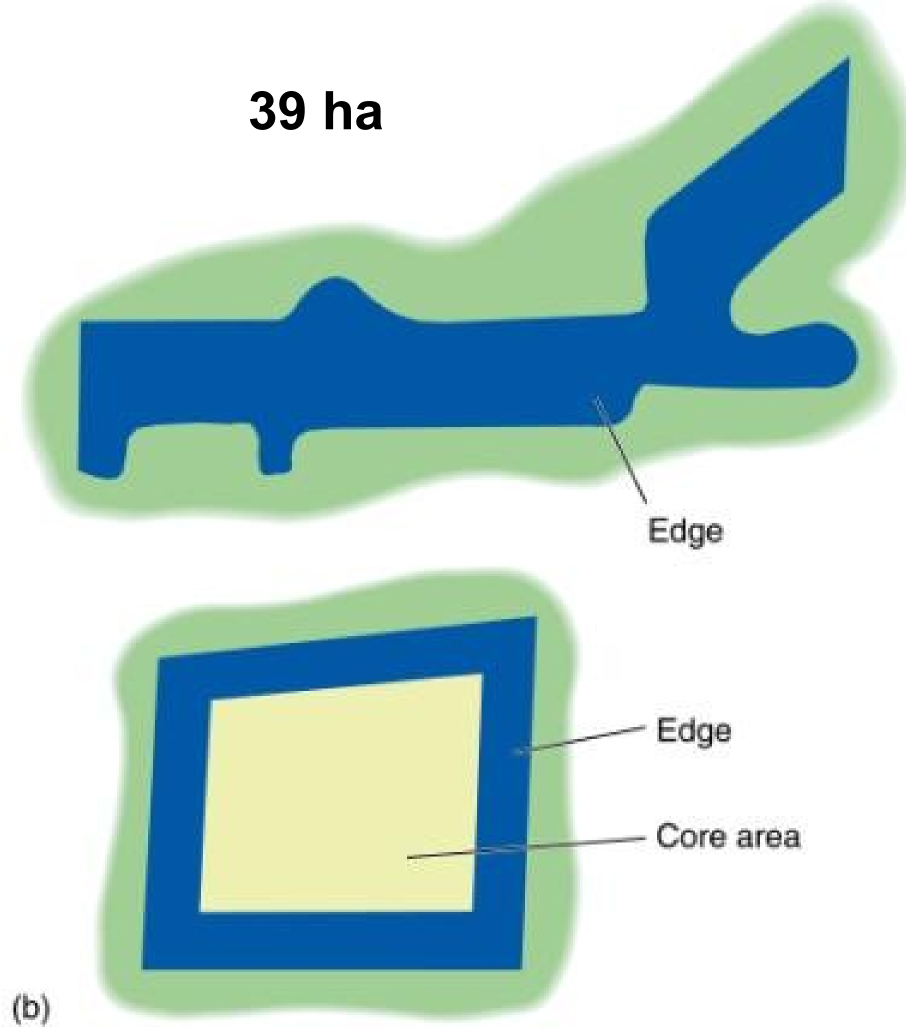
For example, long, narrow islands of sufficient size may still be all edge habitat.

Relationship of island or fragment size to edge and interior conditions. (c) A graph shows the relationship between edge and interior as island size increases. Below A, the woodland is all edge. As its size increases, interior area increases and the ratio of edge to interior decreases. This relationship of size to edge holds for circular or square islands.



(c)

Relationship of island or fragment size to edge and interior conditions. (b) Size alone is not a determinant of interior-edge conditions. Shape of the island is also critical. A long or rectangular habitat patch is all edge.



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Disturbance creates colonization sites, thereby increasing the abundance of opportunistic species and diversity while simultaneously initiating secondary succession.

Disturbances can be characterized on the basis of intensity, frequency and scale:

- Intensity is a measure of the magnitude of the physical force of the disturbance, usually expressed in terms of the proportion removed or mortality of individuals, species, or biomass.

  It is influenced by the magnitude of the physical force involved, morphological and physiological characteristics of the organisms that influence their response, and the nature of the substrate.

- **Frequency** is the rate of disturbance, or return interval—number of disturbances/time.
- **Scale** is rather abstract but refers to the size of the disturbance and must be considered in the context of the scale of the community being affected.

o Sources of landscape disturbance include fire (surface, crown, and ground fire), wind, ice, moving water, drought, and animals, and human activities such as timber harvest, land clearing, cultivation, and mining.

oSome species have developed adaptations to periodic disturbances, such as fire. They may be loosely classified as “seeders, sprouters, or tolerators.”

o The effects of disturbance on animals depend on the species affected and the size and type of disturbance.

A wee break…

• Ecosystem Productivity

Ecosystem Productivity [Chpt 24]

- Components
- Nature of Energy
- Laws of thermodynamics
- Storage and utilization of energy by plants
- Primary productivity around the world
- Secondary production
- Energy balance
- Food chains or Energy flow

Structural and Functional Components of Ecosystems

One of the primary functional processes of ecosystems is the flow and use of energy.

- **The biotic and abiotic components of the ecosystem exchange energy and materials.**

- **All ecosystems have three structural and functional components:**
    - **Autotrophs-the energy-capturing base of the system.**
    - **Heterotrophs (consumers and decomposers)-organisms that utilize the energy stored by the autotrophs and ultimately decompose complex materials into simple, inorganic substances.**
    - **Inorganic and dead organic matter - the basis of the internal cycling of nutrients in the ecosystem.**

- Inputs into the system are both biotic (includes other organisms that move into the ecosystem and influences imposed by other ecosystems in the landscape) and abiotic (energy, inorganic substances, mineral nutrients, organic compounds, and precipitation).

- The driving force of the system is the energy of the sun which causes other inputs to circulate through the system.

- Outflows from one system become inflows to another.

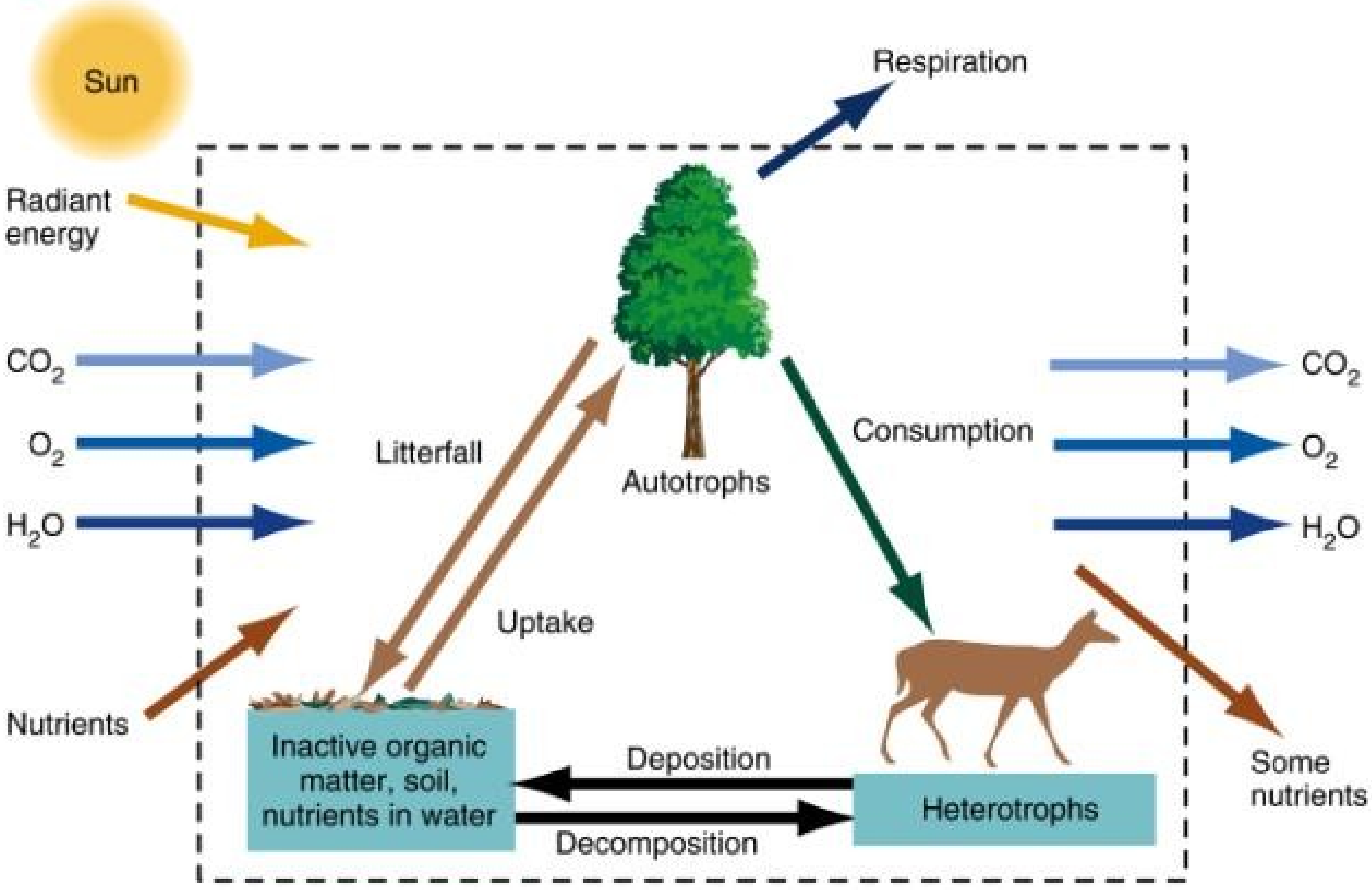
Energy is being used and dissipated as heat of respiration while chemical elements are being recycled.

- Consumers regulate the speed at which nutrients are recycled.

- A given ecosystem on any particular site is not a permanent entity, but part of a shifting pattern on the landscape.

- Biotic and abiotic components making up the ecosystem structure may change, biomass accumulate or decline, but functional processes still operate.

COMPONENTS OF ECOLOGICAL SYSTEMS



The Nature of Energy

Energy is the ability to do work; it is what happens when a force acts through distance.

Energy can be potential or kinetic:

- **Potential energy - energy at rest and is capable of and available for work.**
- **Kinetic energy - energy in motion.**

- **Work that results from the expenditure of energy can either store or concentrate energy (as potential energy) or arrange or order matter without storing energy.**

- **Energy is measured in joules (1 joule is 4.168 one-gram calories), calories (1 calorie is the amount of heat needed to raise 1 gram of water 1^{o}C at 15^{o}C), or kilogram calories (kcal or the amount of heat required to raise 1 kilogram of water 1^{o}C and 15^{o}C).**

The Laws of Thermodynamics

The first law of thermodynamics is concerned with the conservation of energy:

energy is neither created nor destroyed.

It may change form, pass from one place to another, or act on matter, transforming it to energy, but in the process there is no gain or loss in total energy from the system.

- **An exothermic reaction releases potential energy as heat into the surrounding.**
- **When energy from outside flows into a system to raise it to a higher energy state, the reaction is endothermic. (i.e. heat goes in)**

Much of the potential energy in any reaction is degraded in quality and becomes unable to perform further work.

This energy ends up as heat, serving to disorganize or randomly disperse molecules.

The measure of this relative disorder is termed entropy.

- The second law of thermodynamics states that when energy is transferred or transformed, part of the energy is lost as waste;

The tendency, then, is to create disorder (entropy) out of order—the system is running down hill.

The second law applies theoretically to isolated closed systems, in which there is no exchange of energy or matter between the system and its surroundings.

Biological systems do not seem to conform to the second law of thermodynamics.

Ecological systems are open, steady-state systems in which entropy is offset by the continual input of free energy.

Any discussion of energy flow through ecosystems is fundamentally a discussion of solar energy and carbon.

Storage and Utilization of Energy by Plants

Primary production - energy accumulated by plants resulting from photosynthesis.

Gross primary production (GPP)-all of the energy assimilated in photosynthesis.

Net primary production (NPP)-energy remaining after respiration and stored as organic matter

[NPP = GPP – Respiration].

The storage of organic matter in plant tissue in excess of respiration.

Both gross and primary production are measured as the rate at which energy or biomass is produced per unit area per unit time [kcal/m^2/yr or g dry weight/m^2/yr].

Standing crop biomass - the accumulated organic matter found on a given area at a given time.

Because it represents accumulated biomass, a low-productivity ecosystem can accumulate a high standing crop biomass over a long period of time.

- Levels of primary productivity vary immensely among ecosystems, between ecosystems of the same type, and within the same ecosystem from year to year.

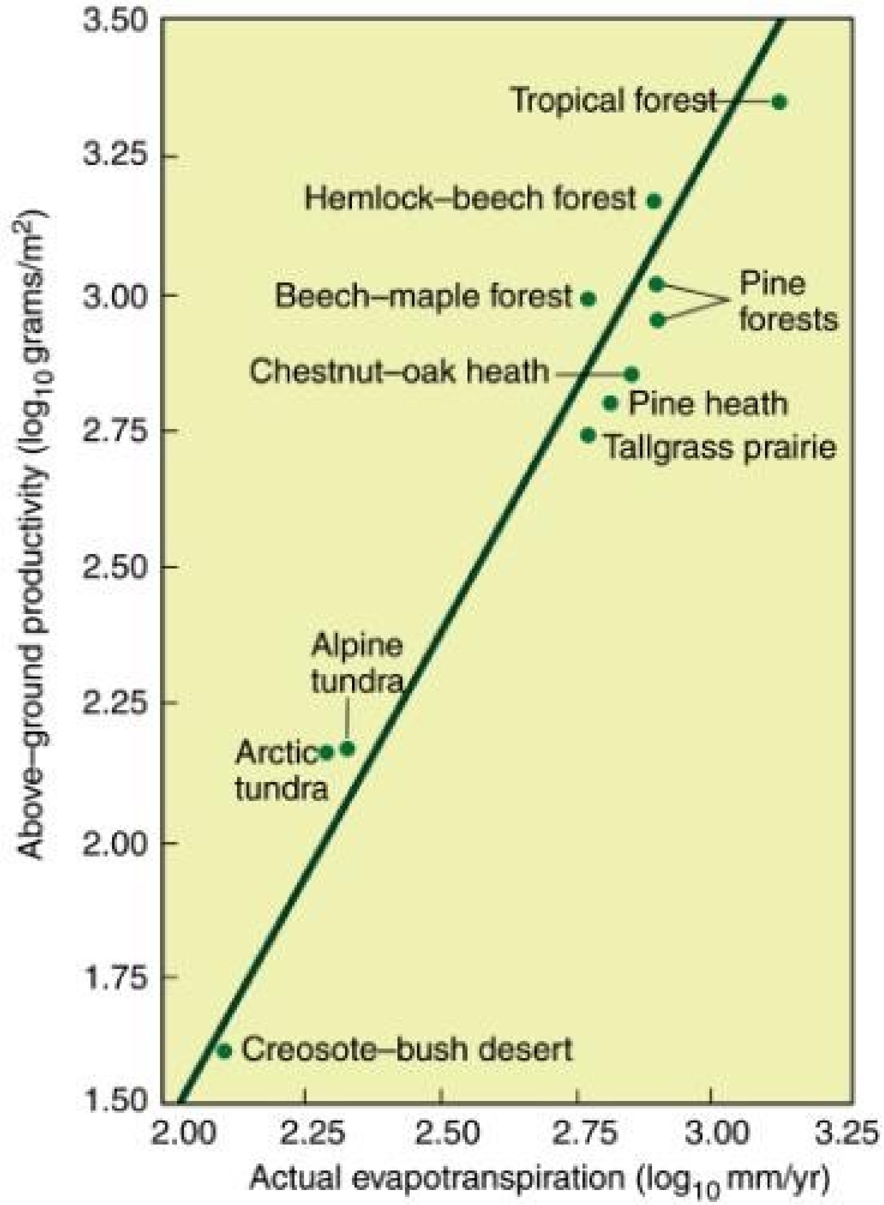
In general, *the productivity of terrestrial ecosystems is most influenced by temperature and precipitation patterns*.

- At the local level, temporal and spatial variation in productivity can be related to nutrient availability, grazing pressure, outbreaks in plant disease or insect infestation, fire, and growing season length.

- Annual net production changes with age.

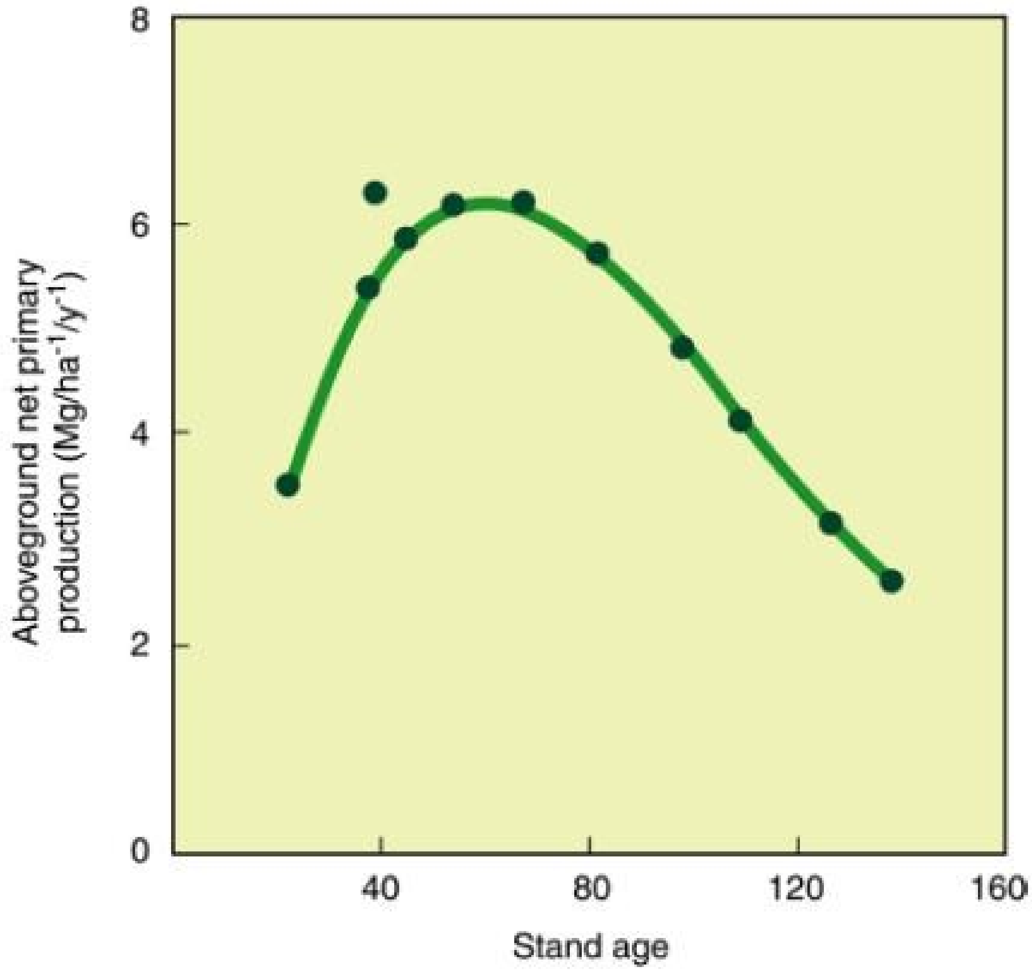
In general, it increases in terrestrial ecosystems during succession or stand development, followed by a decline as time progresses.

Range of above-ground net productivities of world ecosystems based evapotranspiration, which depends on both precipitation and temperature.



- **Temporal changes within ecosystems**

Changes in above-ground net primary productivity with age for a stand of white spruce in the region of Karelia, Russia.



Energy Allocation

Net primary production can be allocated to:

(a) Growth – the build up of components such as stems, roots and leaves that promote further acquisition of energy and nutrients.

(b) Storage - materials built up in the plant for future growth and other functions:

- **Accumulation - the increase of compounds that do not directly support growth (i.e.,starch, fructose, mineral ions).**
- **Reserve formation - synthesis of storage compounds from resources that otherwise would be allocated directly to promote growth.**
- **Recycling - recycling of material from aging tissue to new growth.**

Patterns of energy allocation change with age and size of the individual, species, and availability of water and nutrients.

Primary productivity around the world

The primary productivity of terrestrial ecosystems varies widely over the globe.

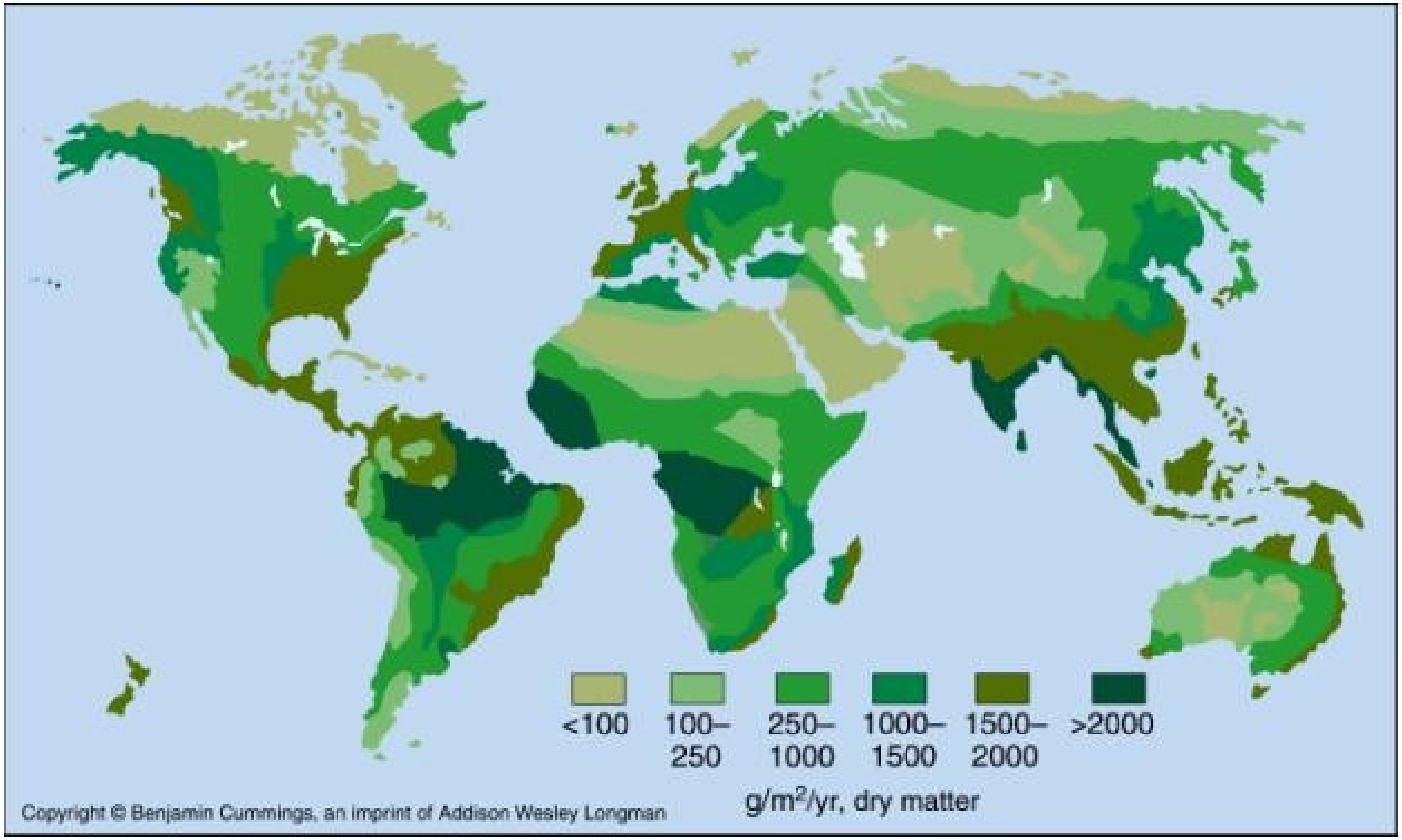
The most productive terrestrial ecosystems are tropical rain forests with high rain fall and warm temperatures; their NPP ranges from 1000 to 3500 g/m^2/yr.

Temperate forests range between 600 and 2500 g/m^2/yr.

Shrublands have net productivities in the range of 700 to 1500 g/m2/yr.

Desert grasslands produce about 200 to 300 g/m^2/yr, whereas deserts and tundra range between 100 and 250 g/m^2/yr.

- Patterns of primary productivity in ecosystems
    - Variation among ecosystems



A map of world terrestrial primary production.

NPP in the open ocean is generally quite low.

Tropical waters tend to have low productivity – due to low nutrients.

Productivity in the open waters of the cool temperate oceans tends to be higher than those of the tropics.

However, in some areas of tropical upwelling, such as the Humbolt current (the band of high productivity off the west coast of South America), net productivity can reach 1000 $g/m^2/yr$.

Coastal ecosystems and the continental shelves generally have higher productivity than the open waters - input of nutrients from terrestrial ecosystems via rivers.

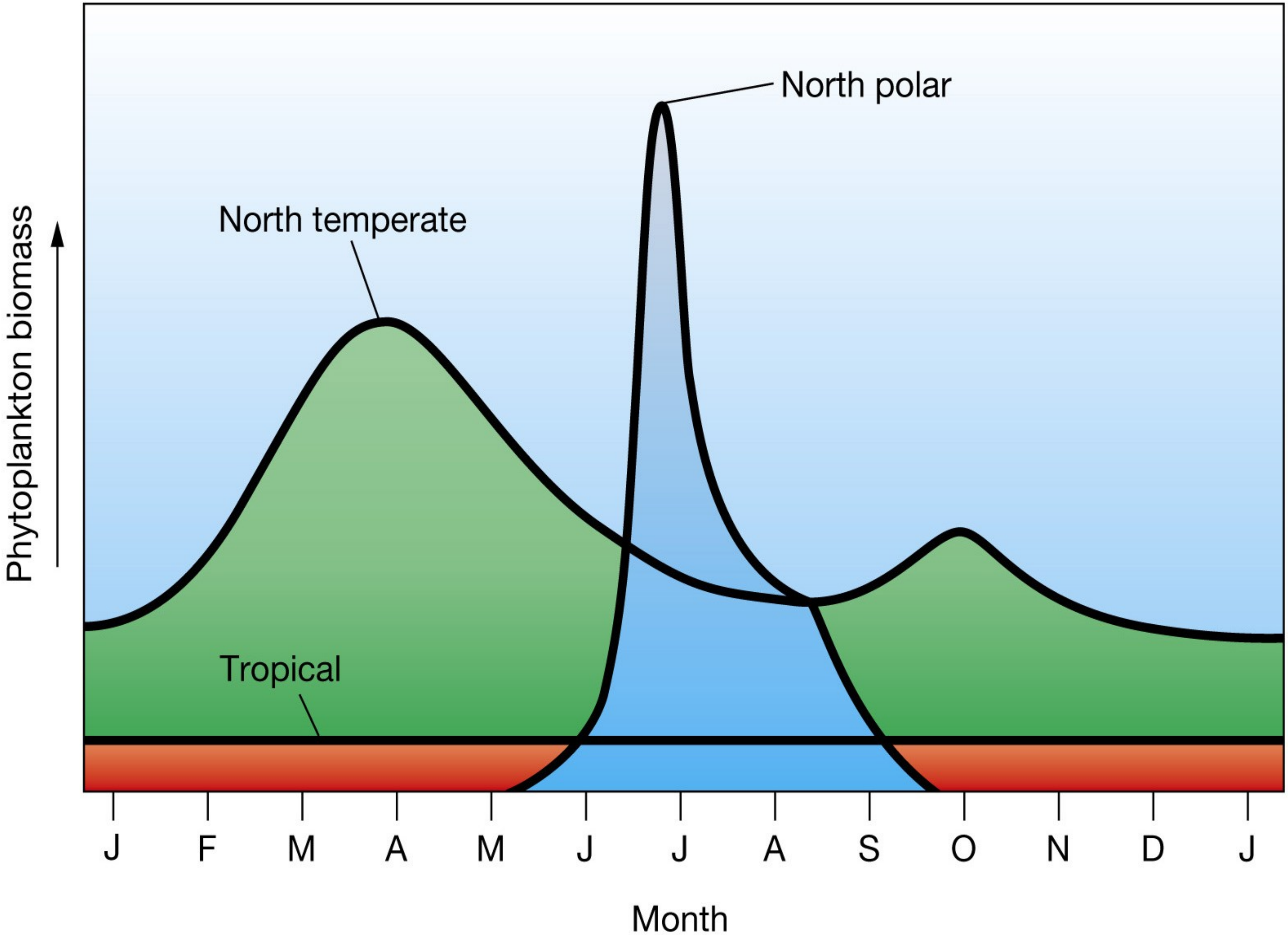
Coastal swamps and marshes have net productivities ranging up to 4000 $g/m^2/yr$.

Estuaries, because of input of nutrients from rivers and tides, can have a net productivity up to 2500 $g/m^2/yr$.

Likewise coral reefs – although coral reefs are found in nutrient poor waters – symbiotic algae in coral help compensate for low nutrients.

High levels of productivity can be found in polar regions, especially Antarctica.

Despite cold temperatures – 24 hours of sunlight in the summer plus nutrient upwellings lead to high productivity.


North polar
North temperate
Tropical
Phytoplankton biomass
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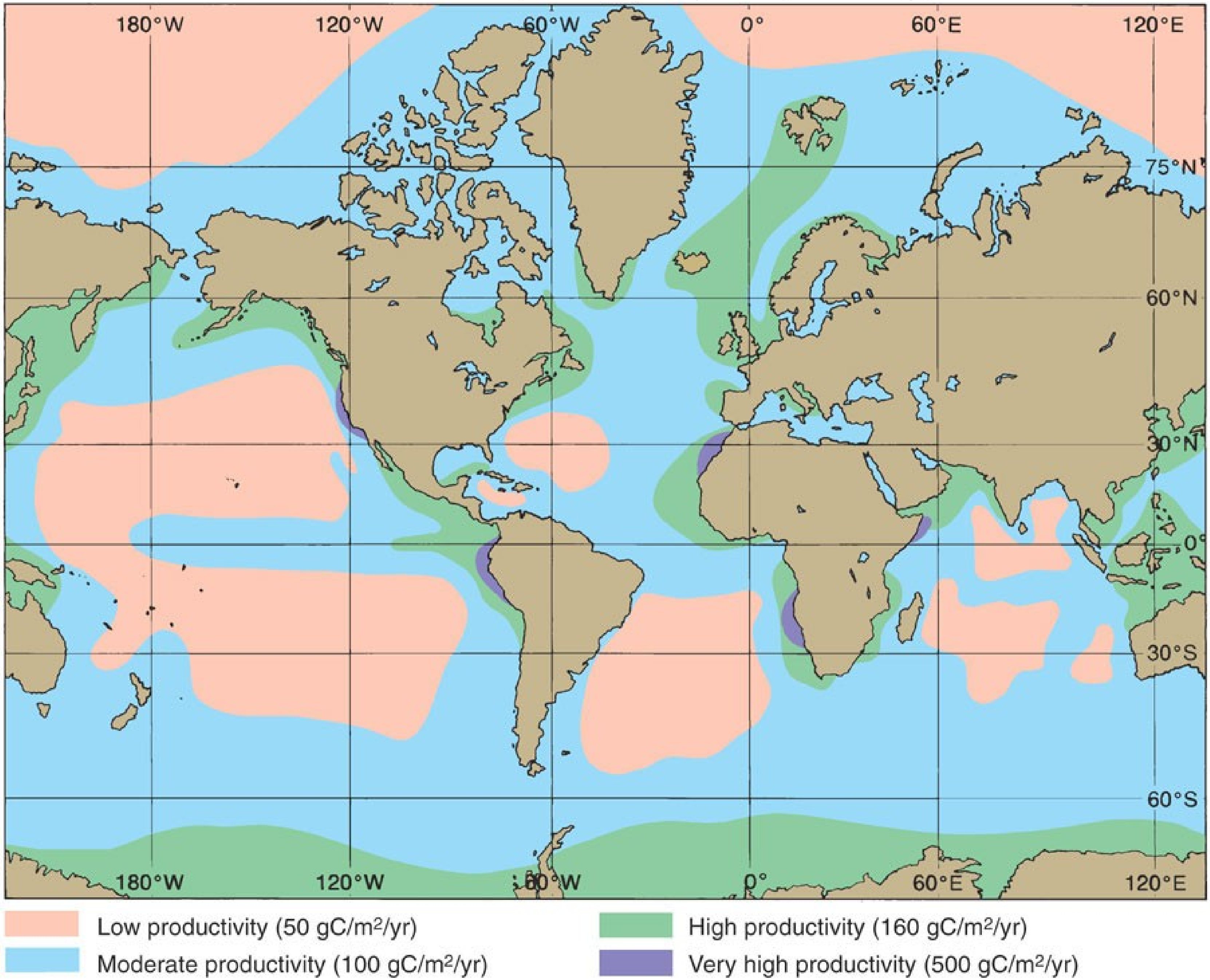

180°W
120°W
60°W
0°
60°E
120°E
75°N
60°N
30°N
0°
30°S
60°S
Low productivity (50 gC/m2/yr)
Moderate productivity (100 gC/m2/yr)
High productivity (160 gC/m2/yr)
Very high productivity (500 gC/m2/yr)

Table 14.1 World Ocean Primary Productivity

Area	Primary Productivity (gC/m²/yr)	World Ocean Area (km²)	World Ocean Area (%)	Total Primary Productivity (metric tons carbon/yr)
Upwellings	640	0.36×10^6	0.1	0.23×10^9
Coasts	160	54×10^6	15.0	8.6×10^9
Open oceans	130	307×10^6	85.0	39.9×10^9
All ocean areas	135	361×10^6	100.0	48.73×10^9

Data from S. Smith and J. Hollibaugh. 1993 Coastal Metabolism and the Oceanic Organic Carbon Balance. *Review of Geophysics 31(1): 75–89.*

Upwellings are 4x more productive than coastal areas and 5x more productive than the open ocean

But coastal area is 100x larger than upwelling areas → greater biomass

Table 14.2 Gross Primary Productivity Land and Ocean

Ocean Area	Range (gC/m²/yr)	Average (gC/m²/yr)	Land Area	Amount (gC/m²/yr)
Open ocean	50–160	130 ± 35	Deserts, grasslands	50
Coastal ocean	100–250	160 ± 40	Forests, common crops, pastures	25–150
Estuaries	200–500	300 ± 100	Rain forests, moist crops, intensive agriculture	150–500
Upwelling zones	300–800	640 ± 150	Sugarcane and sorghum	500–1500
Salt marshes	1000–4000	2471		

Upwellings can be more productive than rainforest or plantations

Secondary Production

Net primary productivity is the energy available to the heterotrophic components of the ecosystem.

Rarely is all of it available and utilized by these organisms, including the decomposers.

Energy, once consumed, either is diverted to maintenance, growth and reproduction, or is passed from the body as waste products.

The energy content of the waste products is transferred to the detrivores.

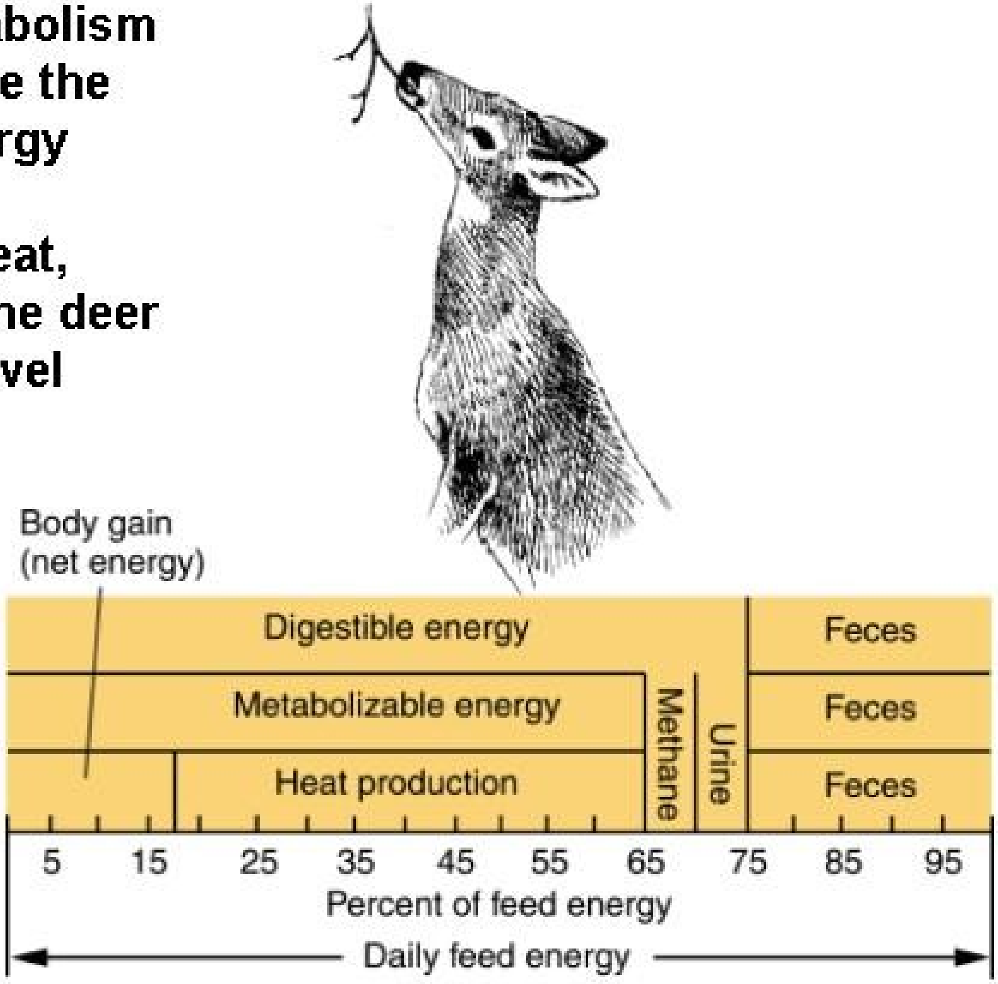
Of the energy left after these losses, part is utilized as heat required for metabolism above the basal or resting metabolism.

The remaining NET ENERGY is available for maintenance, production and reproduction.

Maintenance costs are highest in small, active warm-blooded animals and are fixed or irreducible.

In small invertebrates, energy can vary with temperature, and a positive energy balance exits only within a narrow range of temperatures.

Relative values of the end products of energy metabolism in white-tailed deer. Note the small amount of net energy gained (body weight) in relation to that lost as heat, gas, urine, and feces. The deer is an herbivore, a first-level consumer.

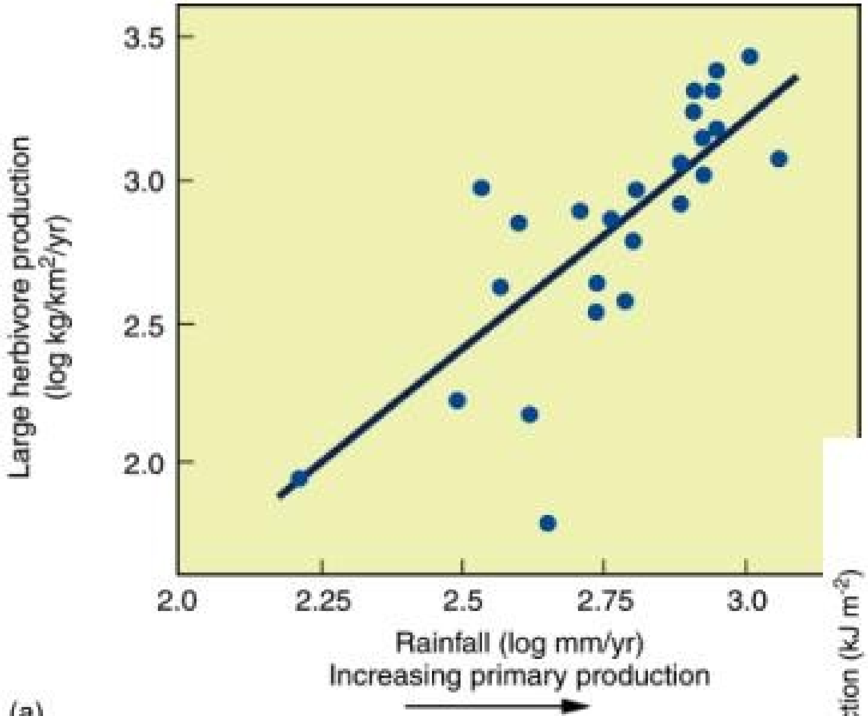


Energy remaining from maintenance and respiration—net energy—goes into secondary or consumer production—fat, growth, and the birth of new individuals.

Within secondary production there is no portion known as gross production — what is analogous to gross production is actually assimilation.

Secondary production depends on the quantity, quality and availability of net primary production as a source of energy.

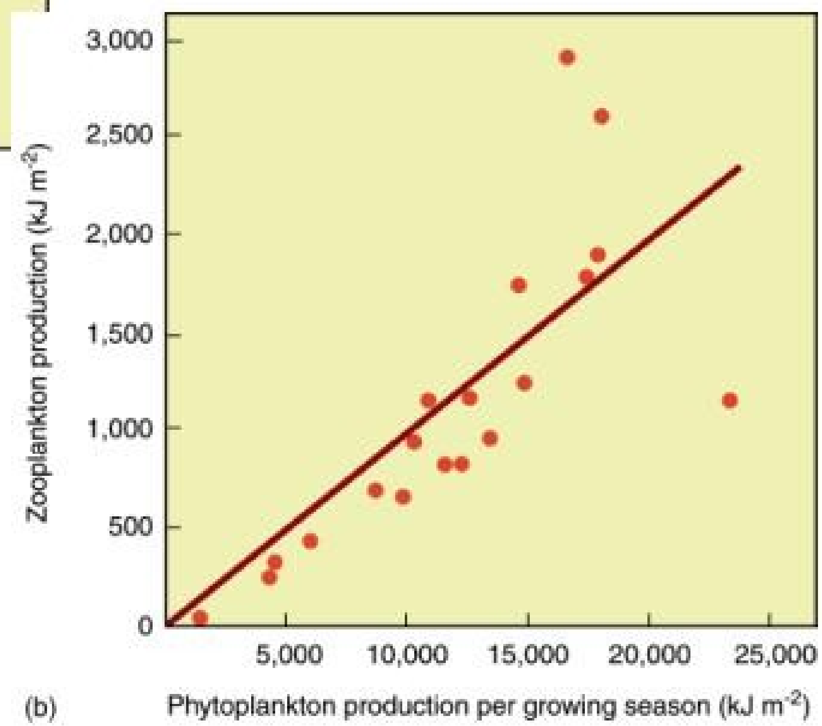
Therefore, any of the environmental constraints on primary productivity, such as climate, soil fertility, and water availability, will also act to constrain secondary productivity.



(a)

The relationship between primary and secondary productivity: (a) rainfall (which affects productivity) and secondary productivity of large mammalian herbivores in Africa.

(b) Phytoplankton and zooplankton production in lake ecosystems.



(b)

Energy Balance or budget

A consumer's energy budget is given by:

$$C = A + (F + U)$$

where C is the energy ingested or consumed;
A is the energy assimilated; and
F and U are the energy lost through feces and nitrogenous wastes (urine).

Assimilation Efficiency and Production Efficiency For Homeotherms and Poikilotherms

Efficiency	All Homeotherms	All Poikilotherms
Assimilation		
A/I	**77.5+/-6.4**	**41.9+/-2.3**
Production		
P/A	**2.46+/-0.46**	**44.6+/-2.1**
P/I	**2.0+/-0.46**	**17.7+/-1.0**

A/I=assimilation to consumption or ingestion, an index of the efficiency of the consumer in extracting energy from the food it consumes. It relates to food quality and effectiveness of digestion.
P/A= production to assimilation, P/A, an index of the efficiency of a consumer in incorporating assimilation energy into new tissue.
P/I= production to consumption, a measure of the efficiency with which energy is made available to the next group of consumers.

Herbivores use plant production with varying degrees of efficiency

- depending on whether they are poikilotherms or homeotherms.

Because they eat foods already converted to animal tissue, carnivores, both poikilothermic and homeothermic, have high assimilation efficiencies.

On North American midwestern grasslands, average herbivore production efficiency, involving mostly poikilotherms, ranges from 5 – 16%;

carnivores have production efficiencies ranging from 13 - 24 %.

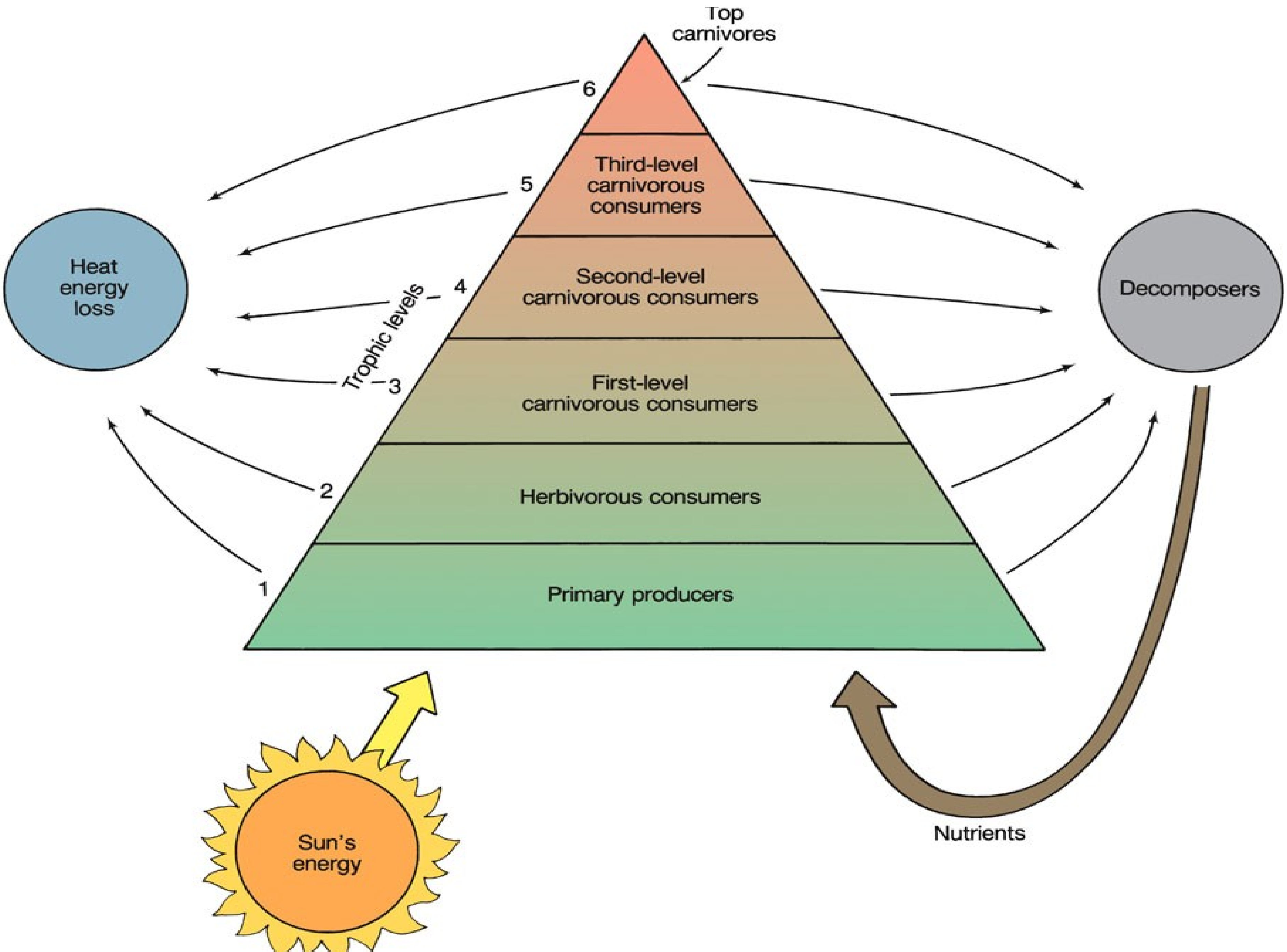
Food Chains and Energy Flow

Energy stored by plants is passed along through the ecosystem in a series of steps of eating and being eaten known as a food chain.

Feeding relationships within a food chain are defined in terms of trophic or consumer levels.

- **At the first level are the primary producers,**
- **At the second level are the herbivores,**
- **And the higher levels are the carnivores.**

- **Some consumers occupy a single trophic level while others, such as omnivores, occupy more than one trophic level.**


Top
carnivores
6
Third-level
carnivorous
consumers
5
Second-level
carnivorous consumers
4
Trophic levels
First-level
carnivorous consumers
3
Herbivorous consumers
2
Primary producers
1
Heat
energy
loss
Decomposers
Sun's
energy
Nutrients

o **Food chains are descriptive with major feeding groups defined on the basis of a common source of energy.**

Each feeding group is then linked to others in a manner that represents the flow of energy.

There are two basic types of food chains:

o **grazing (autotrophs are the primary source of energy for the initial consumers) and**
o **detrital (the initial consumers, primarily bacteria and fungi, use dead organic matter as their source of energy).**

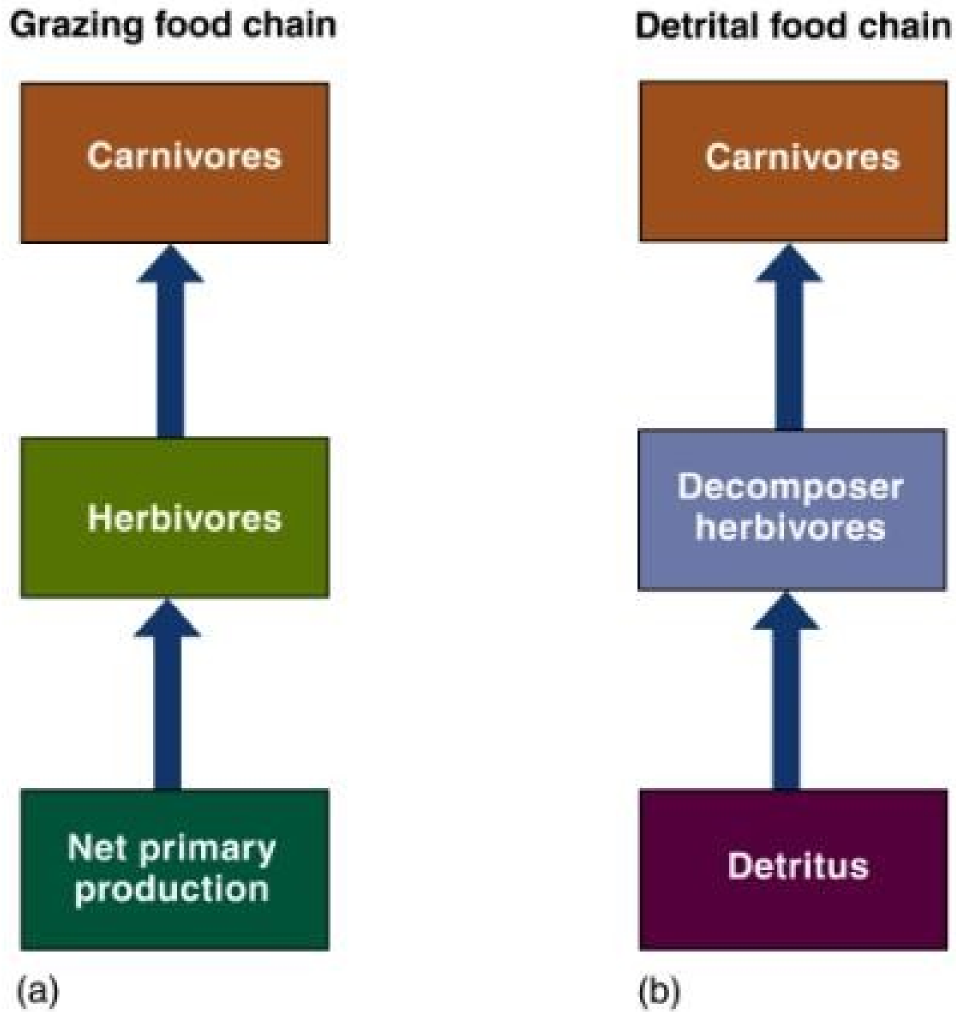
o In terrestrial systems, only a small portion of primary production goes by way of the grazing food chain.

o In terrestrial and littoral ecosystems, the detrital food chain is the major pathway of energy flow.

e.g. In a yellow poplar forest, 50% of gross primary productivity goes into maintenance and respiration,
-13% is accumulated as new tissue,
-2% is consumed by herbivores, and
-35% percent goes into the detrital food chain.

- Major food chains

Two parts of any ecosystem: (a) a grazing food chain and (b) a detrital food chain.



In a very general way, energy transformed through the ecosystem by way of the grazing food chain is reduced by a magnitude of 10 from one level to another.

Thus if an average of 1000 kcal of plant energy is consumed by herbivores,

about 100 kcal is converted to herbivore tissue,

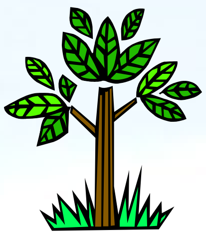
10 kcal to first-level carnivore production, and

1 kcal to second-level carnivores.

The amount of energy available to second- and third-level carnivores is so small that few organisms could be supported if they depended on that source alone.

For all practical purposes, each food chain has from three to four links, rarely five.
The fifth link is distinctly a luxury item in the ecosystem.

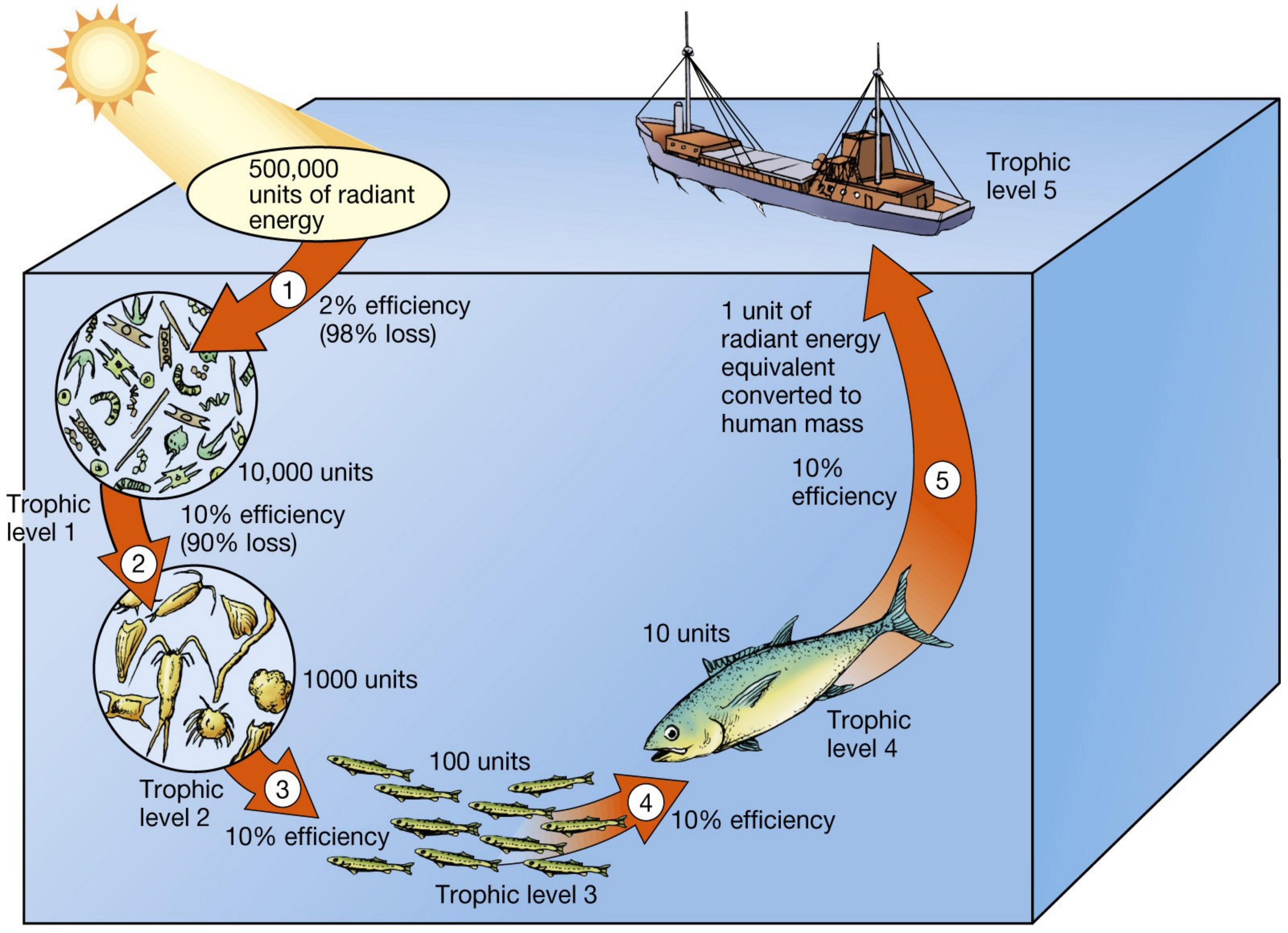
The sun is the original source of energy
(100,000 units of energy)



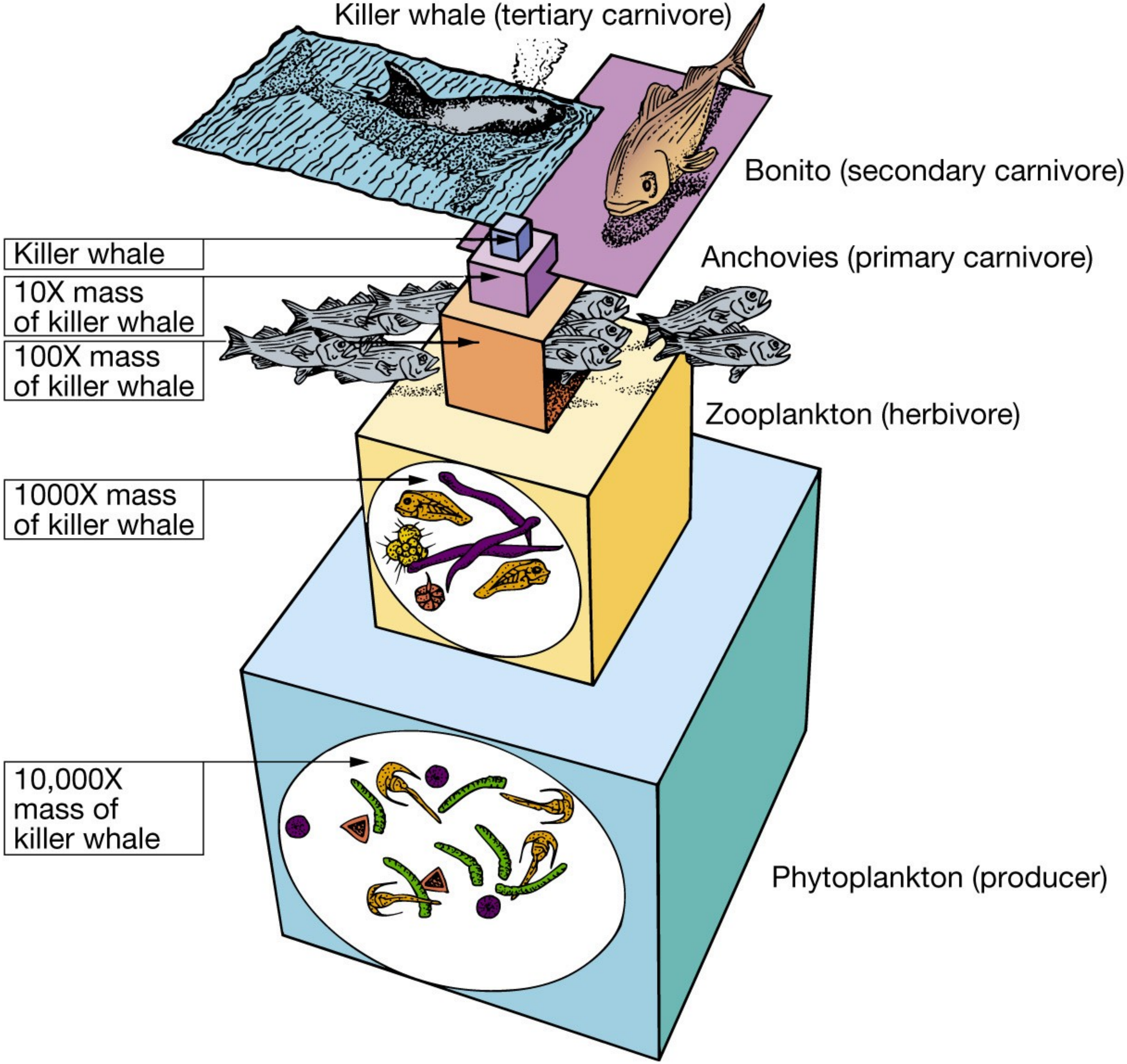
Plants capture <1% of the available light
energy for biomass production by photosynthesis
(1,000 units of energy)

Herbivores consume about 10% of the plant
biomass produced (100 units of energy)

Carnivores capture and consume about 10-15%
of the energy stored by herbivores (10 units of
energy)



500,000 units of radiant energy
1
2% efficiency (98% loss)
10,000 units
Trophic level 1
10% efficiency (90% loss)
2
1000 units
Trophic level 2
3
10% efficiency
100 units
Trophic level 3
4
10% efficiency
10 units
Trophic level 4
10% efficiency
5
1 unit of radiant energy equivalent converted to human mass
Trophic level 5


Killer whale (tertiary carnivore)
Bonito (secondary carnivore)
Anchovies (primary carnivore)
Zooplankton (herbivore)
Phytoplankton (producer)
Killer whale
10X mass of killer whale
100X mass of killer whale
1000X mass of killer whale
10,000X mass of killer whale

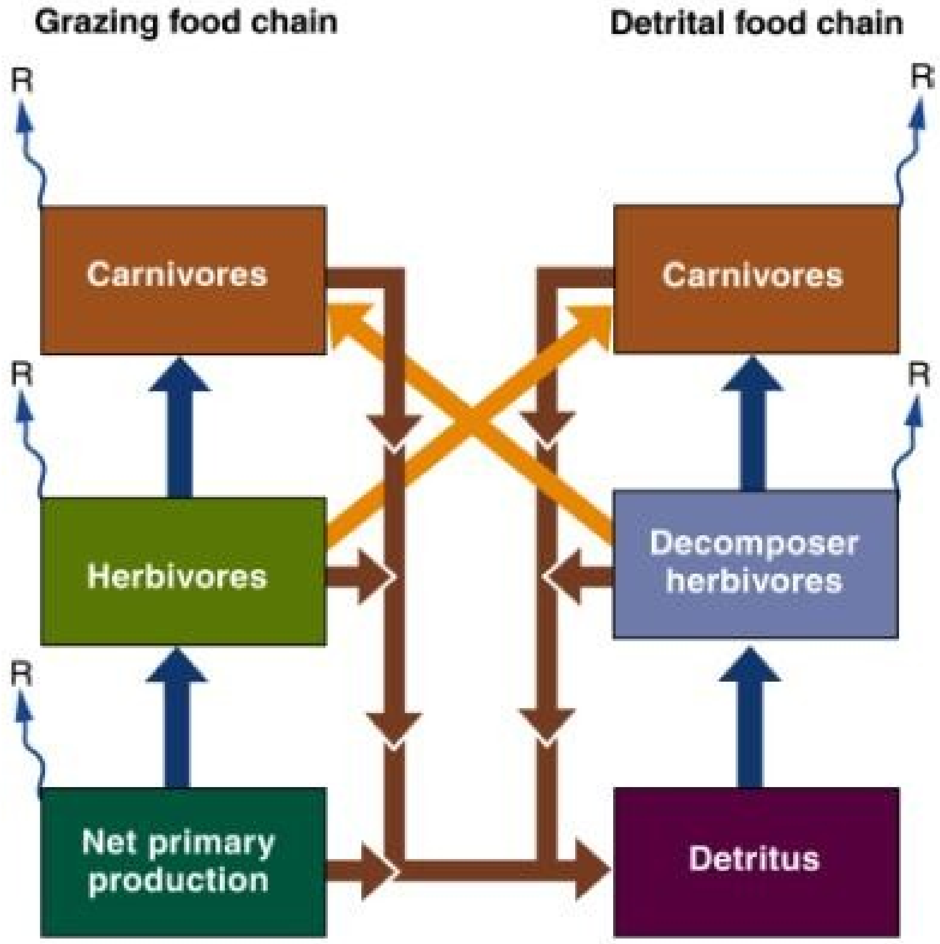
- The grazing and detrital food chains are linked, with the initial source of energy for the decomposer food chain being the input of waste material and dead organic matter from the grazing food chain.

- The main difference between the two food chains is that the flow of energy between trophic levels in the grazing food chain is unidirectional, with net primary production providing the energy source for herbivores, herbivores providing the energy for carnivores, and so forth.

- In the decomposer food chain, the flow of energy is not unidirectional; the waste materials and detritus in each of the consumer trophic levels are recycled, returning as input to the detritus box at the base of the food chain.

- **Interactions between major food chains**

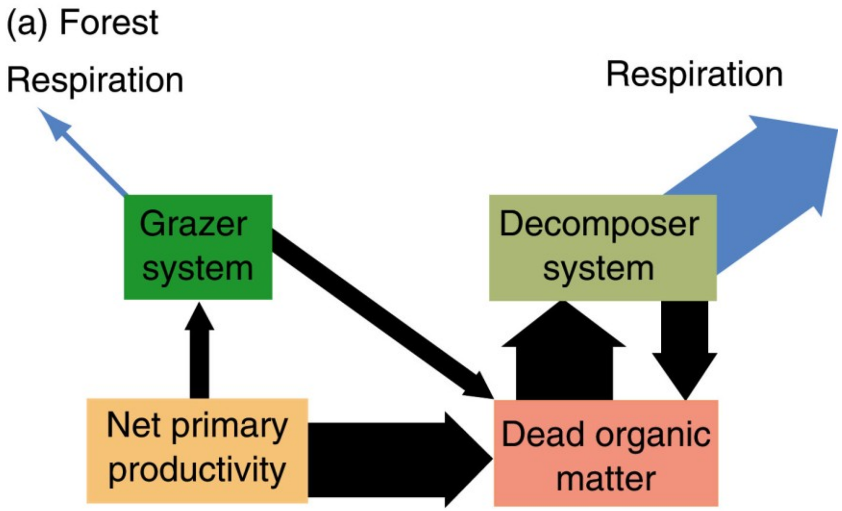
The grazing and detrital food chains from the earlier figure combined, showing their connections. R = respiration.

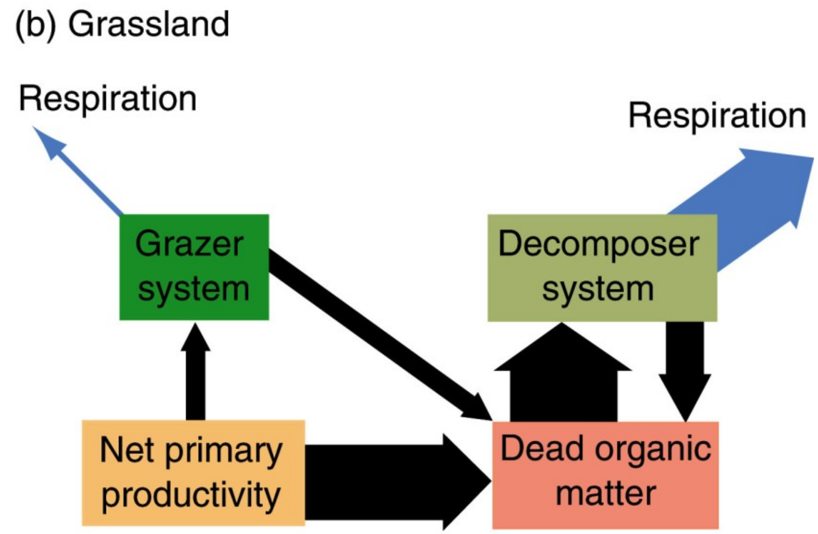


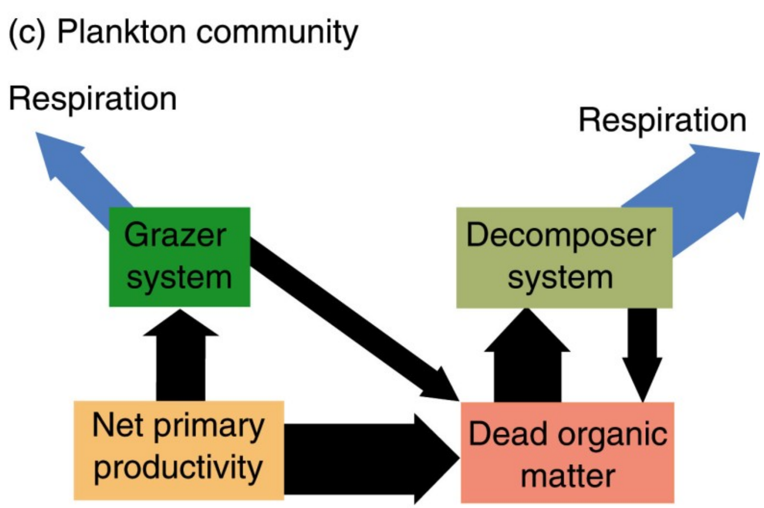
The relative importance of the two food chains and the rate at which energy flows through the various trophic levels can vary widely among different types of ecosystems.

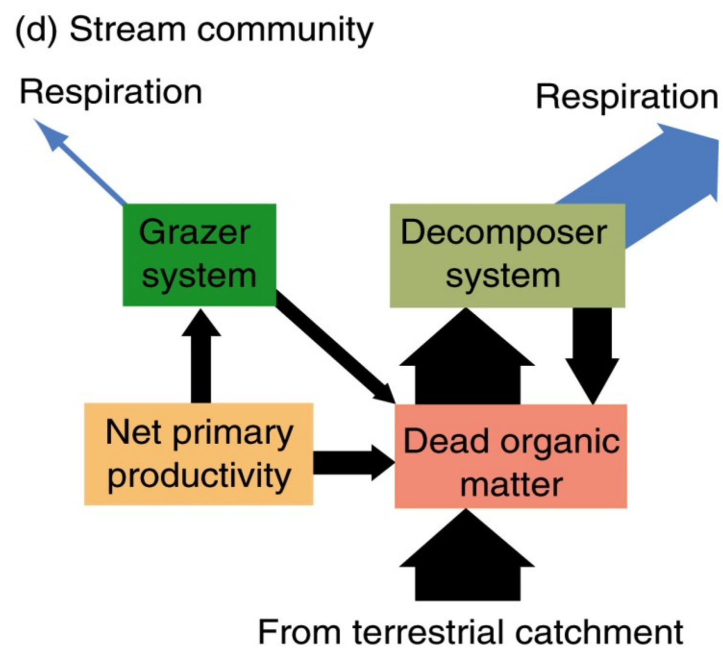
The concept of trophic levels has several weaknesses:

- It discounts detrital material, decomposers, and saprophages (the detrital food chain).
- Consumers, especially above the herbivore level, often occupy more than one trophic level and their contribution to biomass must be apportioned.
- The concept does not take into account the availability of energy — all the energy at any level is not available to consumers.
- The concept gives the false impression that energy does not cycle through ecosystems.


(a) Forest
Respiration
Respiration
Grazer system
Decomposer system
Net primary productivity
Dead organic matter


(b) Grassland
Respiration
Respiration
Grazer system
Decomposer system
Net primary productivity
Dead organic matter


(c) Plankton community
Respiration
Respiration
Grazer system
Decomposer system
Net primary productivity
Dead organic matter


(d) Stream community
Respiration
Respiration
Grazer system
Decomposer system
Net primary productivity
Dead organic matter
From terrestrial catchment

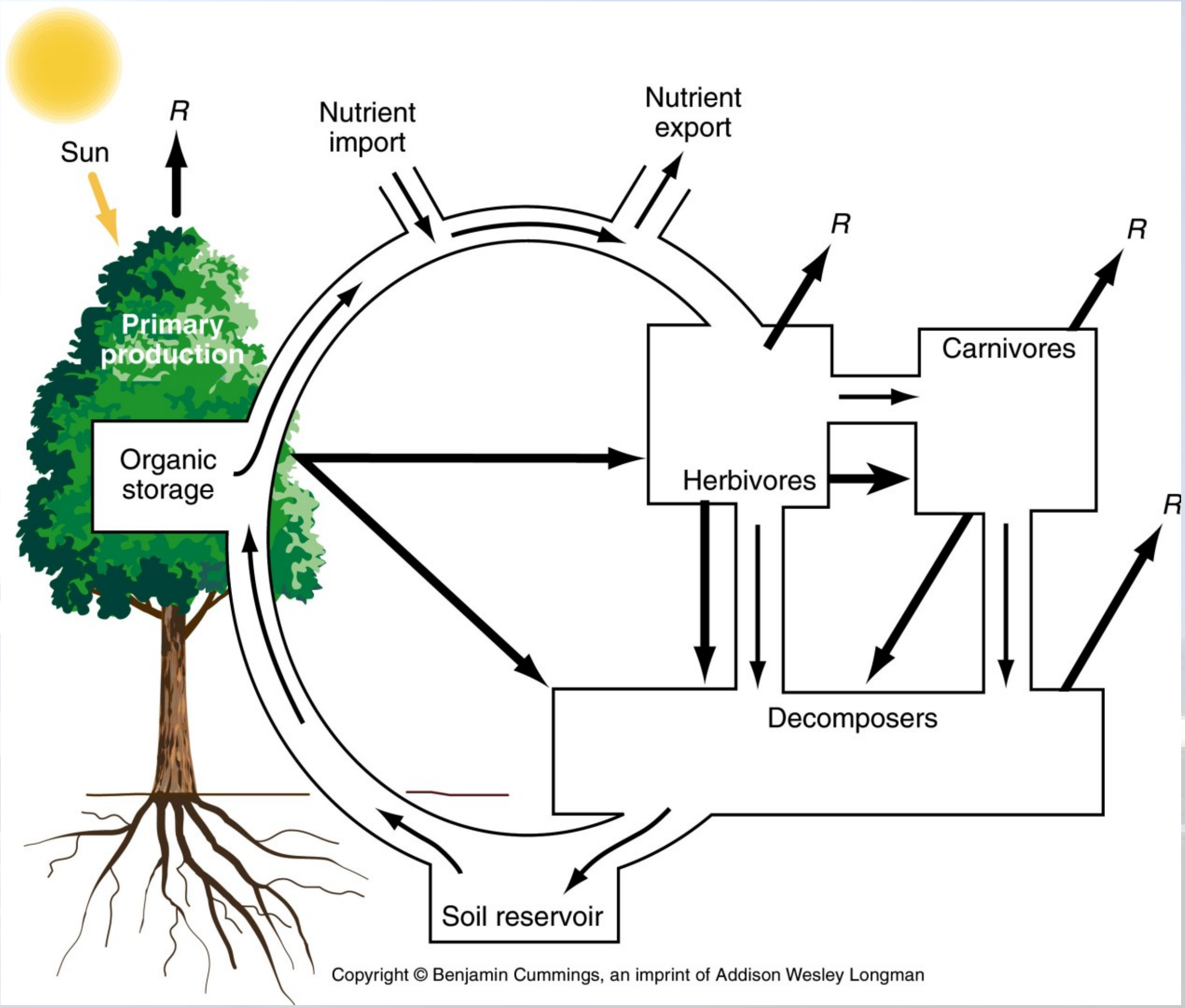
BIOGEOCHEMISTRY: NUTRIENT CYCLING

- ***The living world depends on the flow of energy and the circulation of matter through ecosystems*****. Both influence the abundance of organisms, the rate of their metabolism, and the complexity and structure of the ecosystem.**
- ***Energy and matter flow through the ecosystem together as organic matter*****; one cannot be separated from the other. The link between energy and matter begins in the process of photosynthesis.**

Biogeochemical Cycles

- **Biogeochemical cycles-chemical exchanges of elements among the atmosphere, rocks of the Earth's crust, water, and living things.**

The interrelationship between nutrient cycling and energy flow in the ecosystem.

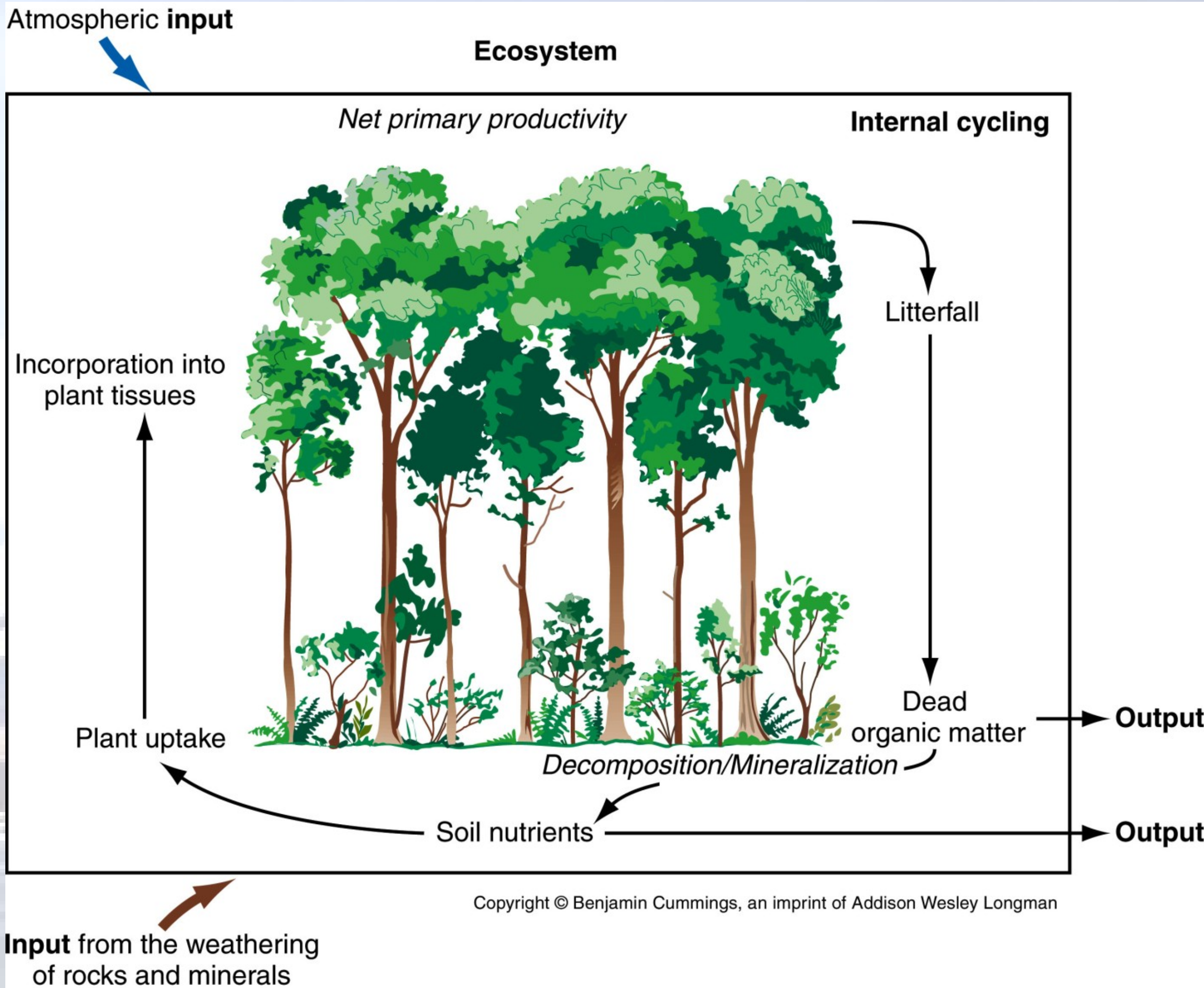


- **There are two types of biogeochemical cycles based on the primary source of the nutrient input to the ecosystem:**
   - **<u>Gaseous cycles</u>-the main source of nutrients possessing a gaseous cycle are the atmosphere and ocean and, therefore, have global circulation patterns.**
   - **<u>Sedimentary cycles</u>-the main reservoirs of nutrients are the soil and the rocks of the Earth's crust. Sedimentary cycles vary from one element to another, but essentially each has two abiotic phases: the salt solution phase and the rock phase. When in the soluble salt phase, unless absorbed by plants the nutrients can move through the soil into lakes and streams and eventually to the seas, where they can remain indefinitely.**

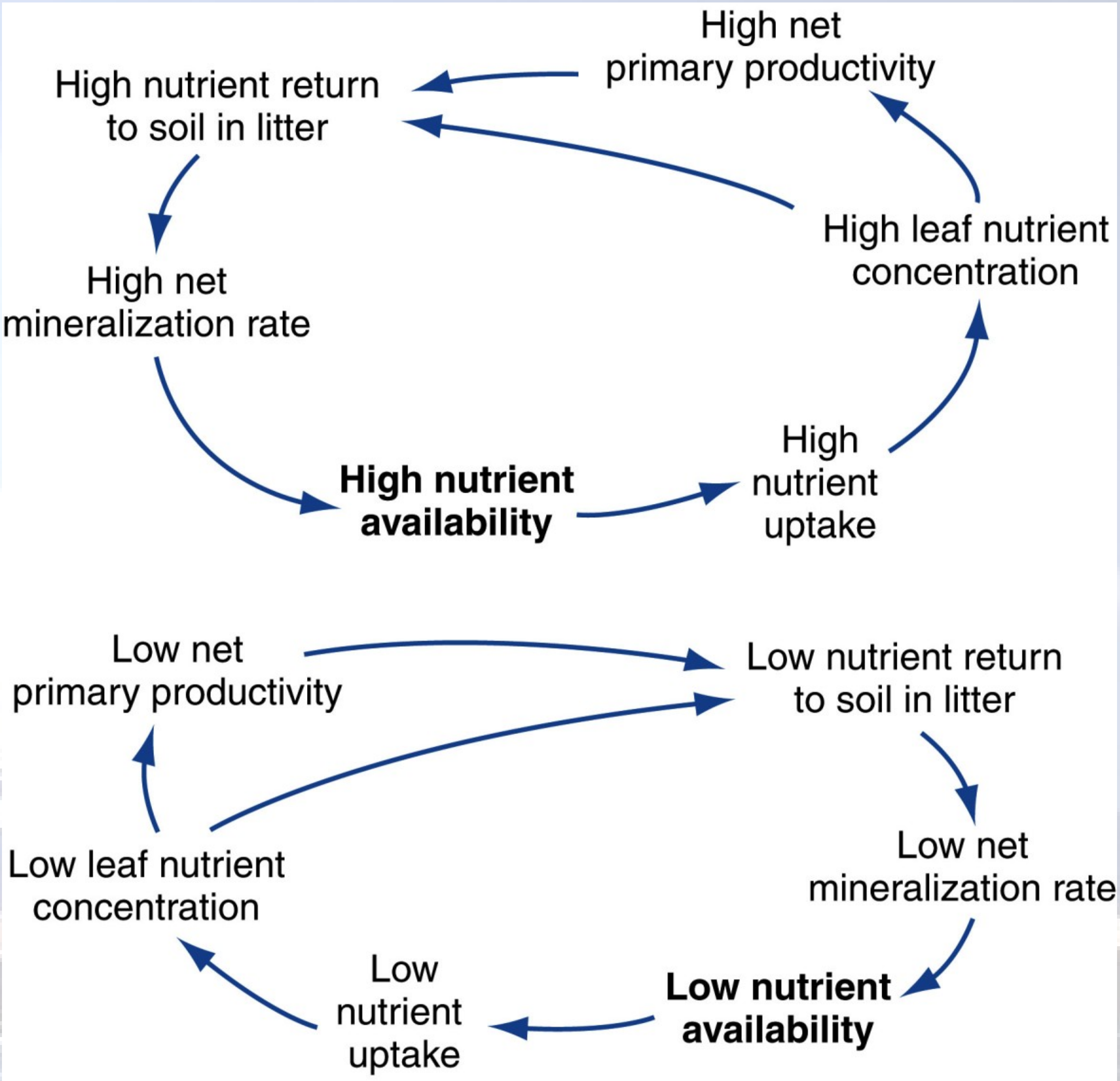
- **Although all of the cycles of the various nutrients vary in detail, from the perspective of the ecosystem, they all have a common structure, sharing three basic components: <u>inputs</u>, <u>internal cycling</u>, and <u>outputs</u>.**
- **The rate of internal cycling of nutrients depends on the rates of primary productivity and decomposition which, in turn, are affected by climate (faster in warmer and wetter climates), the number and type of organisms in the ecosystem, and availability of nutrients.**
- **Nutrients can be lost (outputs) from the ecosystem to the atmosphere, by the migration of organisms, water flow, and harvesting.**

- **MODEL OF NUTRIENT CYCLES**

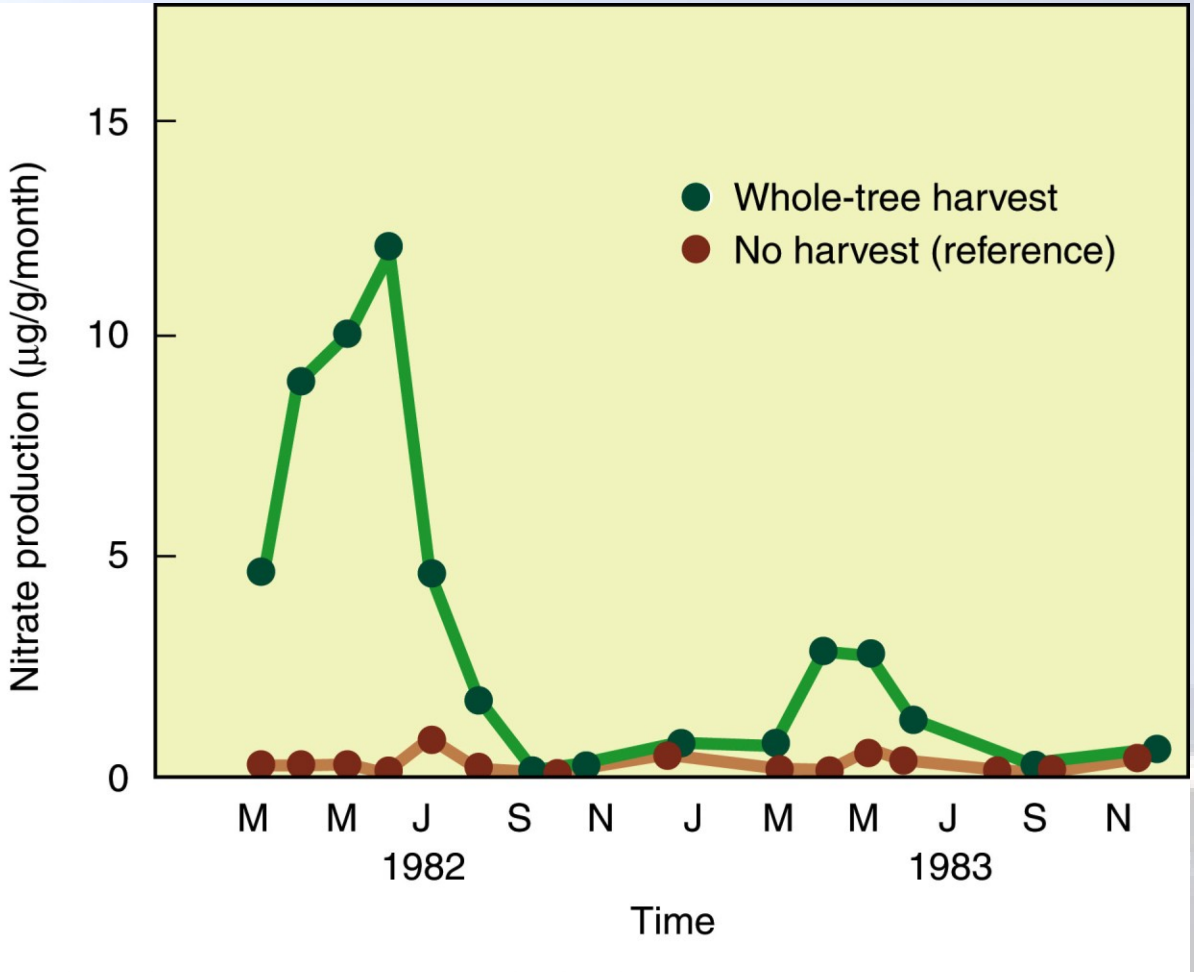
A generalized model of nutrient cycling in a terrestrial ecosystem. The three common components of inputs, internal cycling and outputs are shown in bold. The key ecosystem processes of net productivity and decomposition are italicized.



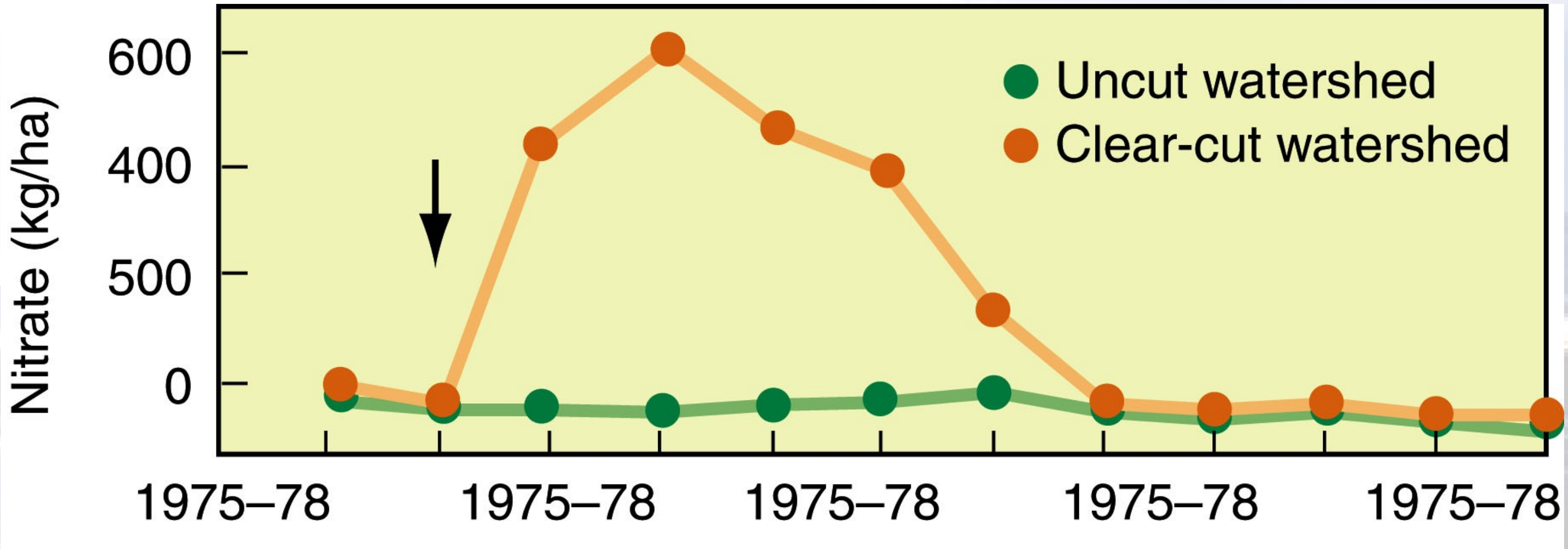
Feedback that occurs between nutrient availability, net primary productivity, and nutrient release in decomposition for initial conditions of low and high nutrient availability.



Comparison of nitrate production following logging for a loblolly pine plantation in the southeastern U.S. Data for the reference stand (no harvest) are compared with those of a whole-tree harvest clear-cut.

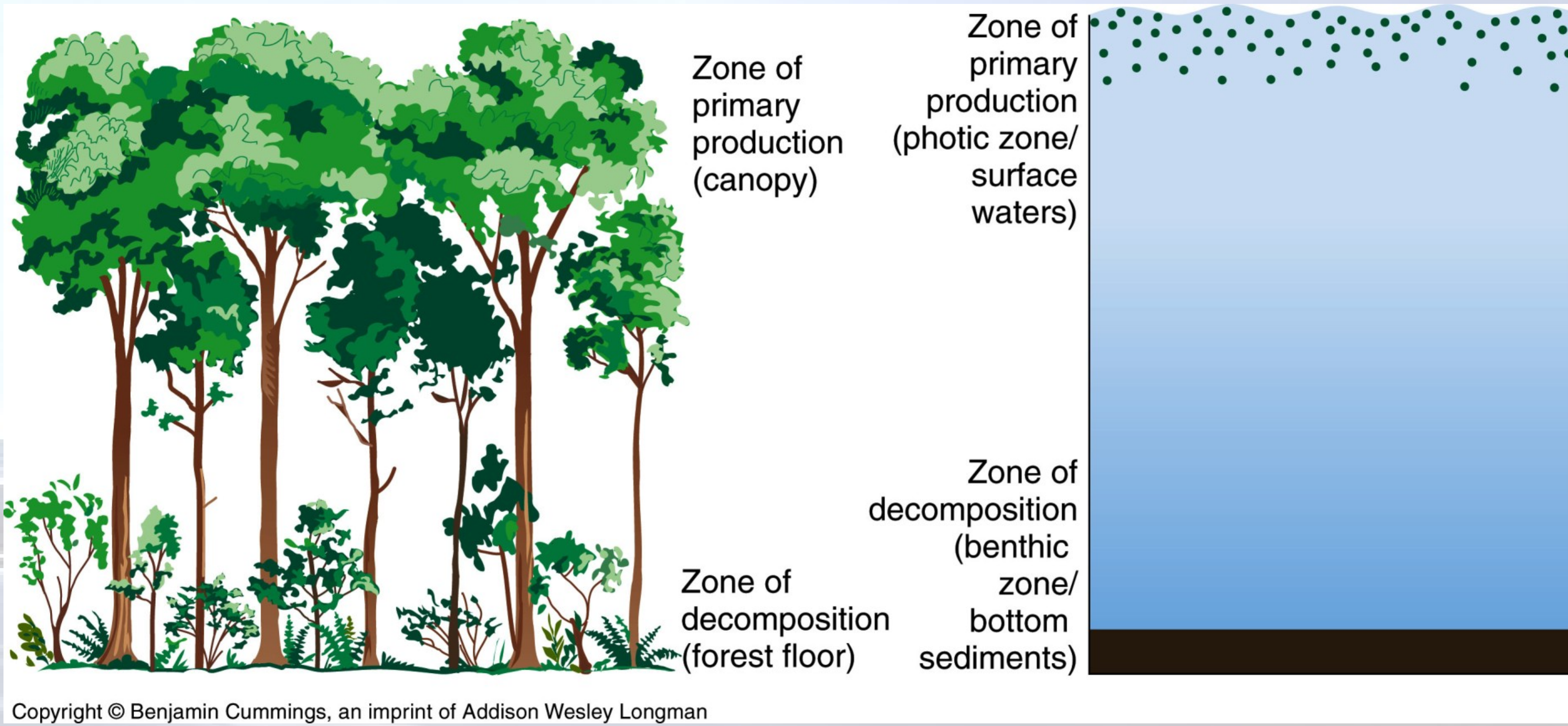


Temporal changes in the nitrate concentration of streamwater for two forested watersheds in Hubbard Brook, New Hampshire. The forest on one watershed was clear cut, while the other remained undisturbed. Note the large increase in concentrations of nitrate in the stream on the clear cut watershed. This increase is due to increased decomposition and nitrogen mineralization following the removal of the trees. The nitrogen was then leached into the surface and groundwater.



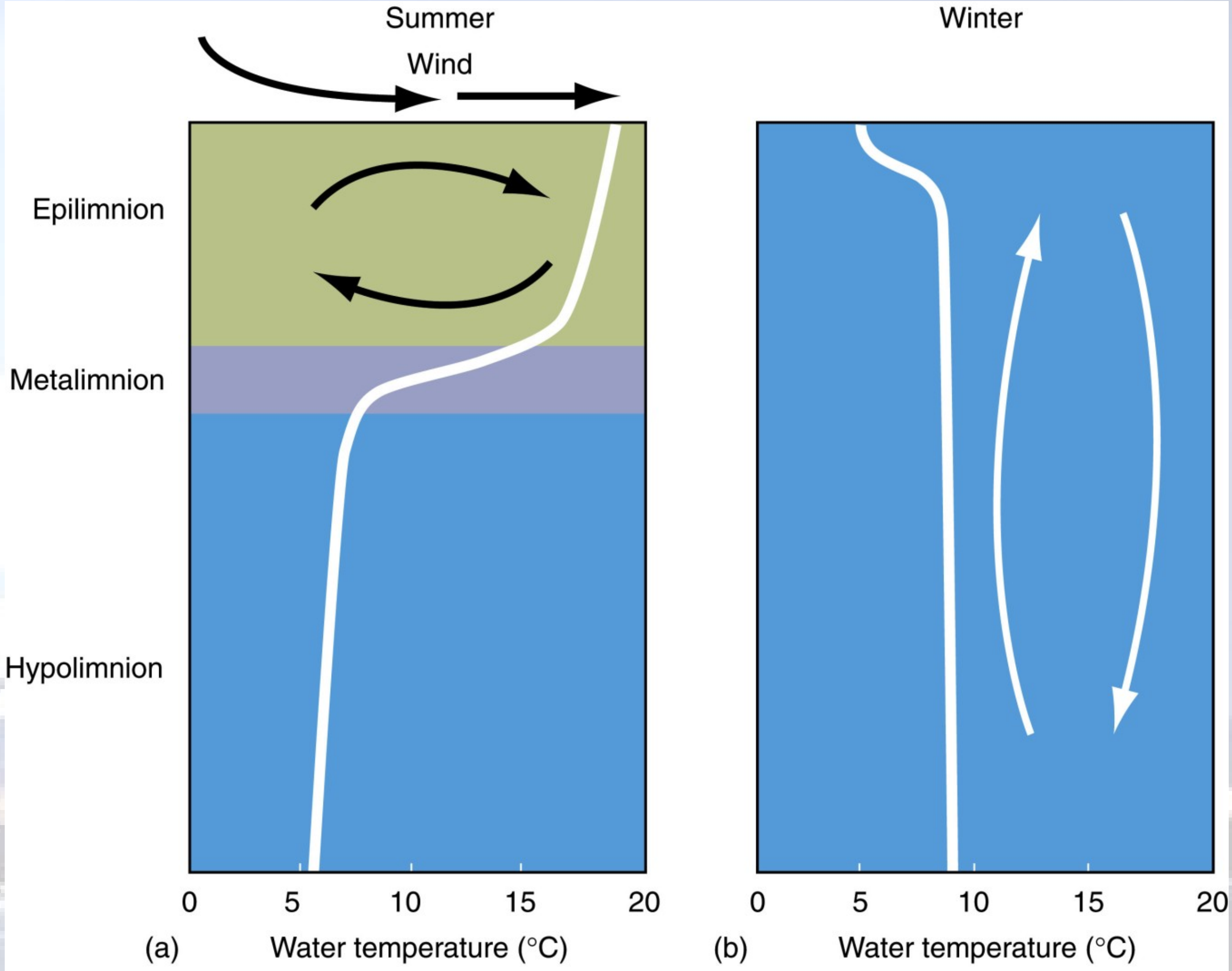
▪ CONTRASTING NUTRIENT CYCLING IN TERRESTRIAL AND AQUATIC ECOSYSTEMS

Comparison of the vertical zones of production and decomposition in (a) a terrestrial (forest) and (b) an open water (lake) ecosystem. Note that in the forest ecosystem the two zones are linked by the vegetation. This is not the case in the lake ecosystem.

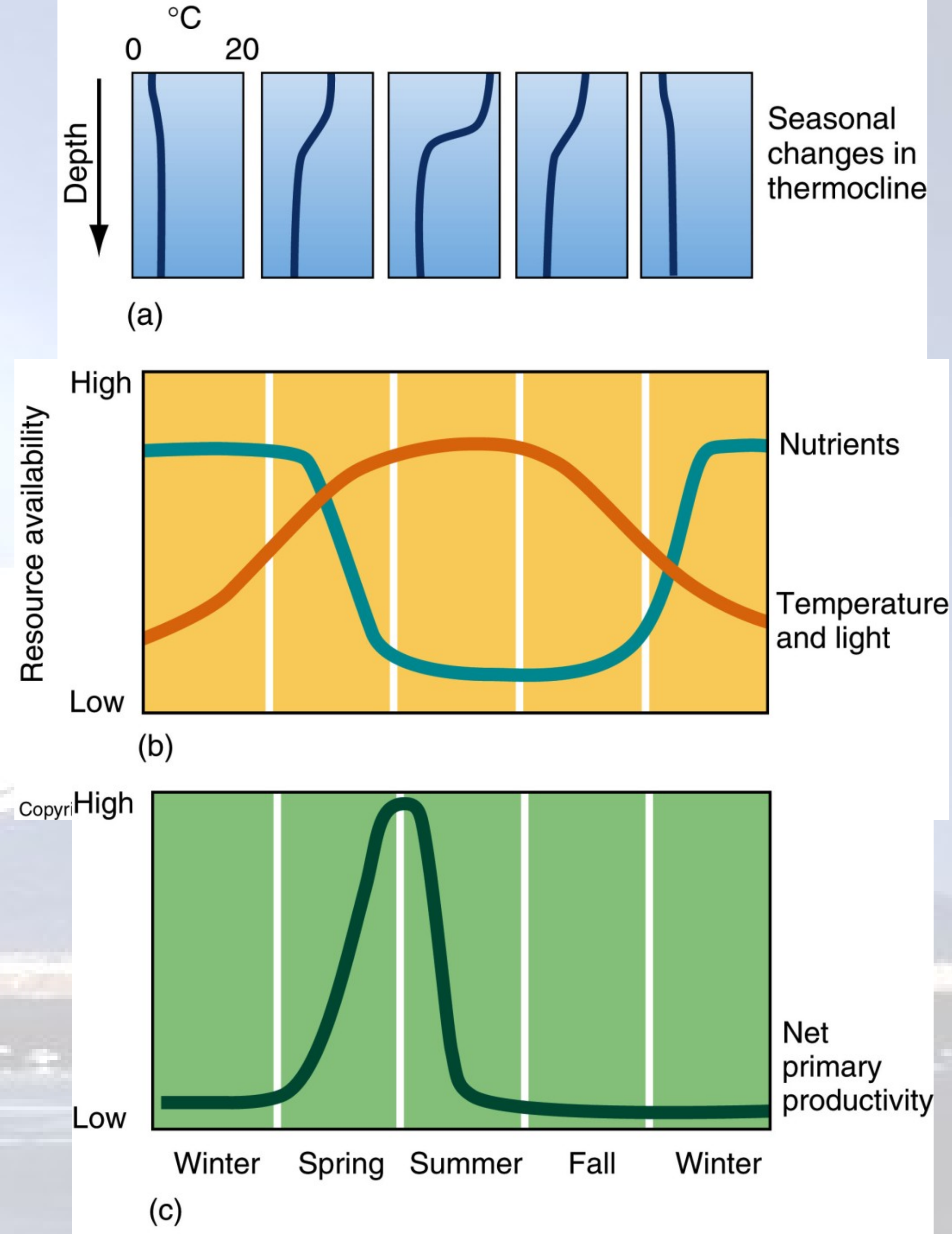


Seasonal dynamics in the vertical structure of an open water ecosystem in the Temperate Zone.

(a) Winds mix the waters within the epilimnion during the summer, but the thermocline isolates this mixing to the surface waters. (b) Turnover occurs during the winter months with the breakdown of the thermocline, allowing mixing and nutrients flow to the surface from the epilimnion.



Seasonal dynamics of: (a) the thermocline and associated changes in (b) the availability of light and nutrients, and (c) net primary productivity of the surface waters.

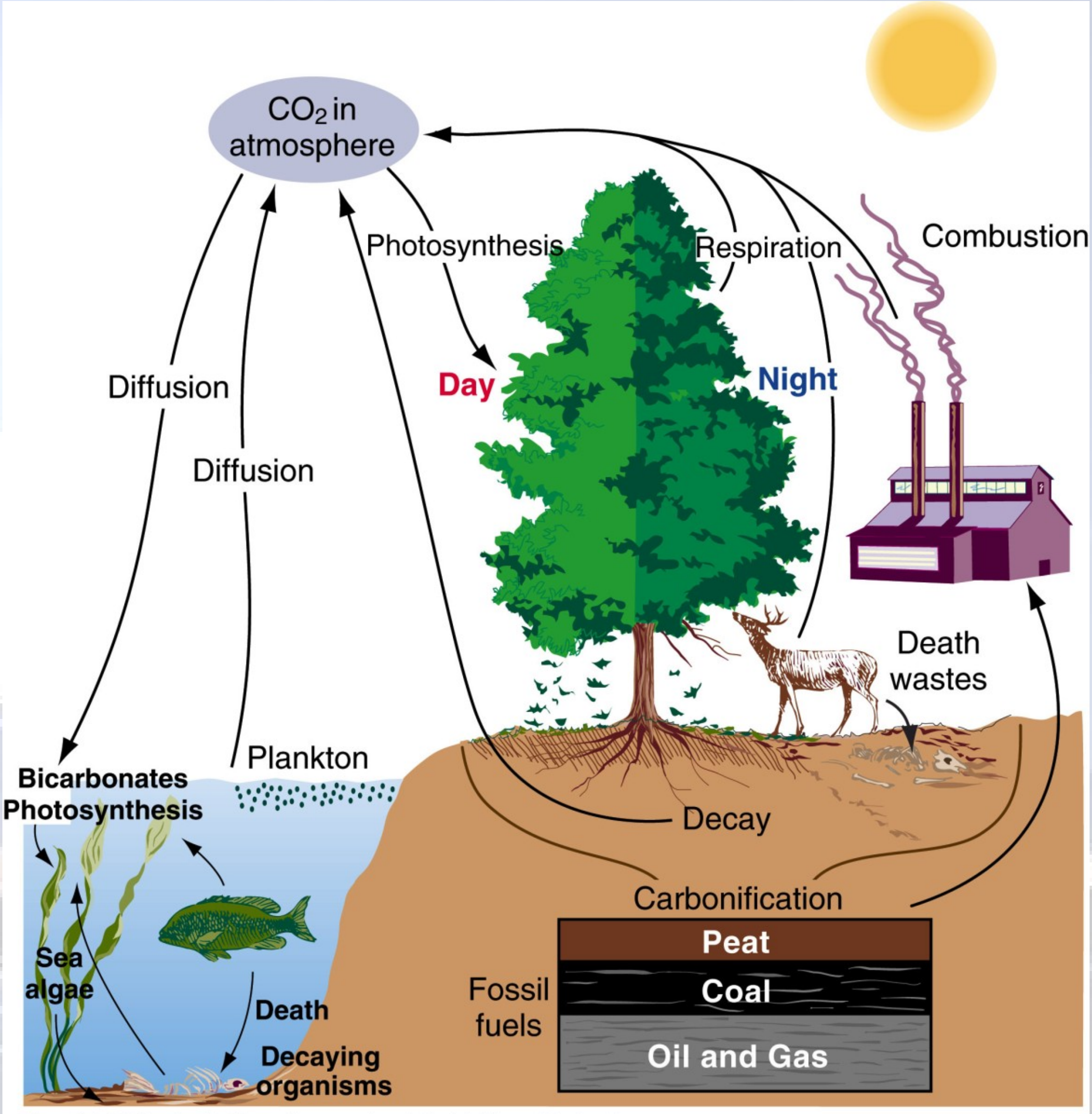


The Carbon Cycle

- **The source of all fixed carbon is carbon dioxide found in the atmosphere and dissolved in water.**
- **Carbon is assimilated by photosynthesis and the flow of carbon through an ecosystem is essentially the flow of energy. In fact, measurement of productivity is commonly expressed in terms of grams of carbon fixed per m^2 per year.**
- **The concentration of carbon dioxide in the atmosphere around plants fluctuates throughout the day and seasonally.**
- **Carbon dioxide is fixed by plants, passed through the food chain, and returned to the atmosphere and water through respiration and decomposition.**
- **Similar cycling occurs in aquatic environments but carbon dioxide is found as a dissolved gas—bicarbonate at pH of 4.3 to 8.3 or carbonate at pH above 8.3.**

- **The Carbon Cycle**

Although the main reservoir is the gas CO_2, considerable quantities are tied up in organic and inorganic compounds of carbon in the biosphere.



The Nitrogen Cycle

- **Nitrogen is an essential constituent of protein and is a major component of the atmosphere (79 percent). However, in its gaseous state, it is unavailable to most life and must be converted to a usable form.**
- **The nitrogen cycle consists of four processes:**

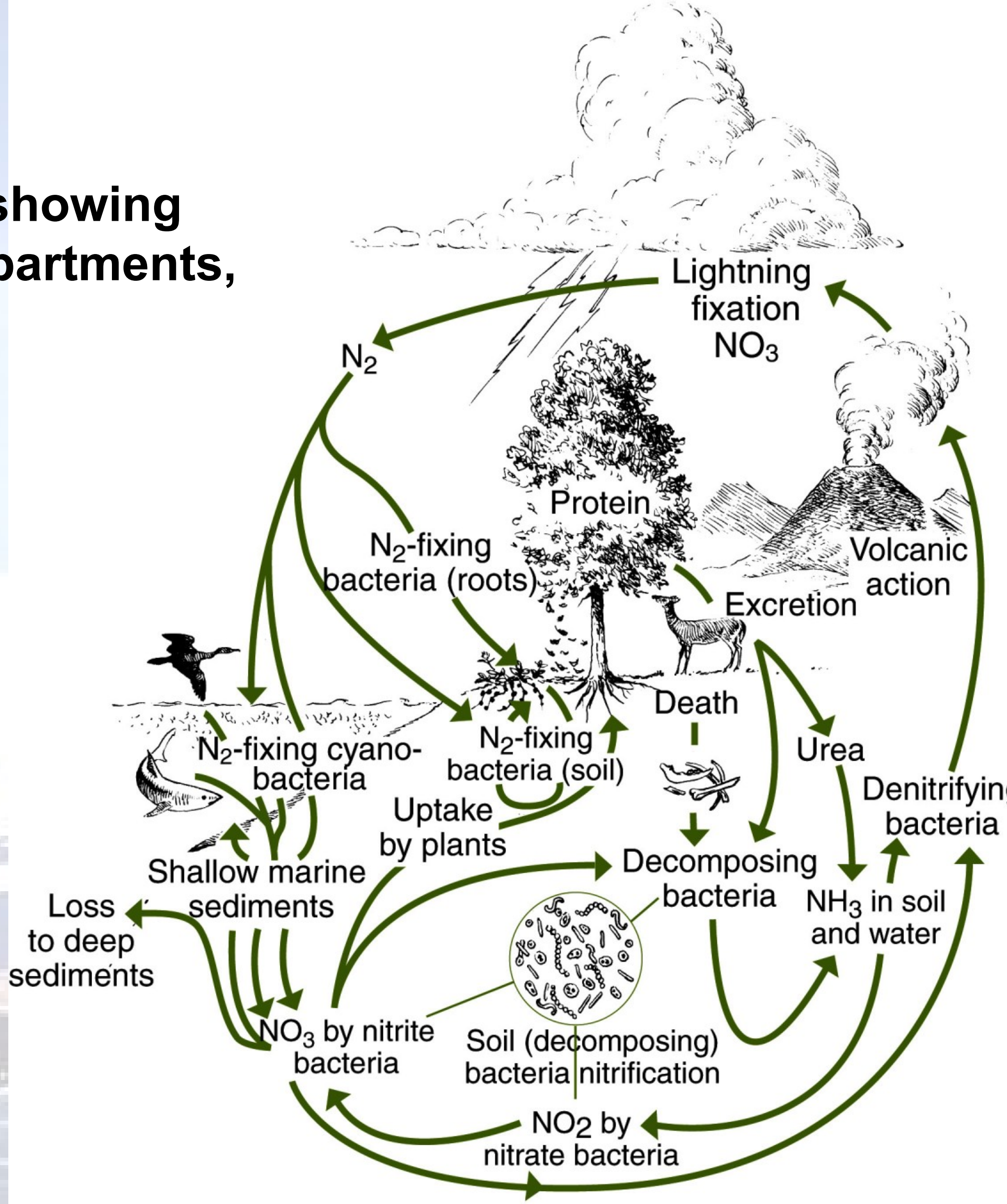
o **Fixation is the conversion of nitrogen in its gaseous state to a usable form. High energy fixation by lightning or occasionally cosmic radiation converts N_2 to ammonia (NH_3). Biological fixation by mutualistic bacteria living in association with leguminous and root-nodulated nonleguminous plants, by free living bacteria, and by cyanobacteria (blue-green algae) accounts for roughly 90 percent of the fixed nitrogen contributed to Earth each year.**

- **Mineralization** or **ammonification**, the conversion of amino acids in organic matter to ammonia. In this process, proteins in dead plant and animal material are broken down by bacteria and fungi to amino acids. The amino acids are oxidized to carbon dioxide, water, and ammonia, with a yield of energy. Ammonia, or the ammonia ion, is absorbed directly by plant roots, incorporated into amino acids, and passed through the food chain.
- **Nitrification** is a biological process which oxidizes ammonia to nitrites and nitrates yielding energy. This process involves *Nitrosomonas* or *Nitrobacter* bacteria.

- **Denitrification** is also a biological process that reduces nitrates to gaseous nitrogen to obtain oxygen. The denitrifiers, represented by fungi and the bacteria *Pseudomonas*, are facultative anaerobes. They prefer an oxygenated environment, but if oxygen is limited, they can use NO_3^- instead of O_2 as the hydrogen acceptor. In doing so they release N_2 in the gaseous state as a by-product.

- Most of the nitrogen cycle is driven by microbes.

The nitrogen cycle, showing major sources, compartments, and processes.



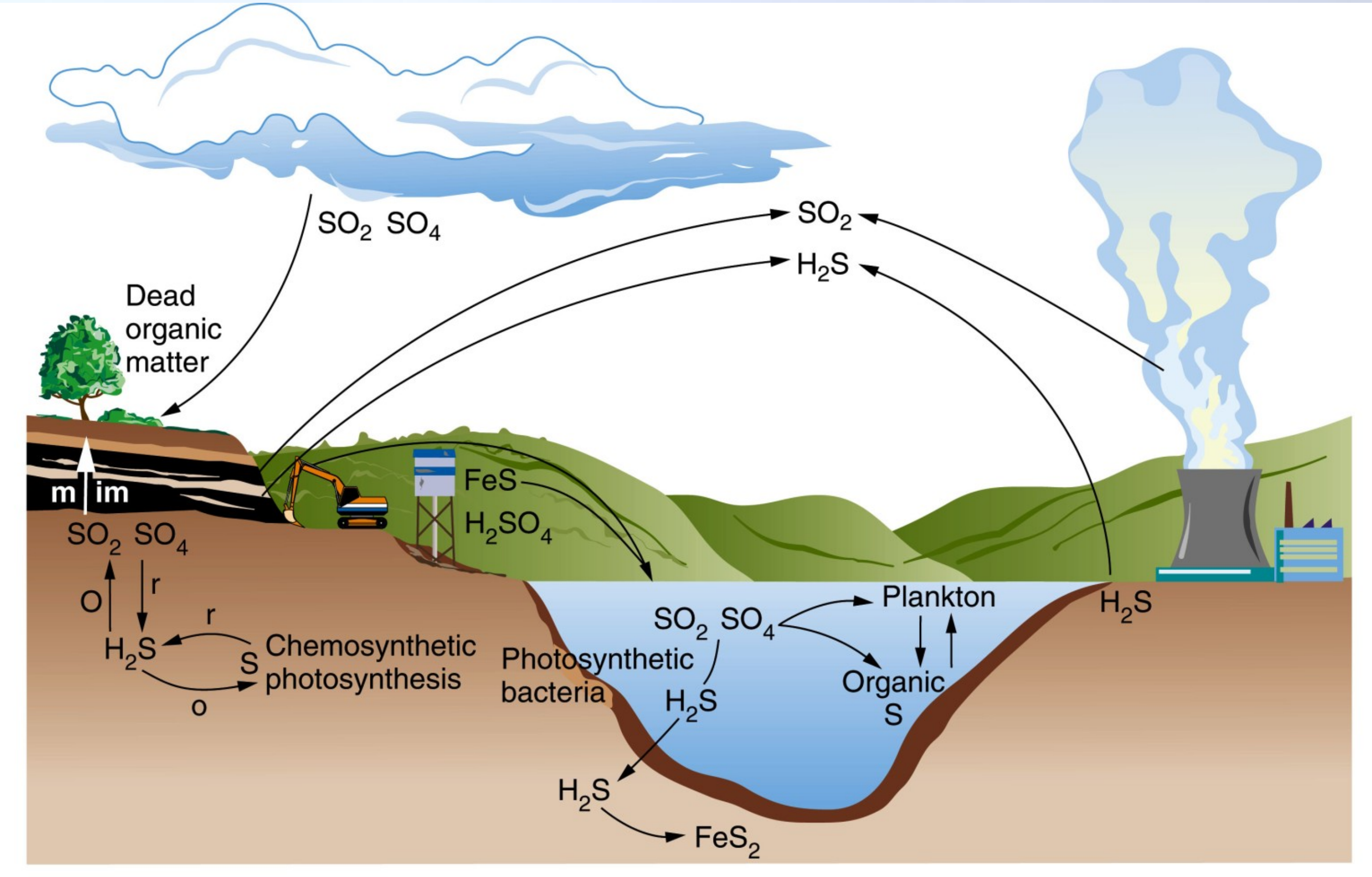
The Sulfur Cycle

- **Sulfur has a long-term sedimentary phase tied up in organic (coal, oil, and peat) and inorganic (pyritic rocks and sulfur deposits) form. It is released by weathering of rocks, erosional runoff, decomposition of organic matter, and industrial production and carried to terrestrial and aquatic ecosystems in a salt solution.**
- **The bulk of sulfur first appears in gaseous phase as hydrogen sulfide in the atmosphere from the combustion of fossil fuels, volcanic eruptions, and gasses released in decomposition. It is quickly oxidized into sulfur dioxide where it is carried back to Earth in rainwater as weak sulfuric acid.**
- **Oceans are another source of gaseous sulfur where dimethysulfide is produced during the decomposition of phytoplankton.**

- **Sulfur is taken up by plants and incorporated into amino acids such as cysteine. From the producers, the sulfur in amino acids is transferred to consumers and ultimately back to the soil and the bottoms of aquatic habitats.**
- **Sulfur, in the presence of iron and under anaerobic conditions, will precipitate as ferrous sulfide, a highly insoluble compound under neutral and alkaline conditions. It is firmly held in mud and wet soil.**

- **The Sulfur Cycle**

The sulfur cycle. Note the two components, sedimentary and gaseous.

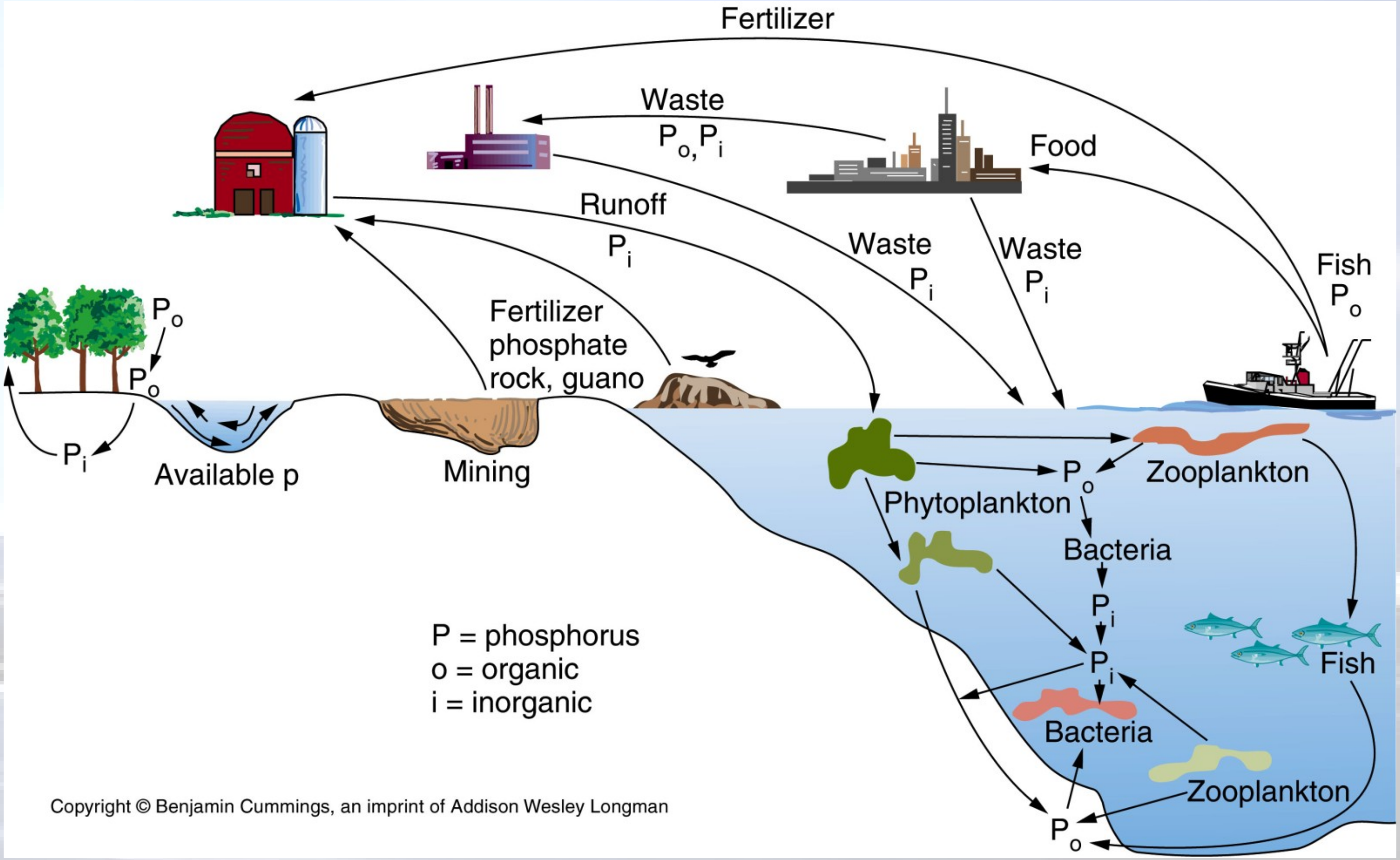


The Phosphorus Cycle

- **Phosphorus occurs only in very minute amounts in the atmosphere and none of its known compounds have an appreciable vapor pressure.**
- **The main reservoirs of phosphorus are rock (especially the mineral apatite) and natural phosphate deposits, from which the element is released by weathering, leaching, erosion, and mining for agricultural use.**
- **Some of the phosphorus passes through terrestrial and aquatic ecosystems as organic phosphorus from plants to grazers, predators, and parasites. It is returned to the ecosystem by excretion, death and decay.**
- **In terrestrial ecosystems, organic phosphates are reduced by bacteria to inorganic phosphates.**

- **The Phosphorus Cycle**

The phosphorus cycle in terrestrial and aquatic ecosystems.



Linkages among Biogeochemical Cycles

- **All of the biogeochemical cycles are linked in various ways.**
  - **They may be linked through common membership in compounds that form an important component of their cycles, such as the link between calcium and phosphorus in the mineral apatite.**
  - **In general, they all travel together through the process of internal cycling because they are all components of living organisms.**
  - **Because of the specific quantitative relationships among the various elements involved in the processes related to carbon uptake and plant growth, the limitation of one nutrient can affect the cycling of all the others.**