SANGKALAN

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Oleh karena itu, mohon untuk membatasi penyebarluasan materi ini secara daring; materi ini hanya untuk penggunaan pribadi mahasiswa peserta mata kuliah ini.

EKOLOGI KOMUNITAS

ENERGY FLOW IN THE ECOSYSTEM

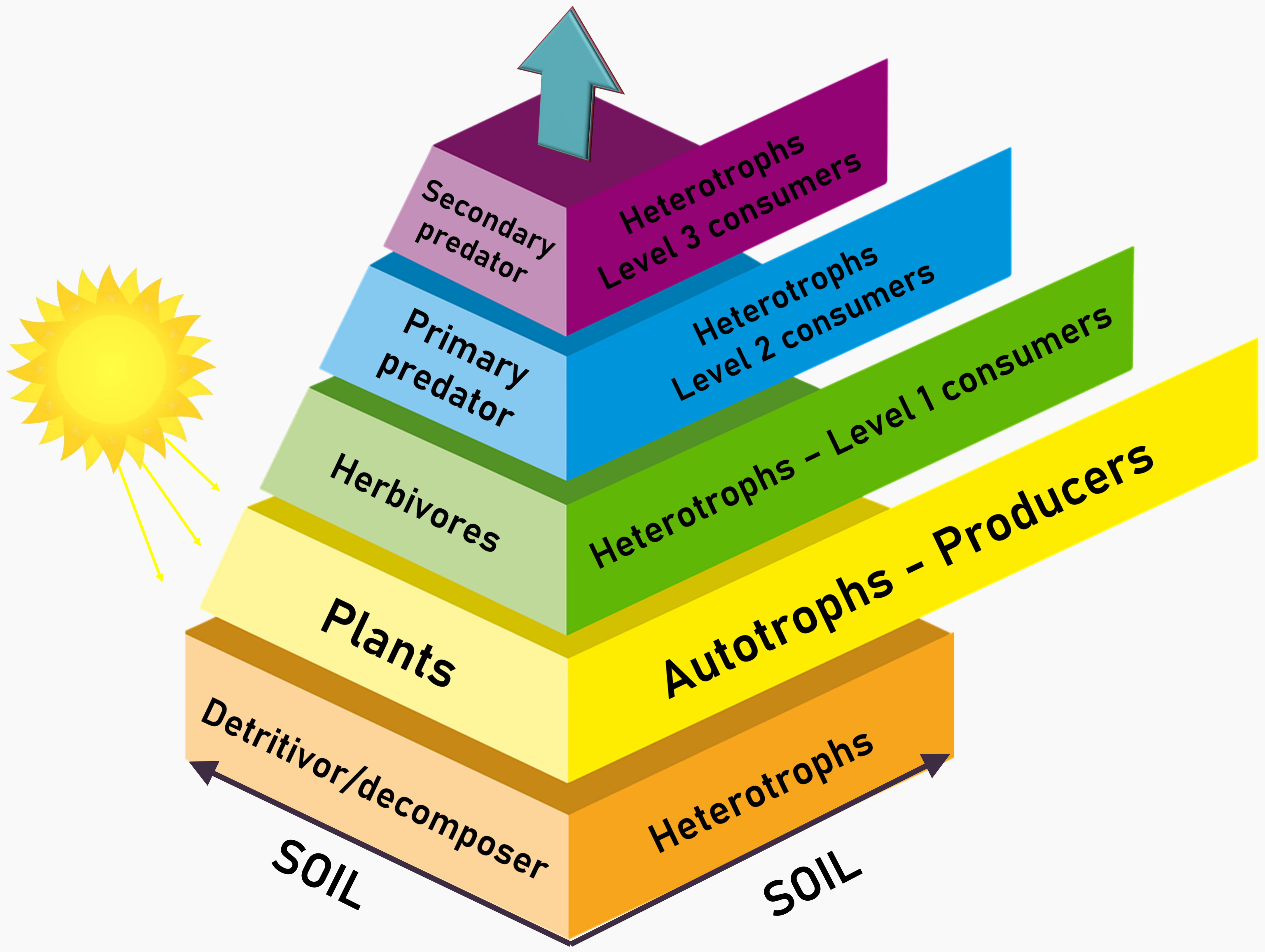
TABLE OF CONTENTS

01

SPECIES ROLES IN FOOD WEBS

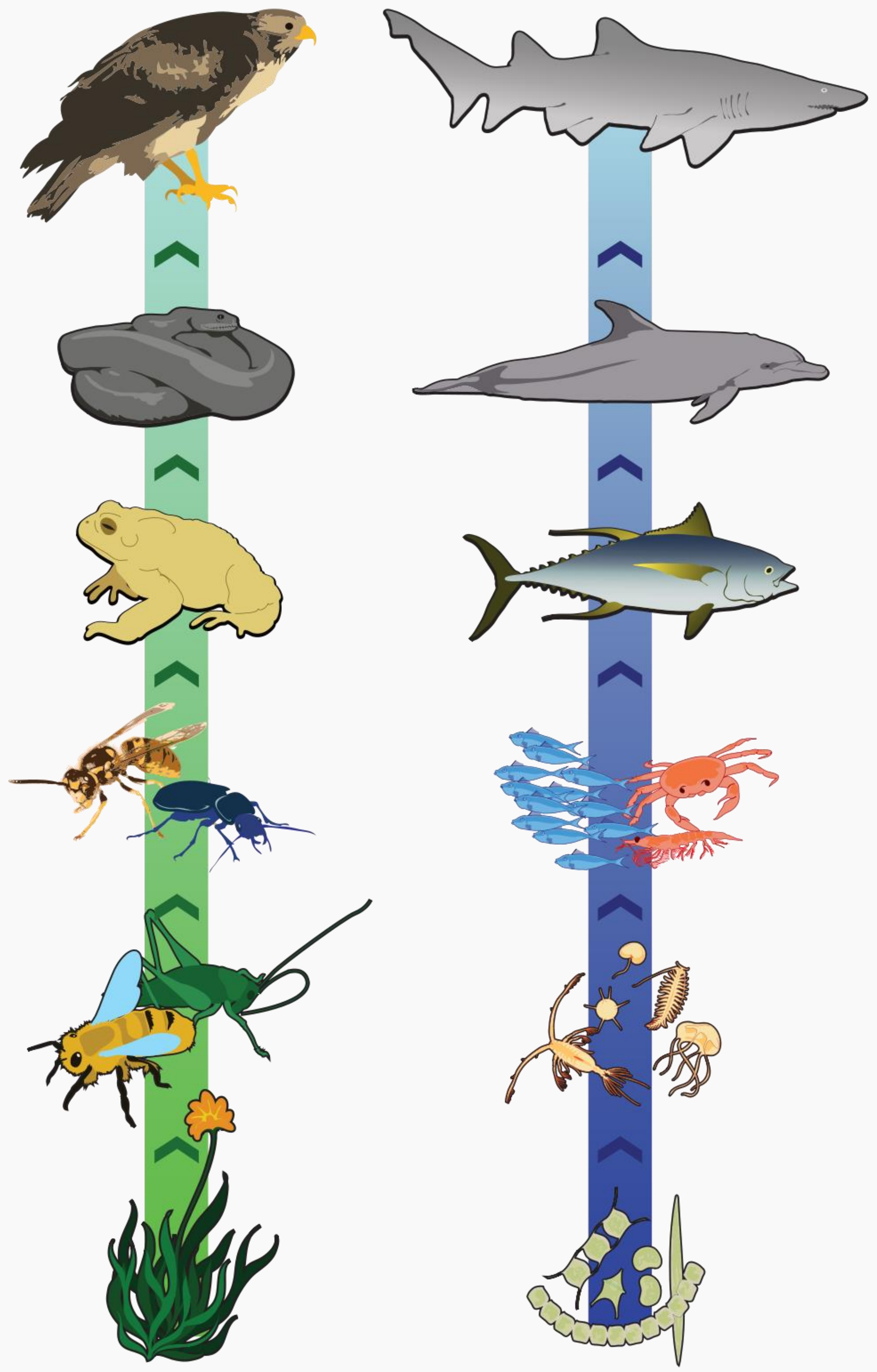
Species roles in the community

- Biological communities are complex.
- Species are categorized into different roles related to their functions in the ecosystems.
- One categorization: feeding relationships.
  - Each species can be placed on one of several **trophic** levels (*trophos* = “nourishment”).
  - Classification within trophic levels: **guilds** (groups of species that feed on similar resources, and often have similar ways of life).



Feeding relationships and community structure

- Feeding relationships are used to describe the structure of a community.
  - Numbers of species and trophic levels.
- **Food web** is an important concept.
  - Represents feeding relationships within a community.
  - The interactions affect species richness, ecosystem productivity and stability.
  - An important tool for investigating energy flows and predator-prey relationship.

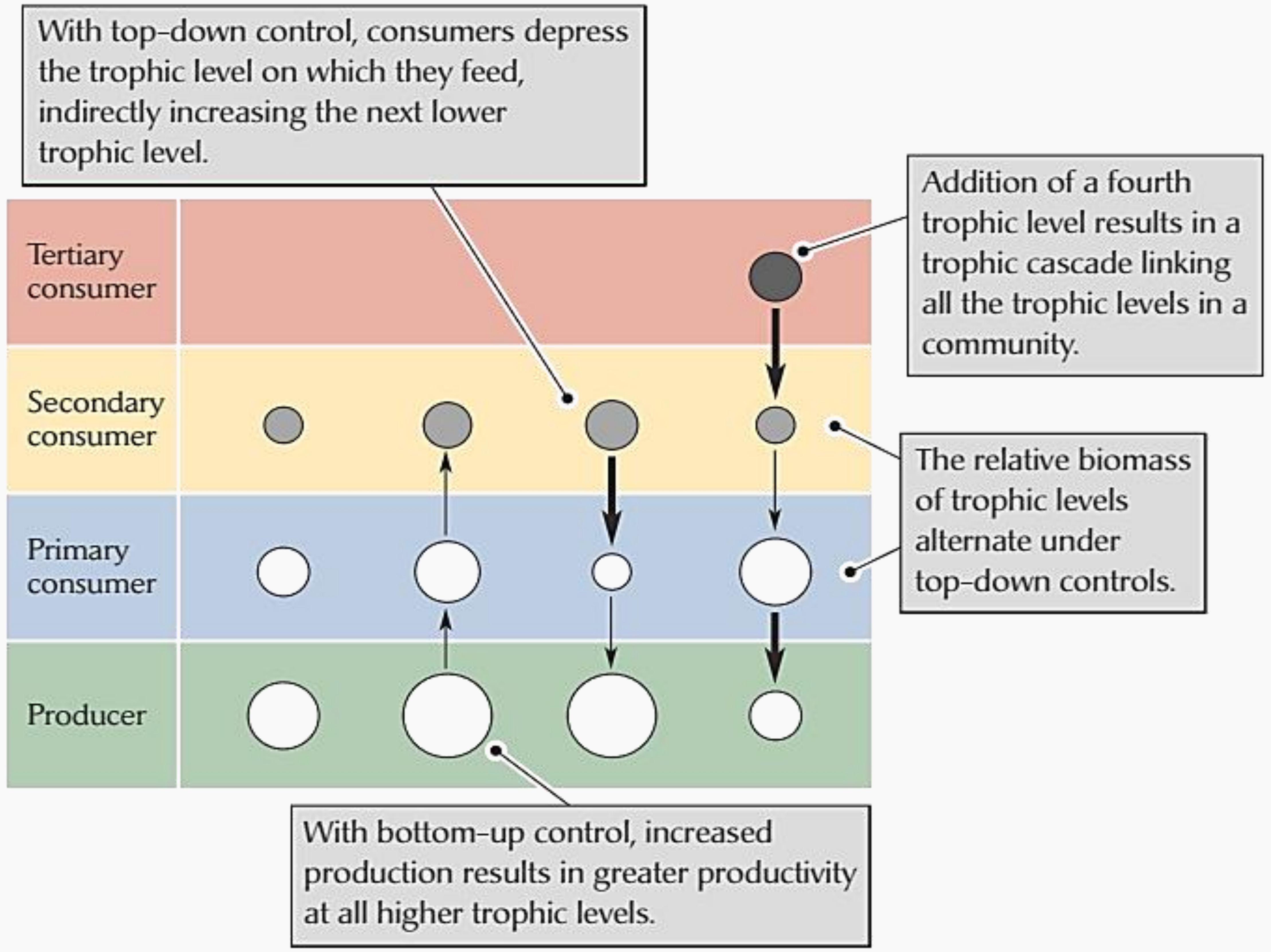


Species interactions in a food web

- Direct interactions
  - Feeding relationship among species in a community.
  - Interactions between trophic levels.
    - Basal species–intermediate species–top predator.
- Indirect interactions
  - Interaction of two species via a third species.
  - Example: a competition influenced by a predation.

Food webs control of community structure

- Bottom-up control.
  - The size of a trophic level is determined by the rate of production of its food resource.
- Top-down control.
  - Higher trophic levels determine the sizes of the trophic levels below them.
  - The abundance or biomass of lower trophic levels depends on effects from consumers at higher trophic levels.
  - Indirect effect of predation: trophic cascade.



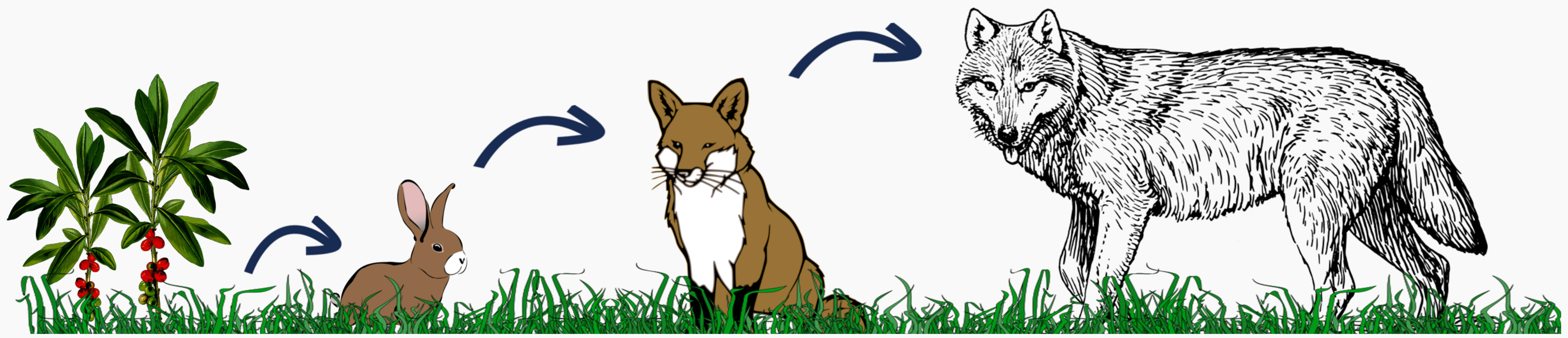
The trophic structure of a community may be determined by bottom-up or top-down control.

[Figure 18.19], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.

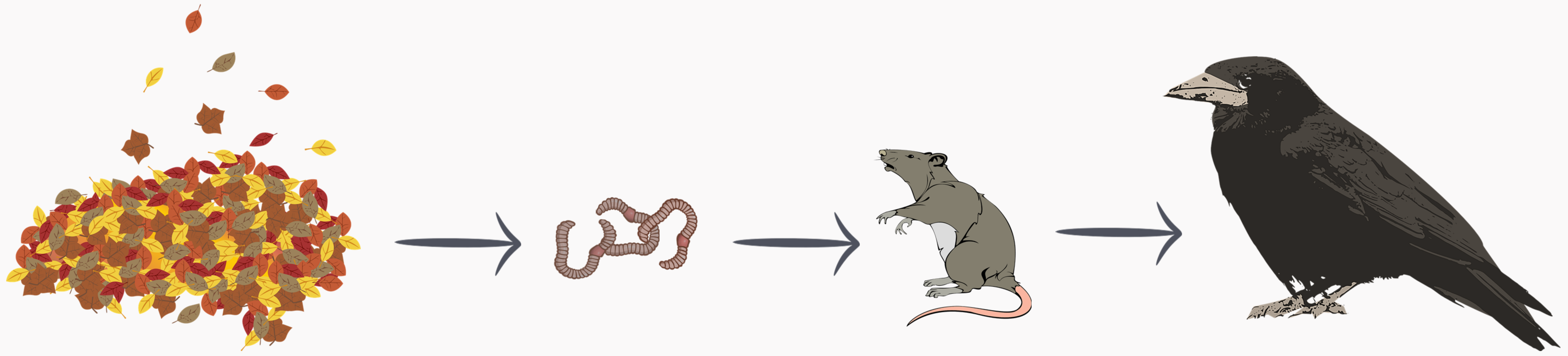
Types of food chains

- The **grazing** food chain
  - Begins with autotrophs.
- The **detrital** food chain
  - Begins with dead organic matter.

Grazing food chain



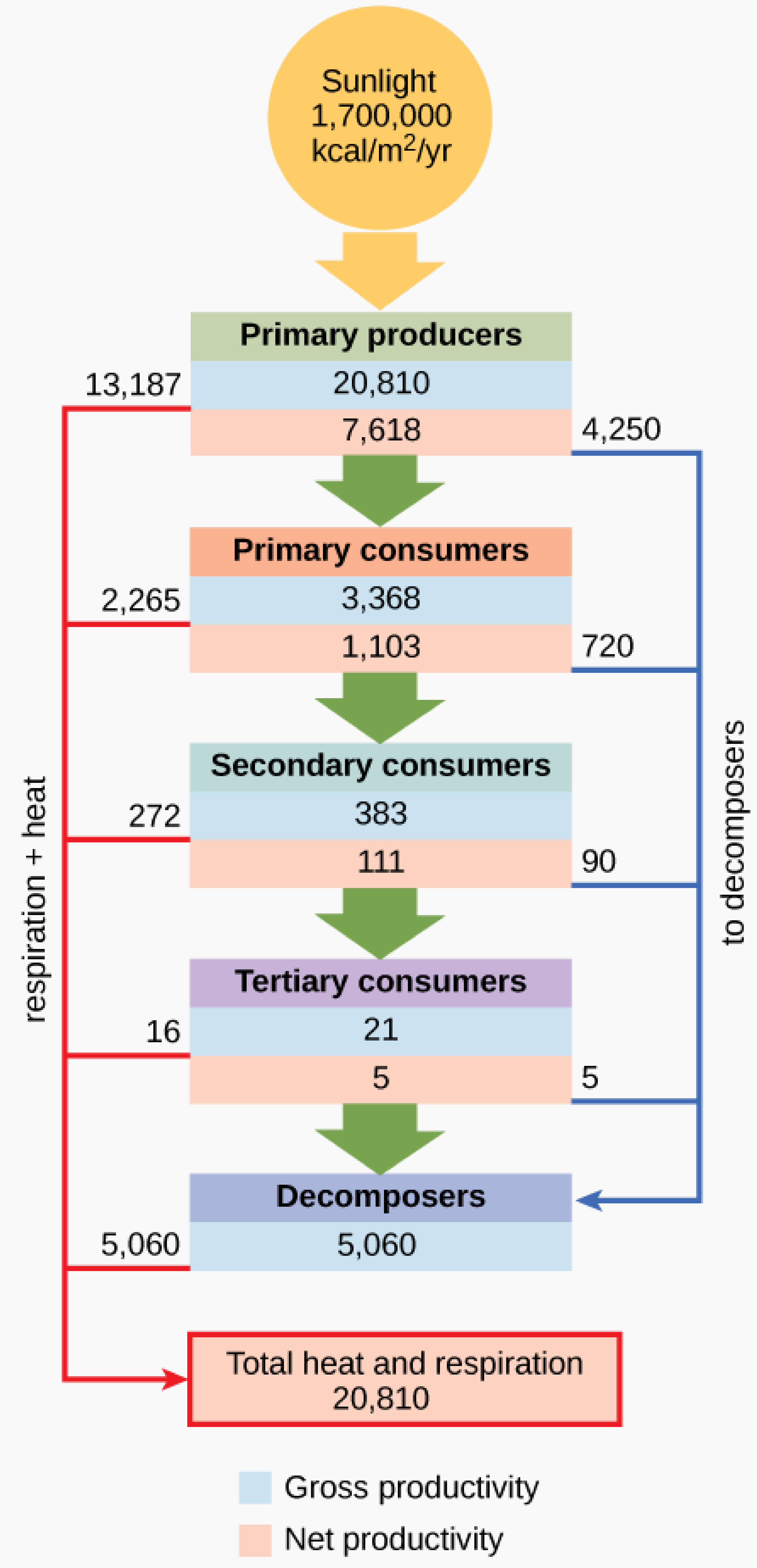
Detrital food chain



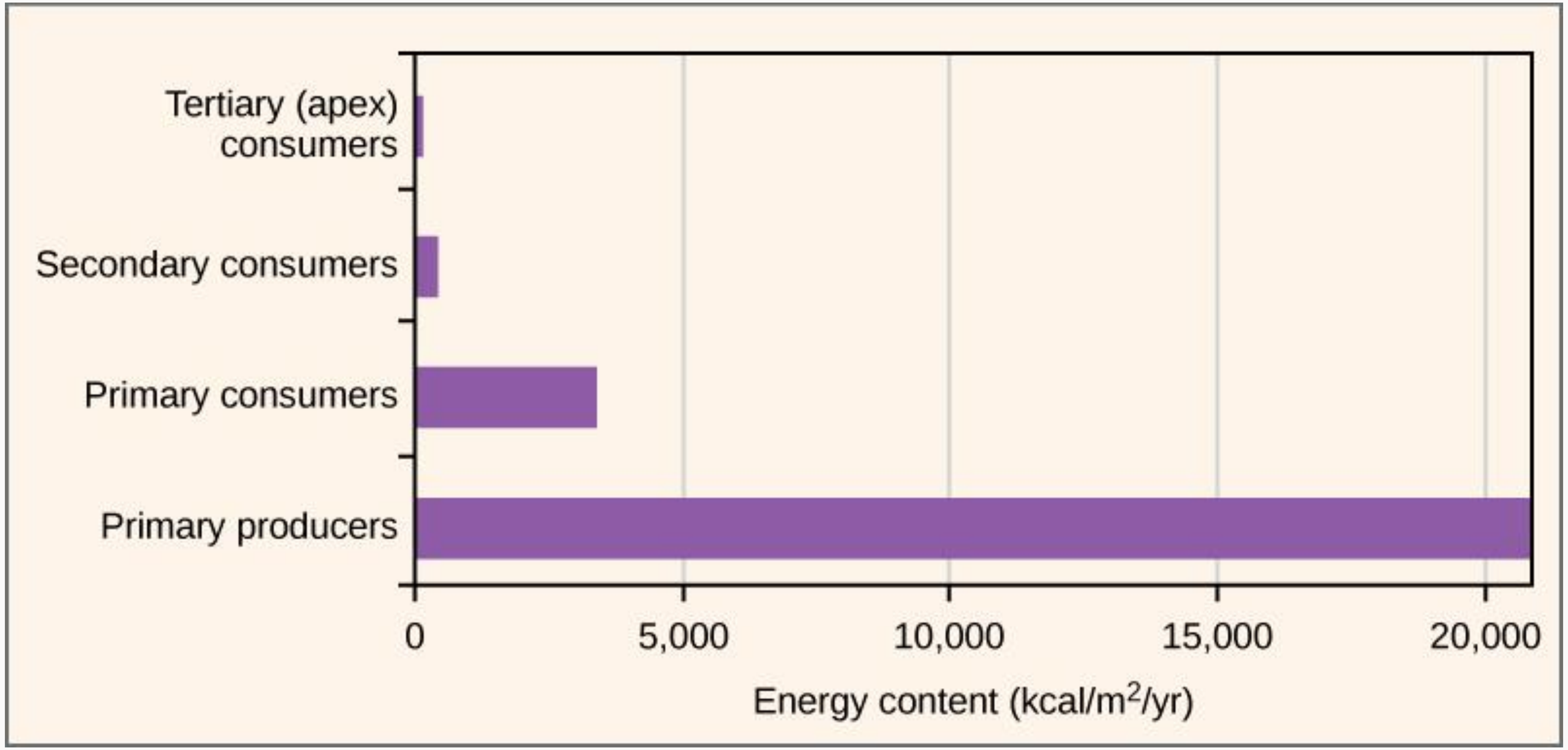
Ecosystem framework

- Ecosystems are organized into trophic levels.
  - Primary producers, consumers (various levels), detritivores/decomposers.
- Laws of physics and chemistry apply to ecosystems.
  - Law of conservation of energy.
  - Second law of thermodynamics.
  - Law of conservation of elements.

An overview of ecosystem dynamics



Relative energy content in trophic levels



The relative energy in trophic levels in a Silver Springs, Florida, ecosystem. Each trophic level has less energy available and supports fewer organisms at the next level

Terms used

DEFINITIONS

BIOMASS
The mass of organisms per unit area or volume.

STANDING CROP
The total dried biomass of the living organisms within a unit area.

PRIMARY PRODUCTIVITY
The rate of biomass production per unit area by the primary producers.

GROSS PRIMARY PRODUCTIVITY
The total fixation of energy by photosynthesis

NET PRIMARY PRODUCTIVITY
The rate of new biomass production, available for consumption by heterotrophic organisms.

SECONDARY PRODUCTIVITY
The rate of production of biomass by heterotrophs

Types of food webs

- The relationships among species in a food web vary.
  - Some relationships are more important than others.
  - Some connections are more influential on species population change.
- Three types of food webs (R. Paine):
  1. Connectedness web (or topological food web)
     - Shows feeding relationships among organisms.
  2. Energy flow web
     - Shows connections quantified as energy flux.
  3. Functional web (or interaction food web)
     - Emphasizes the influence of populations on growth rates in other populations.

02

PRIMARY PRODUCTIVITY

Energy flow through ecosystems

- Energy and nutrients enter ecosystems through **photosynthesis**.
  - The amount of energy captured determines the ecosystem support.
- The energy stored in producers: NPP
  - Measured through biomass (dry biological material).
- Resources needed: CO_2, light, water, minerals, O_2.

Gross and net primary production

- **Gross primary production (GPP)** = total primary production.
- **Net primary production (NPP)** = GPP minus energy used by primary producers for respiration (R).

Primary production

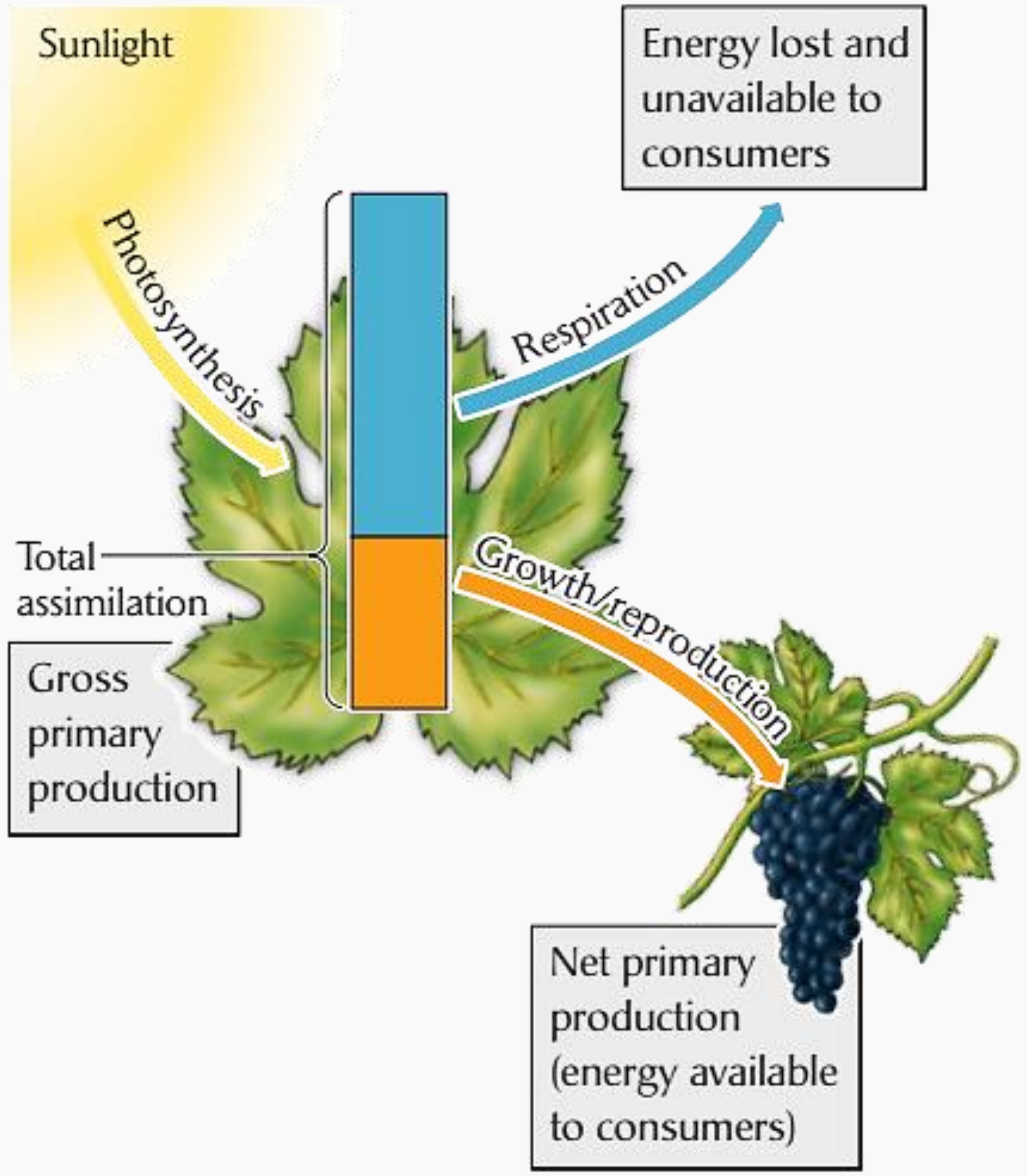


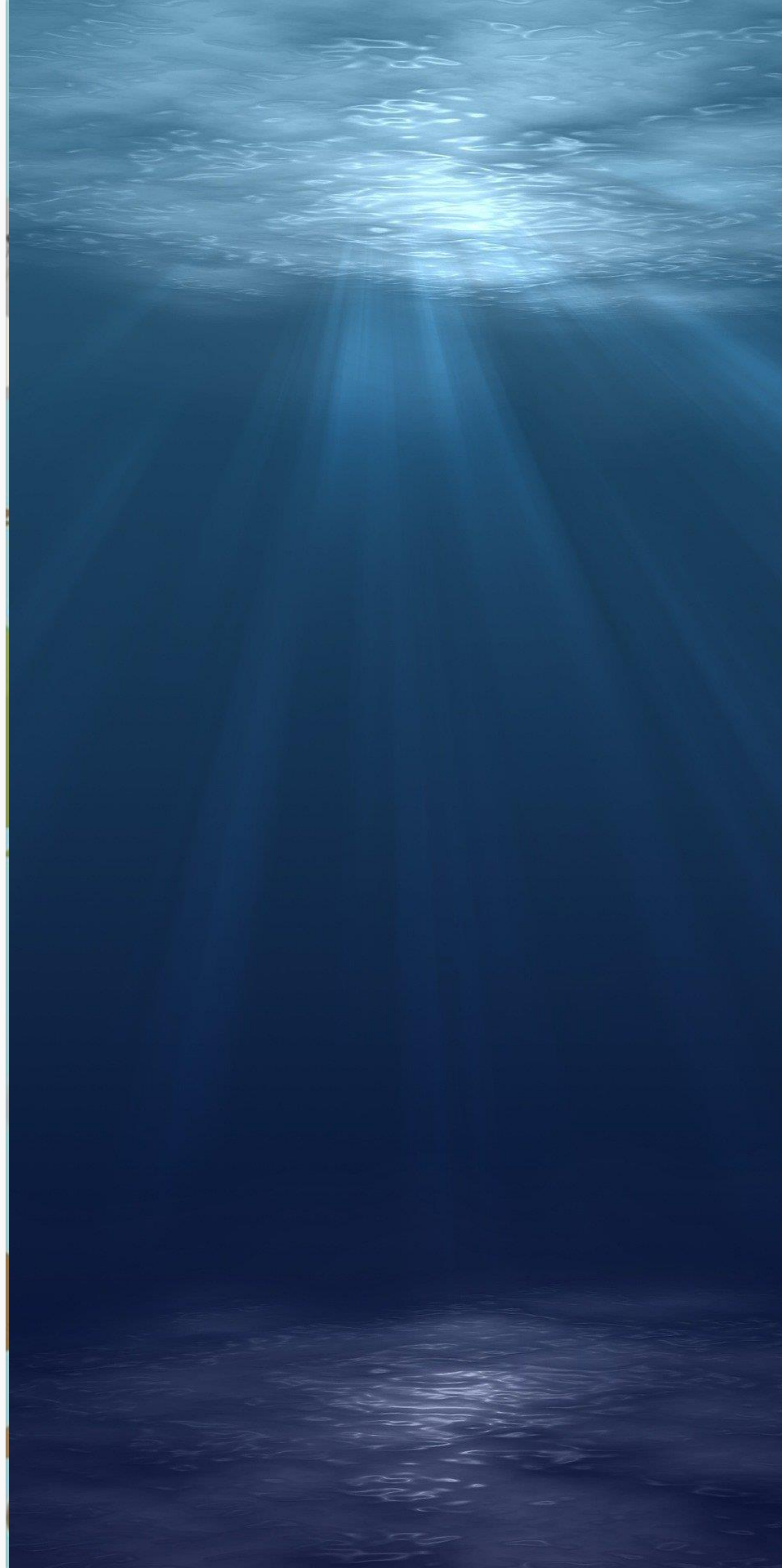
FIGURE 22.3 Gross primary production can be partitioned into respiration and net primary production.

- Amount of light energy converted to chemical energy (organic compounds) by autotrophs in an ecosystem during a given time period.
  - Net photosynthesis is the fixation of carbon in excess of simultaneous releases of CO_2 by plant metabolism.
- Photosynthesis usually captures only ~1% of total energy received in sunlight.
  - Biosphere is fueled by a relatively inefficient process.

[Figure 22.3], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.

Factors limiting primary productivity

- Terrestrial systems
  - Temperature
  - Water (moisture)
  - Nutrients
- Marine/aquatic systems
  - Light
  - Nutrients



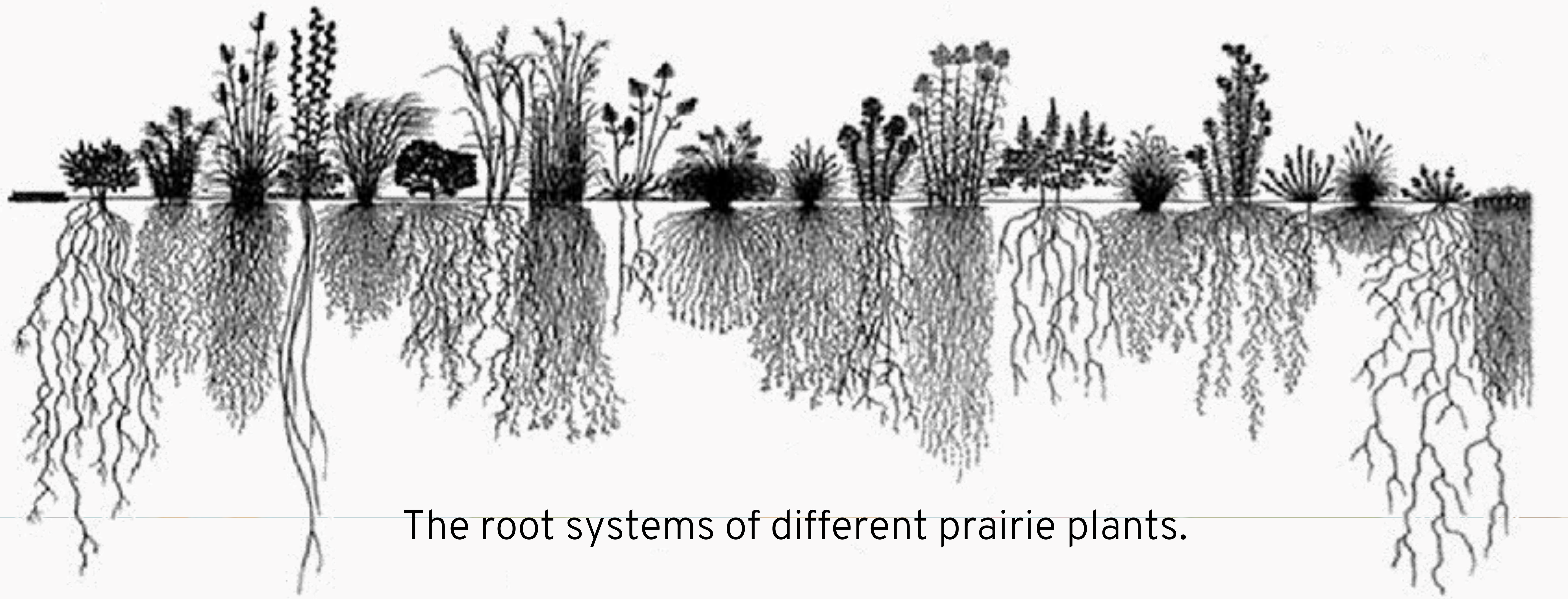
Measurement

NPP

- Annual increase in biomass per unit area [$g.m^{-2}.yr^{-1}$]
- Usually only aboveground; but much production is allocated belowground.

GPP = NPP + R

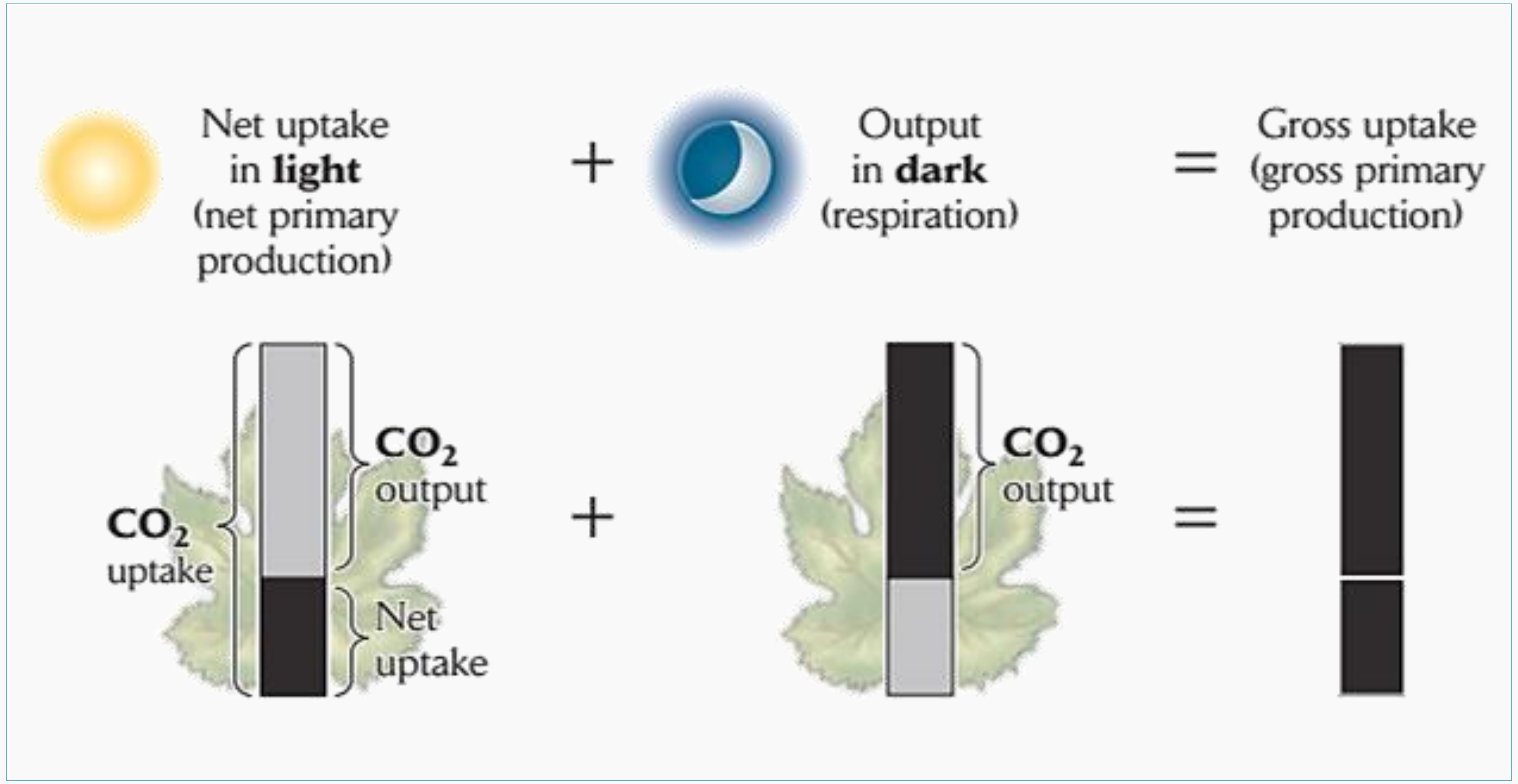
- Standing mass (crop) = Total (bio)mass present (including new tissue, old living tissue and dead material.)



The root systems of different prairie plants.

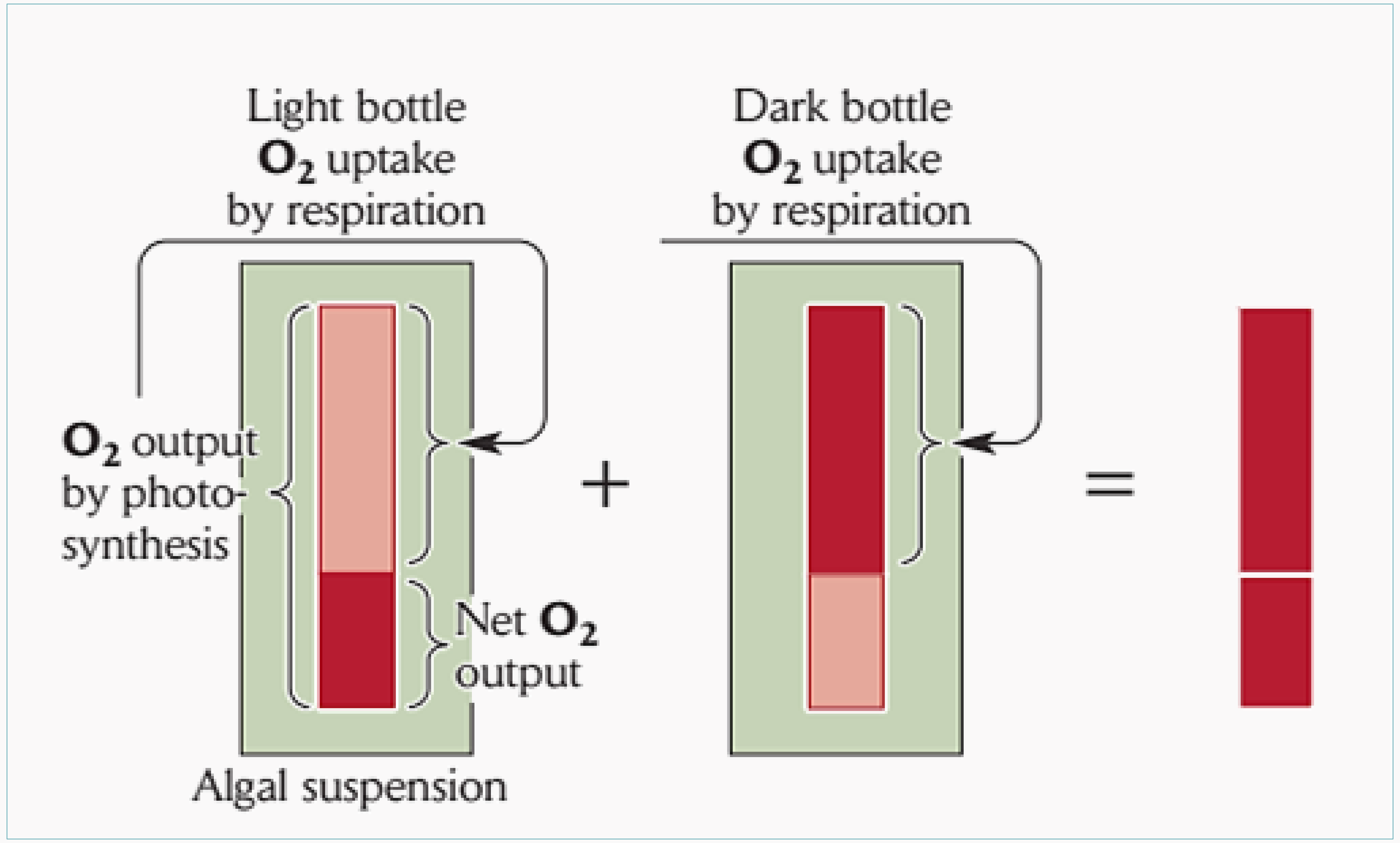
[Figure 3], Mazzolai et al., 2010, DOI: 10.4161/psb.5.2.10457, used under a Fair Use rationale.

NPP measurement: Light & dark bottle method



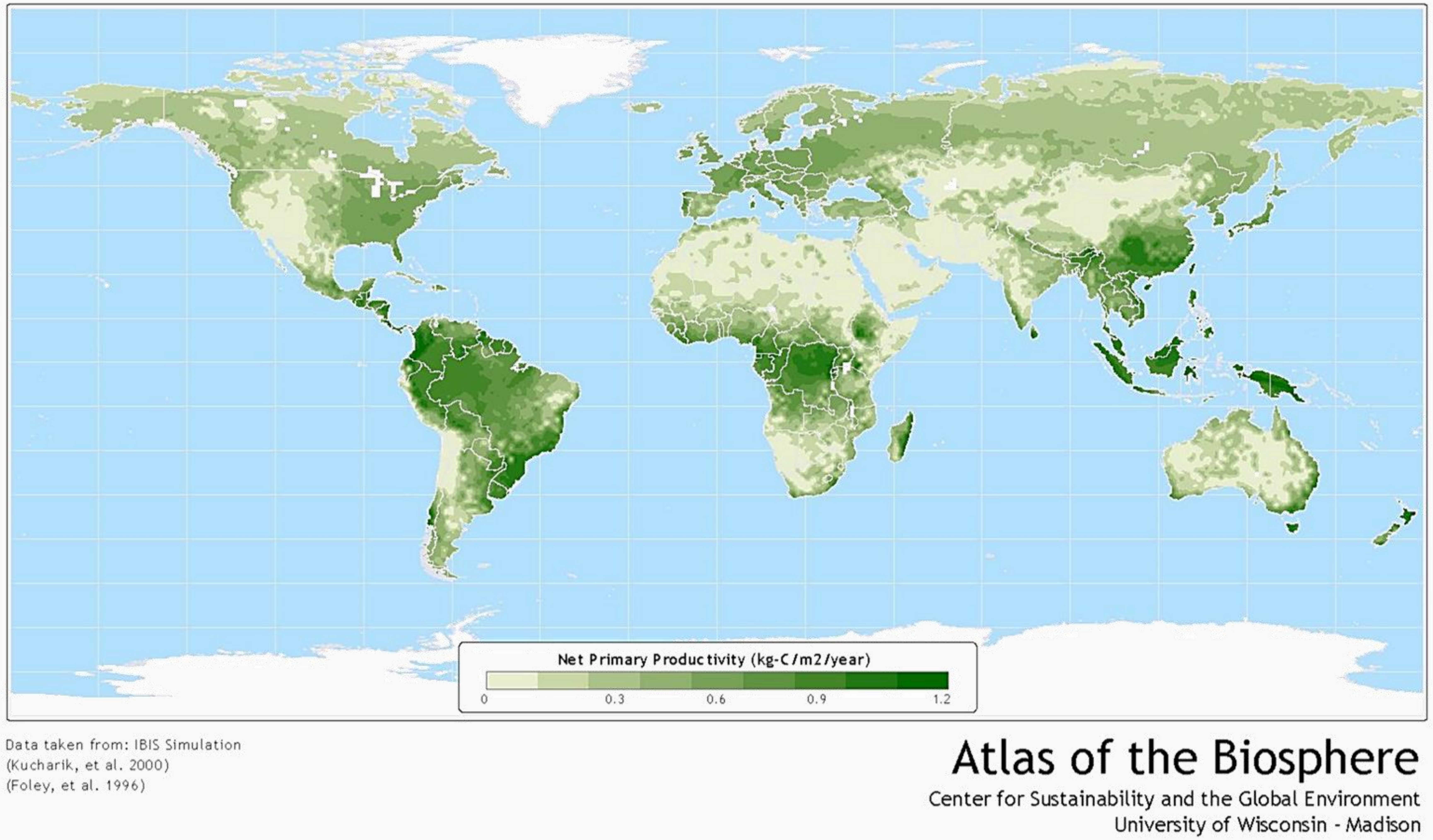
Measurements of carbon dioxide flux in dark and light to estimate GPP.

Paired light and dark bottles can be used to measure production by aquatic phytoplankton.



[Figure 22.5 and 22.6], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.

Global variation of NPP



- High near the equator.
- Intermediate in temperate zones.
- Low near poles.
- Very low in the arid zones.

[Global variation of NPP], Foley et al., 1996, DOI: 10.1029/96GB02692, used under a Fair Use rationale.

Latitudinal patterns in primary productivity

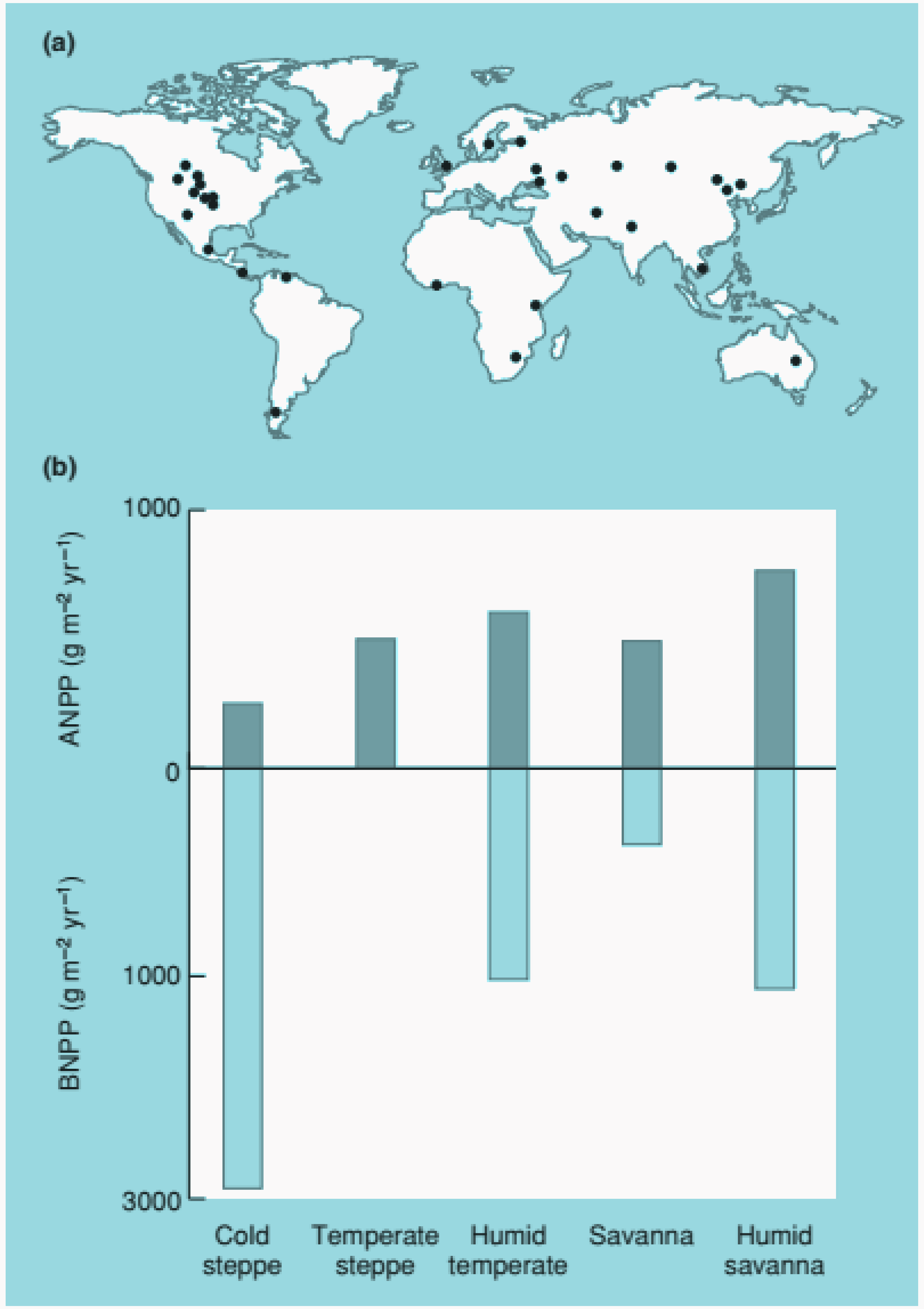
Marine	*NPP*	*Terrestrial*	*NPP*
Tropical and subtropical oceans	13.0	Tropical rainforests	17.8
Temperate oceans	16.3	Broadleaf deciduous forests	1.5
Polar oceans	6.4	Mixed broad/needleleaf forests	3.1
Coastal	10.7	Needleleaf evergreen forests	3.1
Salt marsh/estuaries/seaweed	1.2	Needleleaf deciduous forests	1.4
Coral reefs	0.7	Savannas	16.8
		Perennial grasslands	2.4
		Broadleaf shrubs with bare soil	1.0
		Tundra	0.8
		Desert	0.5
		Cultivation	8.0
Total	48.3	Total	56.4

Annual NPP for major biomes and for the planet in total in petagrams (10^{15}) of C.

[Table 17], Begon et al., 2006, Ecology: from individuals to ecosystems, 4th ed., Massachusetts: Blackwell Publishing, used under a Fair Use rationale.

Above- vs below-ground NPP in different latitudes

- Latitudinal trend in productivity of grasslands.
- Considerable differences in the relative importance of above- and below-ground productivity in the different grassland.
- The overall trends with latitude suggest that radiation and temperature may often limit the productivity of communities.
  - Other factors frequently constrain productivity within even narrower limits.



[Figure 17.1], Begon et al., 2006, Ecology: from individuals to ecosystems, 4th ed., Massachusetts: Blackwell Publishing, used under a Fair Use rationale.

Autochthonous and allochthonous production

- Organisms need a source of energy.
  - **Autochthonous** sources vs **allochthonous** sources
- Terrestrial ecosystems
  - Autochthonous production in situ by the photosynthesis of plants (main source).
  - Allochthonous source from animals feces derived from food consumed elsewhere.
- Aquatic ecosystems
  - Autochthonous input by the photosynthesis of large plants, algae, phytoplankton.
  - Allochthonous material via rivers, groundwater, or the wind.
  - The relative importance of the autochthonous vs allochthonous sources of organic material varies.

03

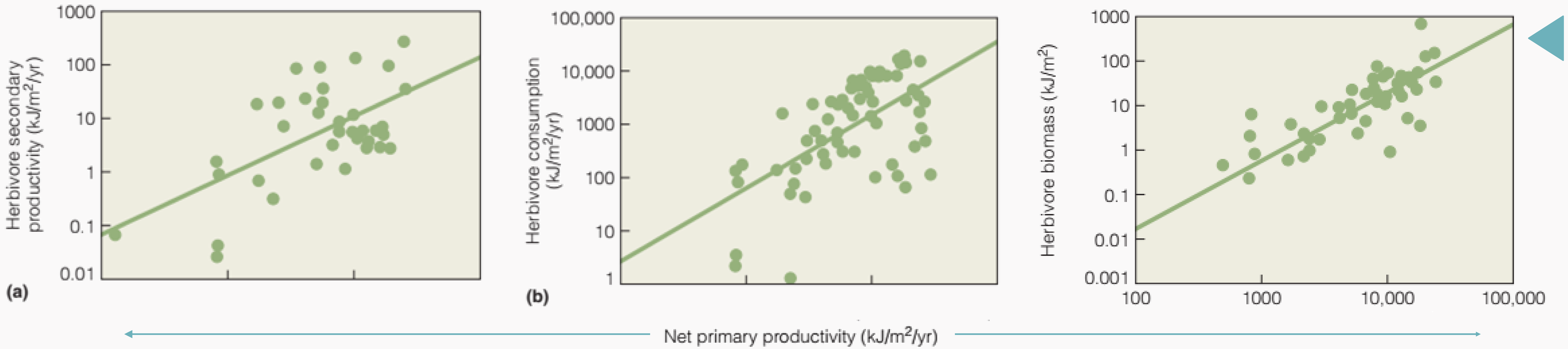
SECONDARY PRODUCTIVITY

Characteristics of energy in food webs

- Non-cyclic, unidirectional flow.
- Losses at each transfer from one trophic level to another.
  - Losses as heat from respiration.
  - Inefficiencies in processing.
- Total energy declines from one transfer to another.
  - Limits number of trophic levels.

Secondary productivity: the next level in energy flow

- Secondary productivity: the rate at which consumers convert organic material into new biomass of consumers.
  - No additional energy is introduced into the food chain, hence no gross or net values.
- Limited by primary production.

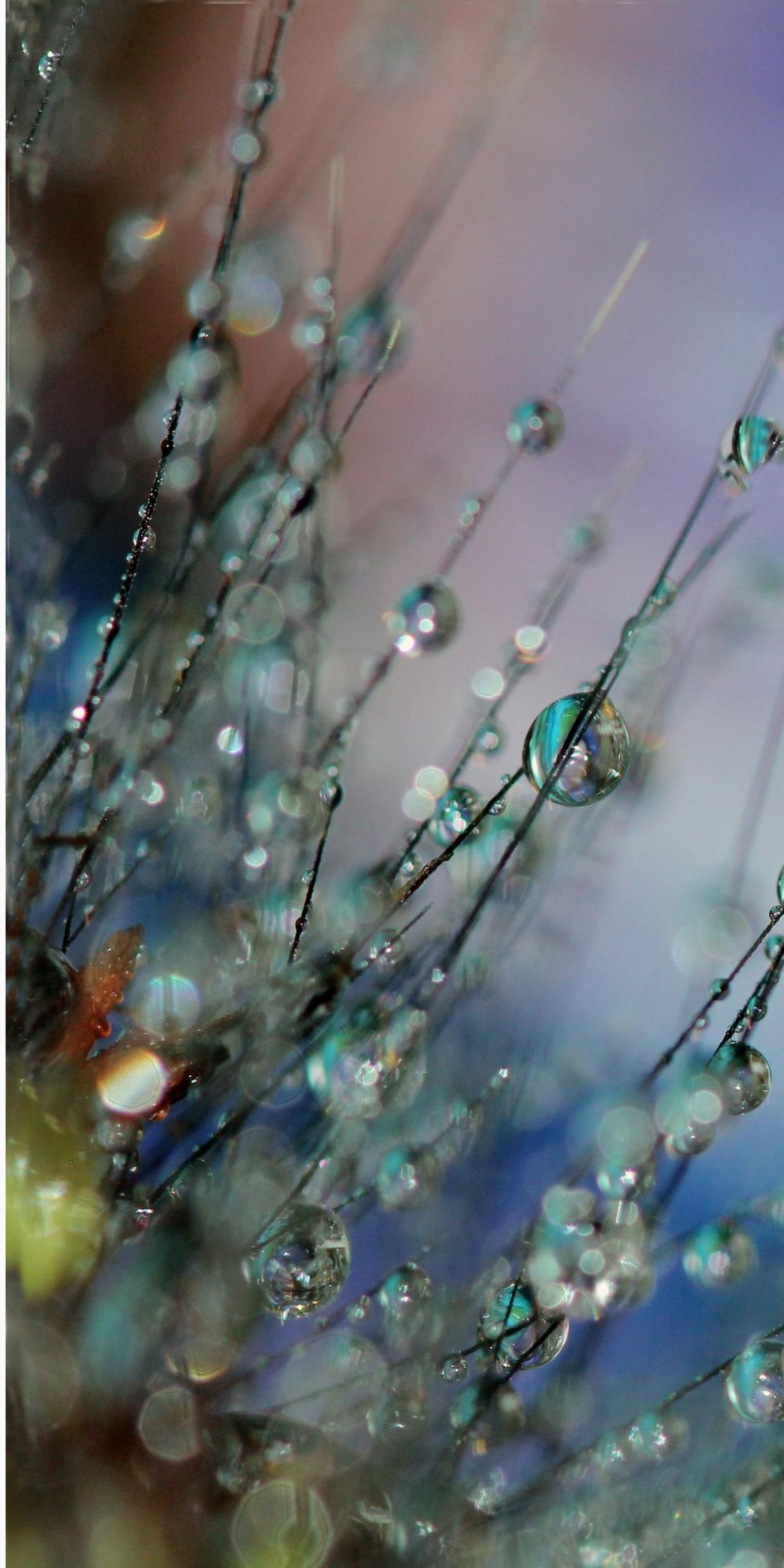


Relationship between aboveground net primary productivity and (a) herbivore productivity; (b) consumption; and (c) herbivore biomass.

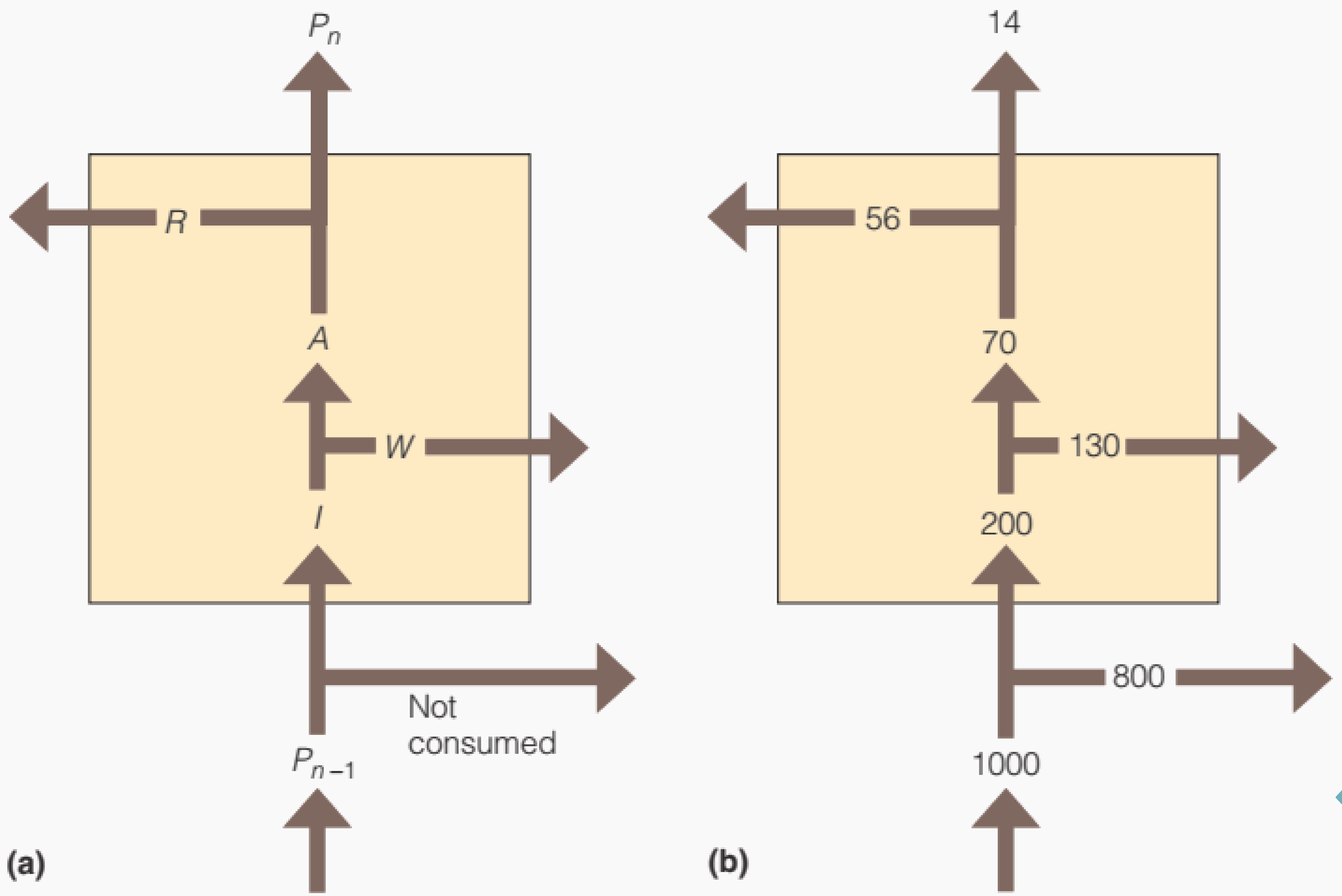
[Figure 20.20], Smith TM & Smith RL, 2015, Elements of Ecology, 9th ed., Pearson Education Ltd. Used under a Fair Use rationale.

Factors limiting secondary production

- Primary production.
- Second law of thermodynamics.
- Water.
- Nutrients.
- Predation.
- Competition.



Quantifying energy flow through trophic levels



P_n = NPP at trophic level n
R = respiration
I = ingested production
A = assimilated energy
W = waste materials

A/I = assimilation efficiency
P/A = production efficiency
I_n/P_{n-1} = consumption efficiency

Invertebrate herbivore efficiencies

$I/P_{n-1} = 20\%$
$A/I = 35\%$
$P_n/A = 20\%$

(a) Energy flow within a single trophic compartment. (b) An example of quantifying energy flow for an invertebrate herbivore using estimates of efficiencies provided in table. Values are in kilocalories (kcal).

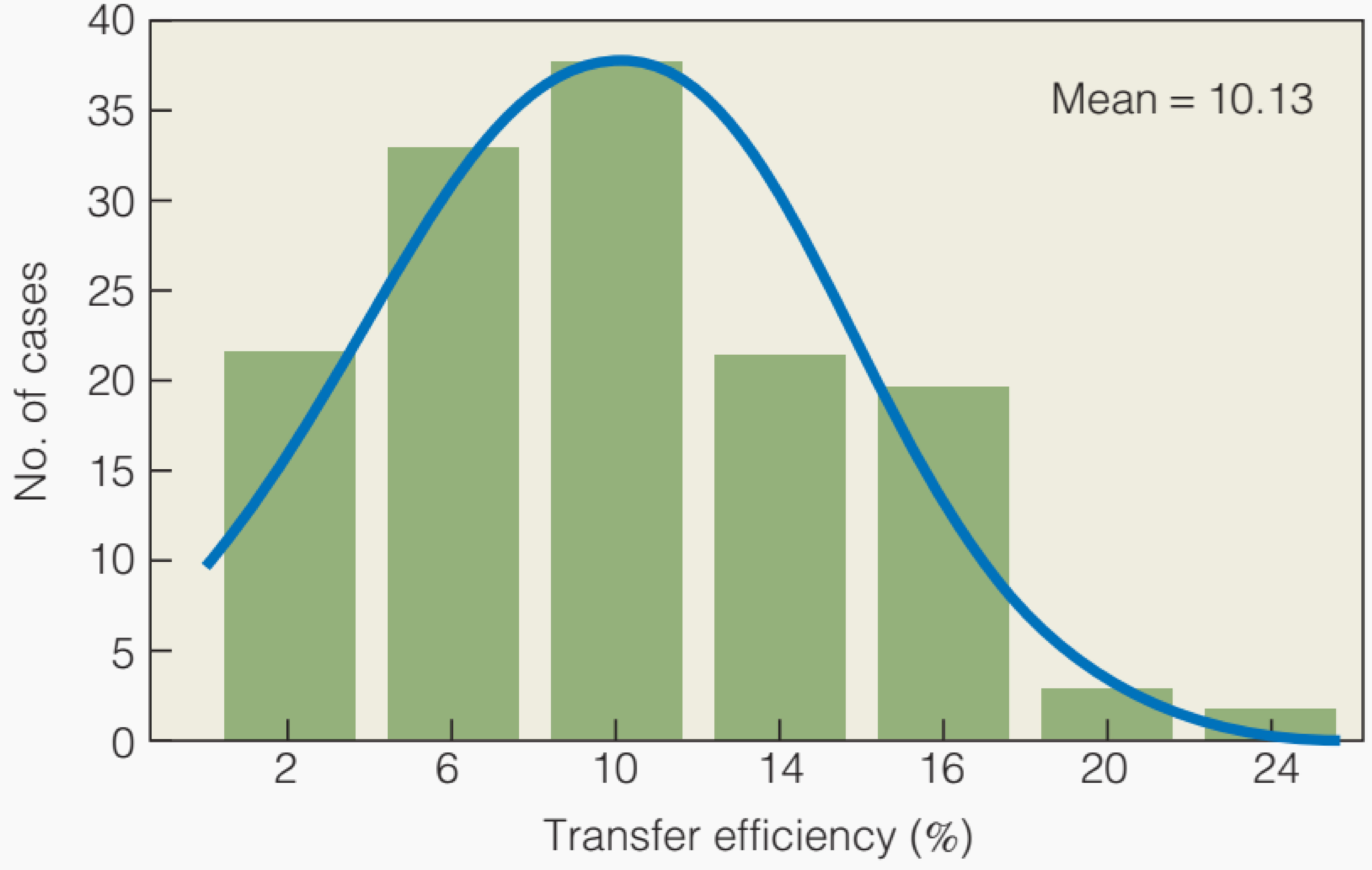
[Figure 20.24], Smith TM & Smith RL, 2015, Elements of Ecology, 9th ed., Pearson Education Ltd. Used under a Fair Use rationale.

Energy transfer efficiencies

- Efficiency of energy transfer called **trophic efficiency** (TE) or transfer efficiency (in percent).
- Result ($\bar{x} = 10.13\%$), close to the general rule of 10% TE.

$$TE = P_n / P_{n-1}$$

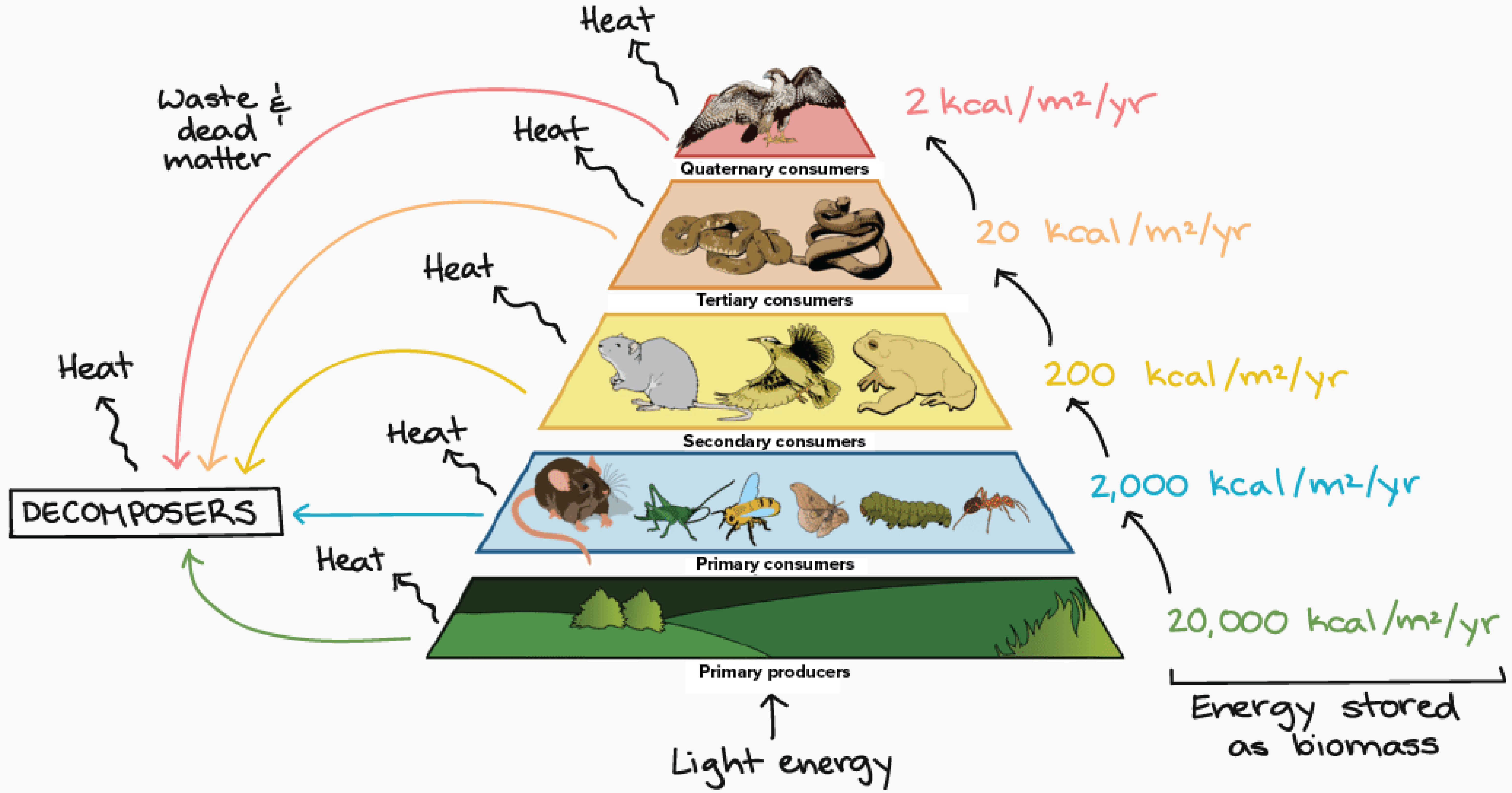
P_n = annual production at level n
P_{n-1} = annual production at level at $n-1$



Frequency distribution of trophic efficiencies (energy transfer efficiencies: TE in percentages) for 48 tropic models of aquatic ecosystems.

Trophic efficiency

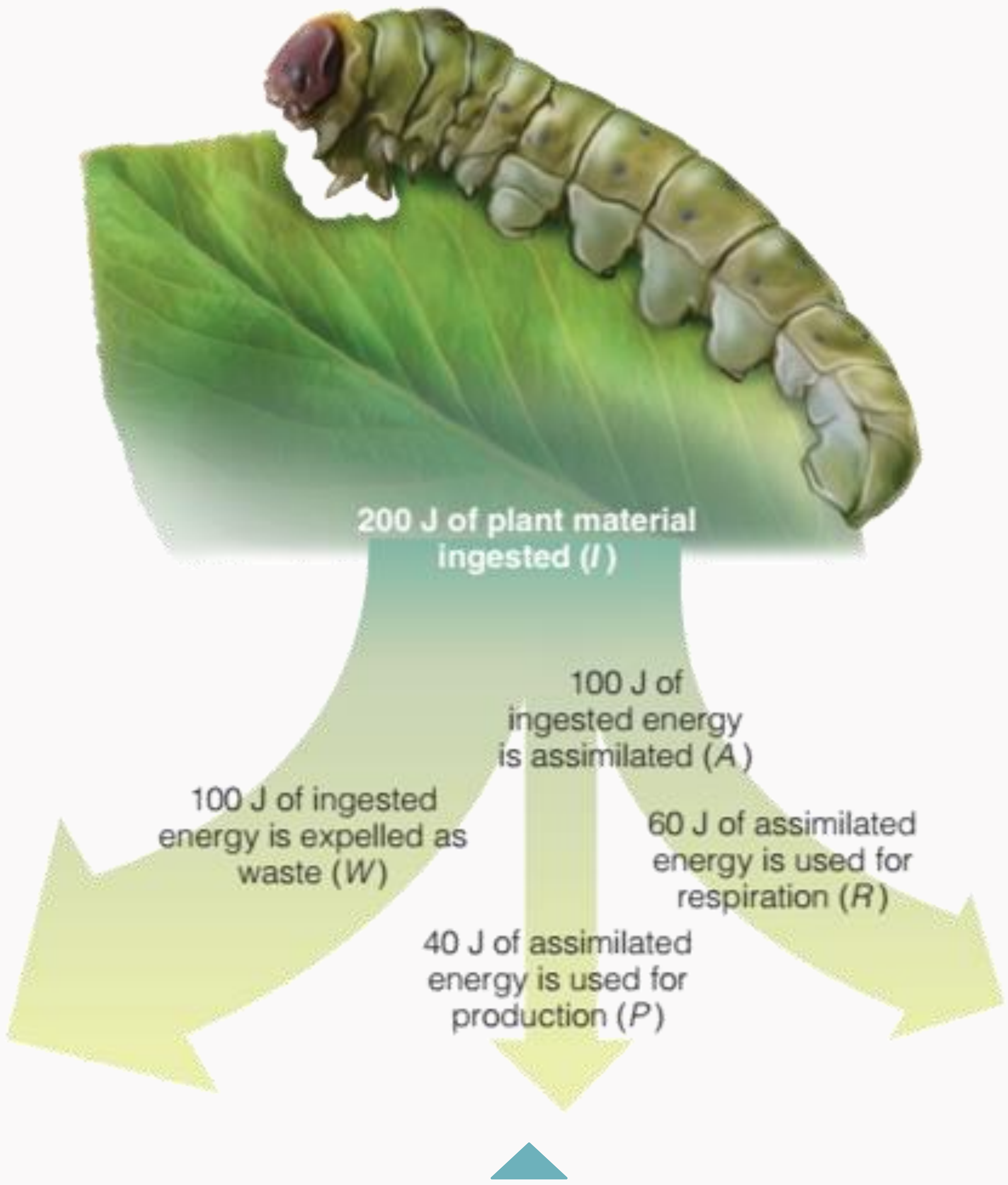
- Trophic efficiencies usually range between 5–20%.
- A consequence of low ecological efficiencies: variation in abundance or biomass across trophic levels.



[Ecological pyramid], Ruiz Villarreal for CK-12 Foundation, CC BY-NC 3.0.

Secondary production efficiency varies with species

- Production efficiency (P/A) is the fraction of food energy that is not used for respiration.
- Production efficiencies: birds and mammals (1–3%), fishes (10%), insects (10–40%).
- No differences across habitats.



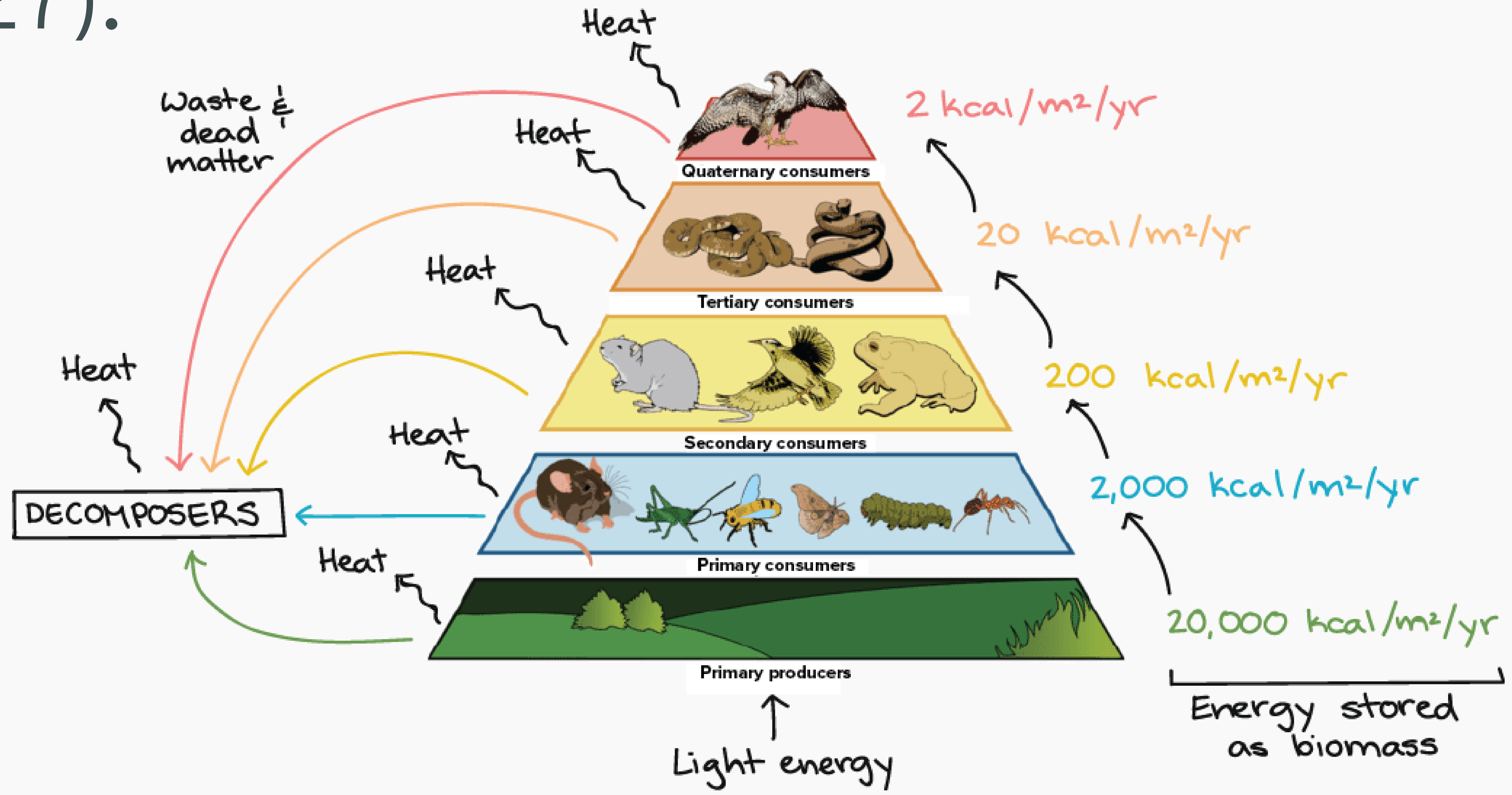
Simple model of energy flow through a consumer.

[Figure 20.22], Smith TM & Smith RL, 2015, Elements of Ecology, 9th ed., Pearson Education Ltd. Used under a Fair Use rationale.

Human at different trophic levels

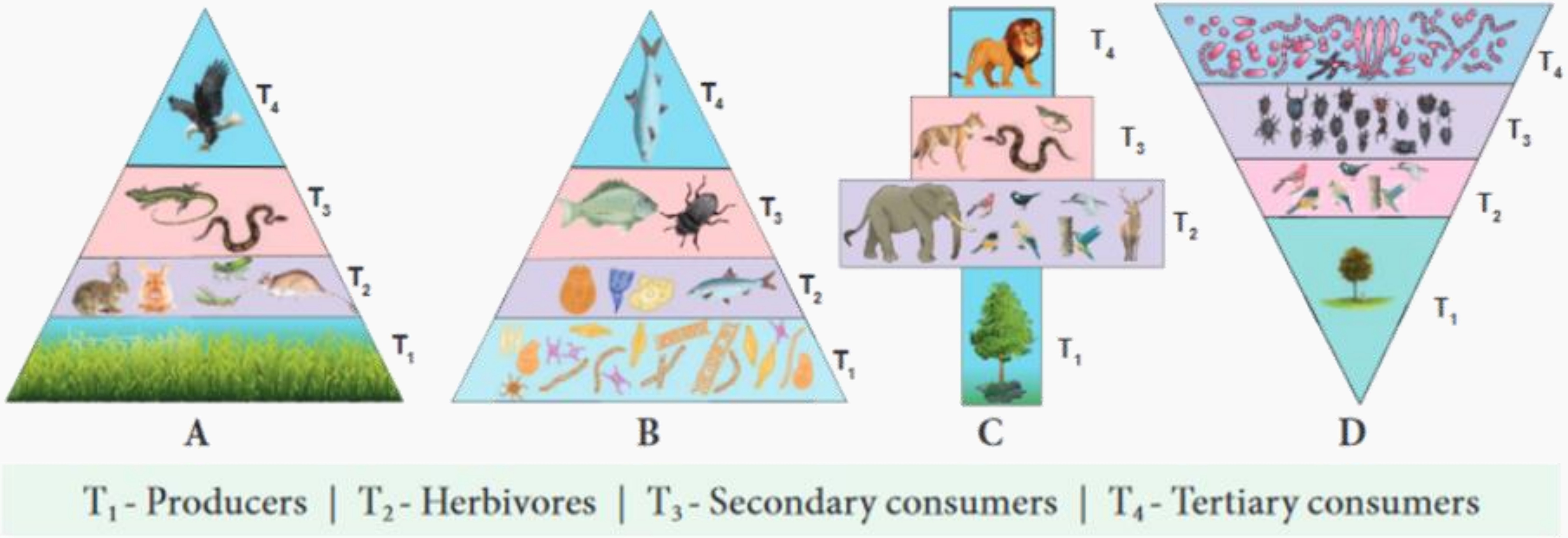
Ecological pyramid models

- A pyramid is used to illustrate the structure of the trophic levels in a food chain.
- Introduced by Charles Elton (1927).
- Types of ecological pyramids:
  - Pyramid of numbers
  - Biomass pyramid
  - Energy pyramid



Pyramid of numbers

- Compares the number of organisms at each trophic level in a food chain.
- Typically in an upright shape, but can be also inverted and spindled.



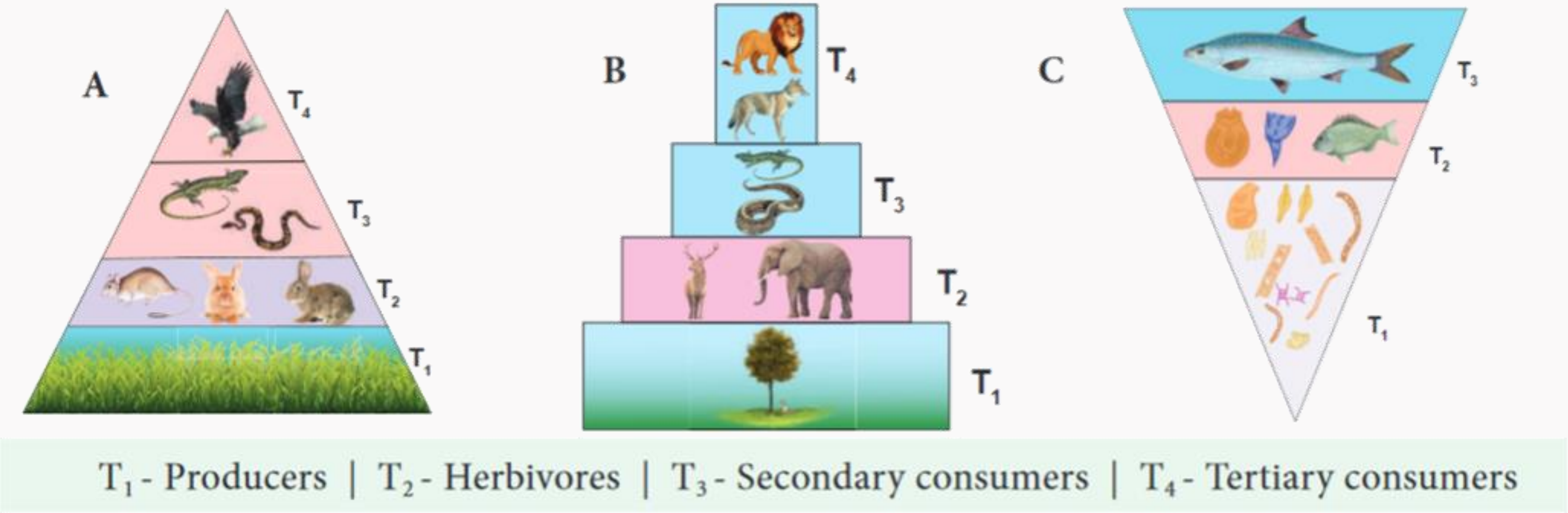
Pyramids of numbers (individuals per unit area) in different types of ecosystems.

Upright:
(A) Grassland ecosystem,
(B) Pond ecosystem;
Spindle shaped:
(C) Forest ecosystem;
Inverted:
(D) Parasite ecosystem.

[Figure 7.8], Biology-Botamy, 1st ed., 2019, Tamilnadu Samacheer Kalvi Books. Used under a Fair Use rationale.

Biomass pyramid

- Compares the the amount of organic material (biomass) present at each successive trophic level in an ecosystem.
- Can be upright or inverted in shape.



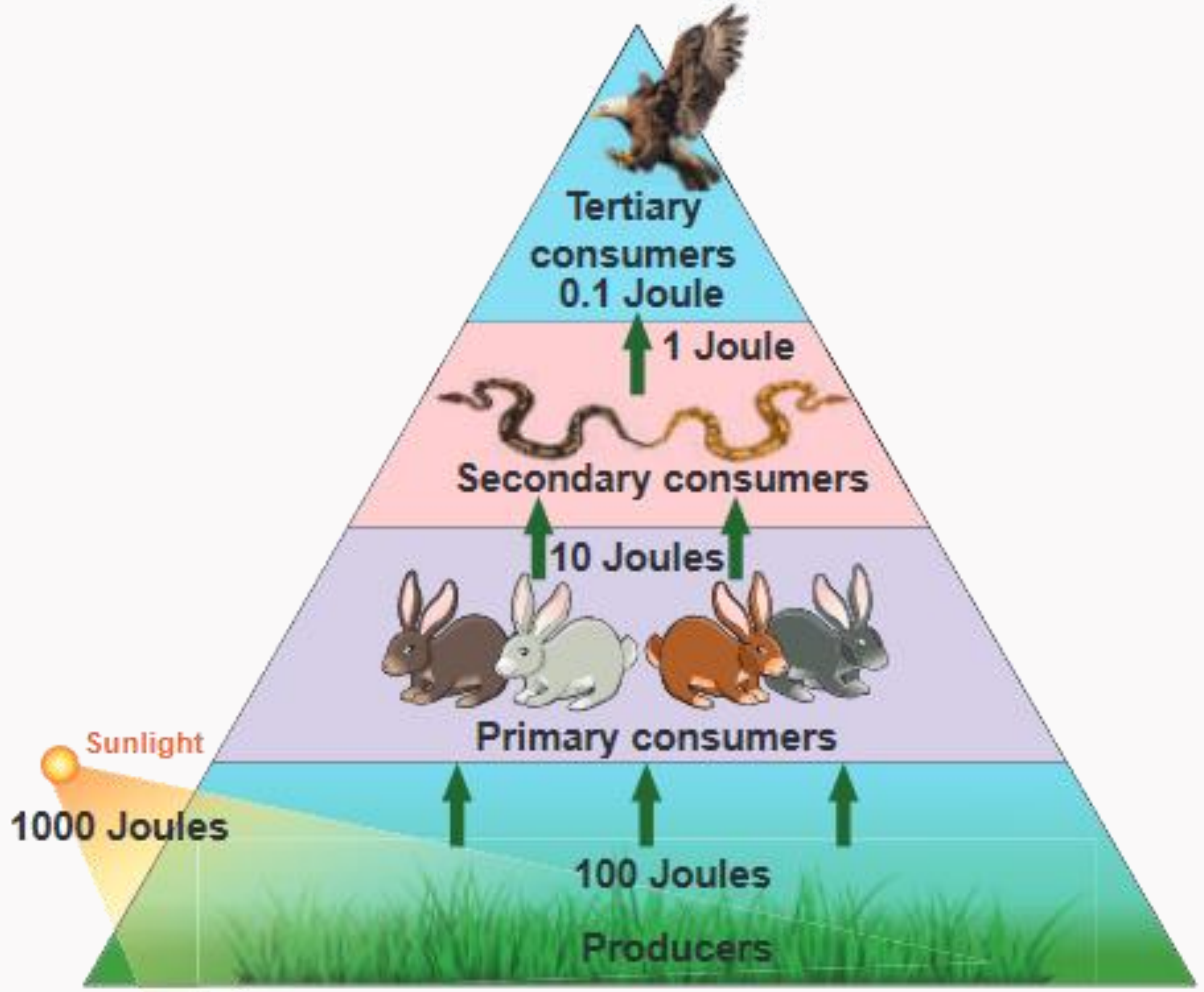
Pyramids of biomass (dry weight per unit area) in different types of ecosystems.

Upright:
(A) Grassland ecosystem,
(B) Forest ecosystem;
Inverted:
(C) Pond ecosystem.

[Figure 7.9], Biology-Botany, 1st ed., 2019, Tamilnadu Samacheer Kalvi Books. Used under a Fair Use rationale.

Energy pyramid

- Energy flow at each successive trophic level in an ecosystem.
- Typically upright pyramid shaped, with the largest number of organisms at the producer level.
    - Competitive relationships can reduce productivity at top levels.

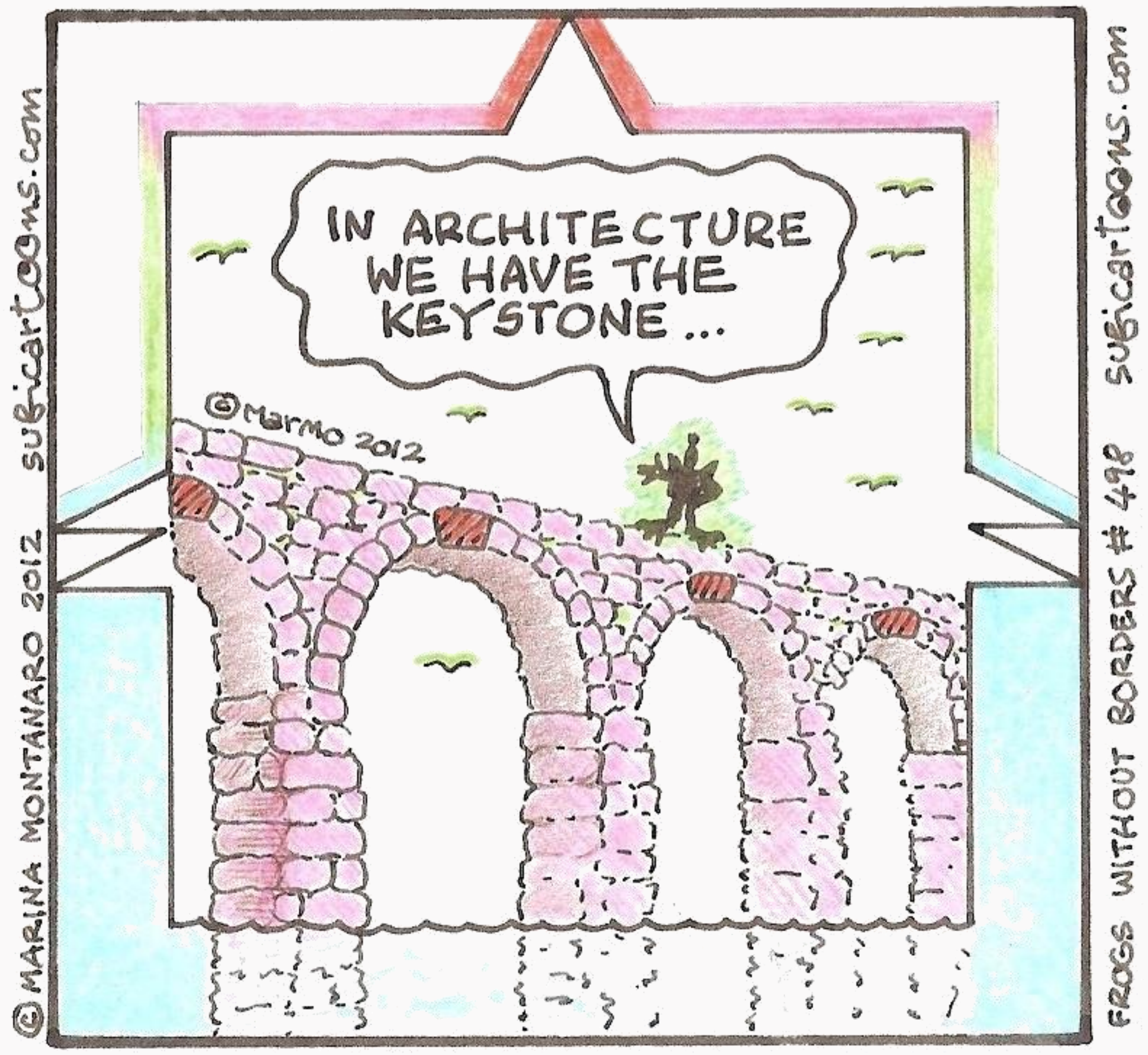


Pyramids of energy (Kcal/unit area/unit time) in any ecosystem.

[Figure 7.10], Biology-Botamy, 1st ed., 2019, Tamilnadu Samacheer Kalvi Books. Used under a Fair Use rationale.

Keystone species

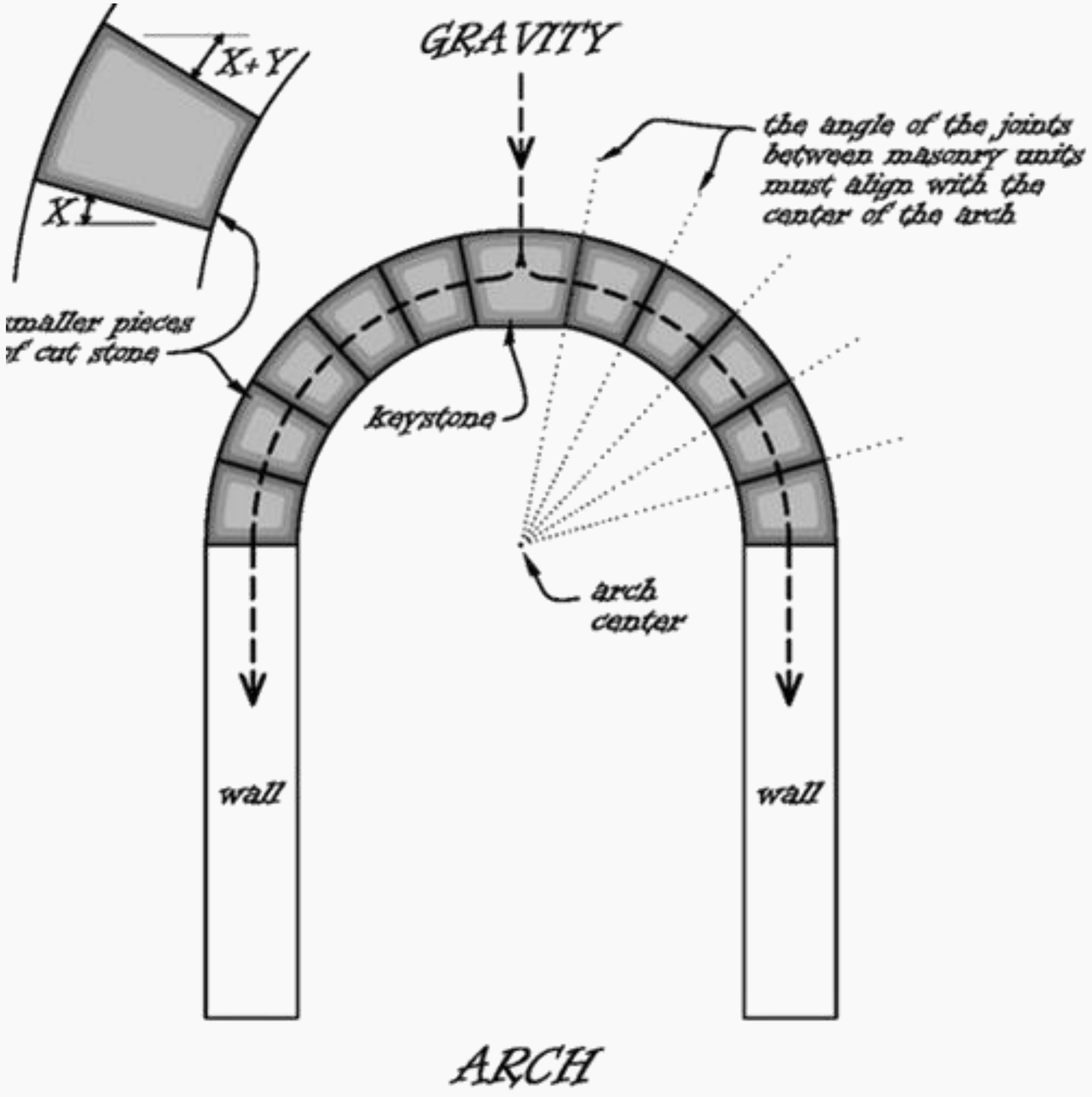
- A species whose removal would produce a significant effect in the ecosystem.
  - Extinction/large change in density in other species.
- Predators often function as keystone species within communities.



Marina Montanaro, Fair Use.

Ed Bowlby, via Wikipedia, Public Domain


“Keystone”



[Arch], George Lafferty, used under a Fair Use rationale.

Keystone predation

- Predation can influence the outcome of competitive interactions between prey species.
- Indirect predation interaction (influenced by a third species).

The purple sea star *Pisaster ochraceus*

D. Gordon/E. Robertson, via Wikimedia Commons, CC BY-SA 3.0

Pisaster surround a patch of Mytilus californianus

Dave Cowles, via Walla Walla University, Fair Use.

Keystone predation, with the purple seas stars as the predator, controlling population of their prey.

Pisaster eating a mussel

Mbz1 (assumed), via Wikimedia Commons, CC BY-SA 3.0.

Predation by *Pisaster ochraceus*

- *P. ochraceus* was one of the first species recognized as a **keystone**.
- Predation by starfish reduced the abundance of mussel and opened up space for other species to colonize and persist.
- Removal of *Pisaster* causing a diversity decline in the experimental plot.
    - Mussels and barnacles crowded out many of the other species.


Gooseneck barnacles *Pollicipes polymerus*
Serenrednib, via Wikimedia Commons, CC BY-SA 4.0.


Acorn barnacles *Balanus glandula*
brewbooks from near Seattle, USA, via Wikimedia Commons, CC BY-SA 2.0.


California mussels *Mytilus californianus*
Sharon Mollerus, via Wikimedia Commons, CC BY 2.0.


Purple sea stars *Pisaster ochraceus*
Keystone Species Sampler, Fair Use.

Paine's experiment: the loss of a top predator collapsed the entire community

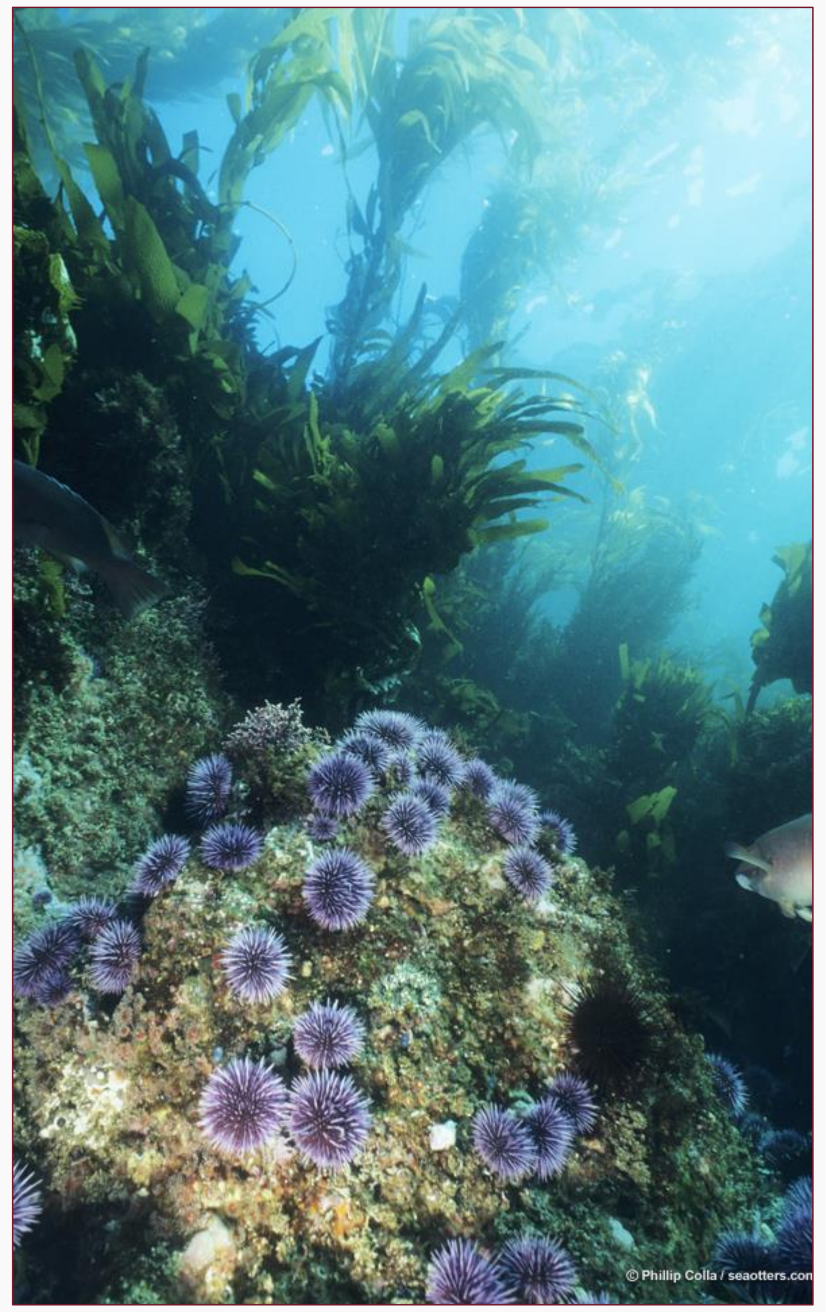
Paine's experiment on keystone predation by *Pisaster ochraceus:* The initial community had 16 species. One year after removing the star fish, the community was down to just eight. After 5 years, only 1 species of mussel remained, taking over the ecosystem.

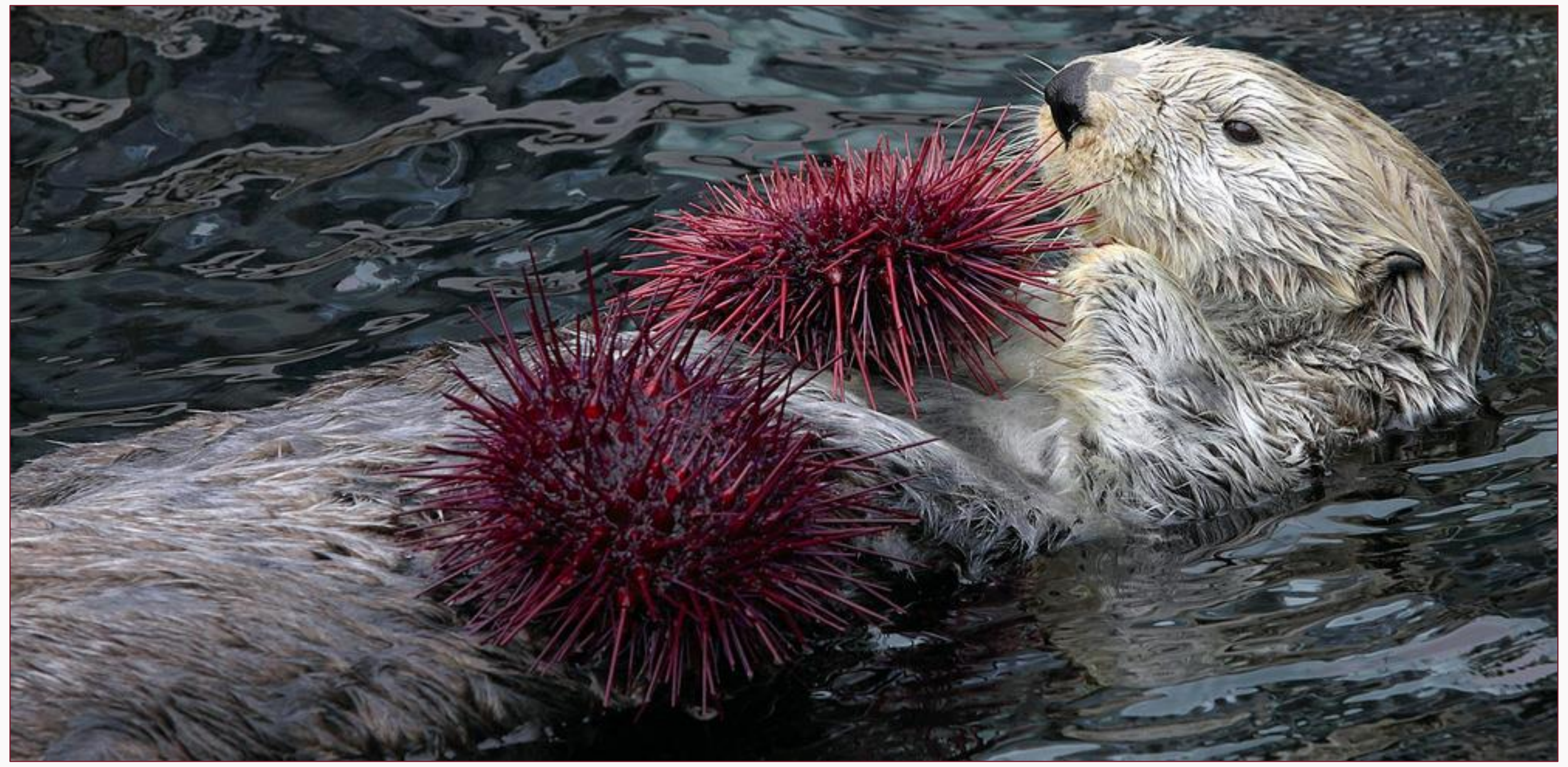
[Purple sea star removal experiment], Keystone Species Sampler, https://media.hhmi.org/biointeractive/click/keystone/sea-star.html, used under a Fair Use rationale.

Keystone species: Otters in kelp forests

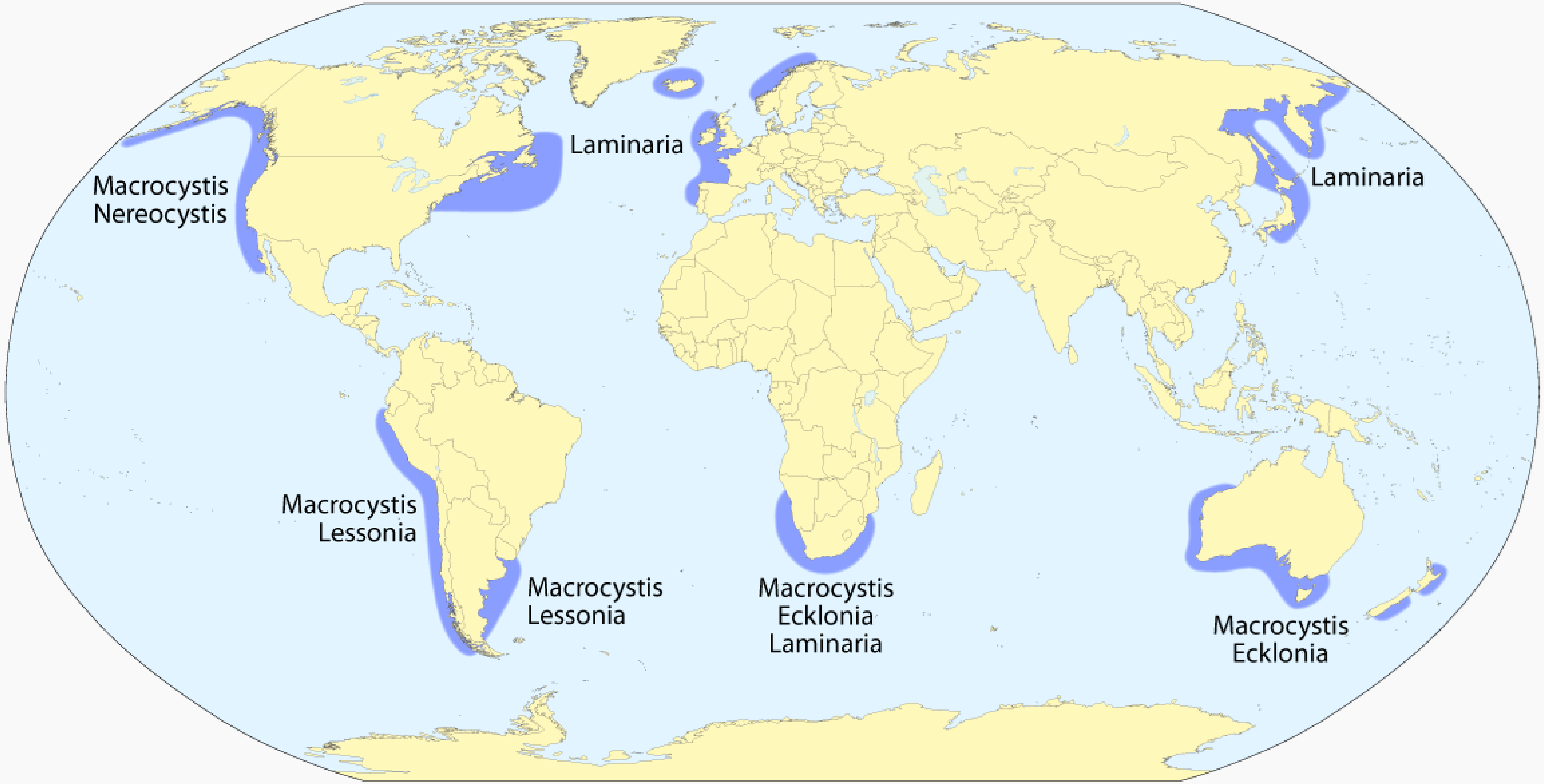
- Kelp forests functions:
  - To provide important nursery areas for juvenile fish.
  - Positively influence (directly or indirectly) the abundance of larger fish & predatory species.
- Most important herbivores: the sea urchins (kelp grazers).
- Sea urchins are otter's favorite prey.
- Their predation allows kelp forest to proliferate.


Kip Evans, via Wikimedia Commons, Public Domain


Phillip Colla, www.seaotters.com, Fair Use.


Neil Fisher, www.climate.gov, Fair Use.

Kelp forests global distribution



The destruction of kelp forests

Sea otters feed on sea urchins, reducing urchin populations

Low sea urchins populations allow for high biomass of kelp

Ideal state of the food web

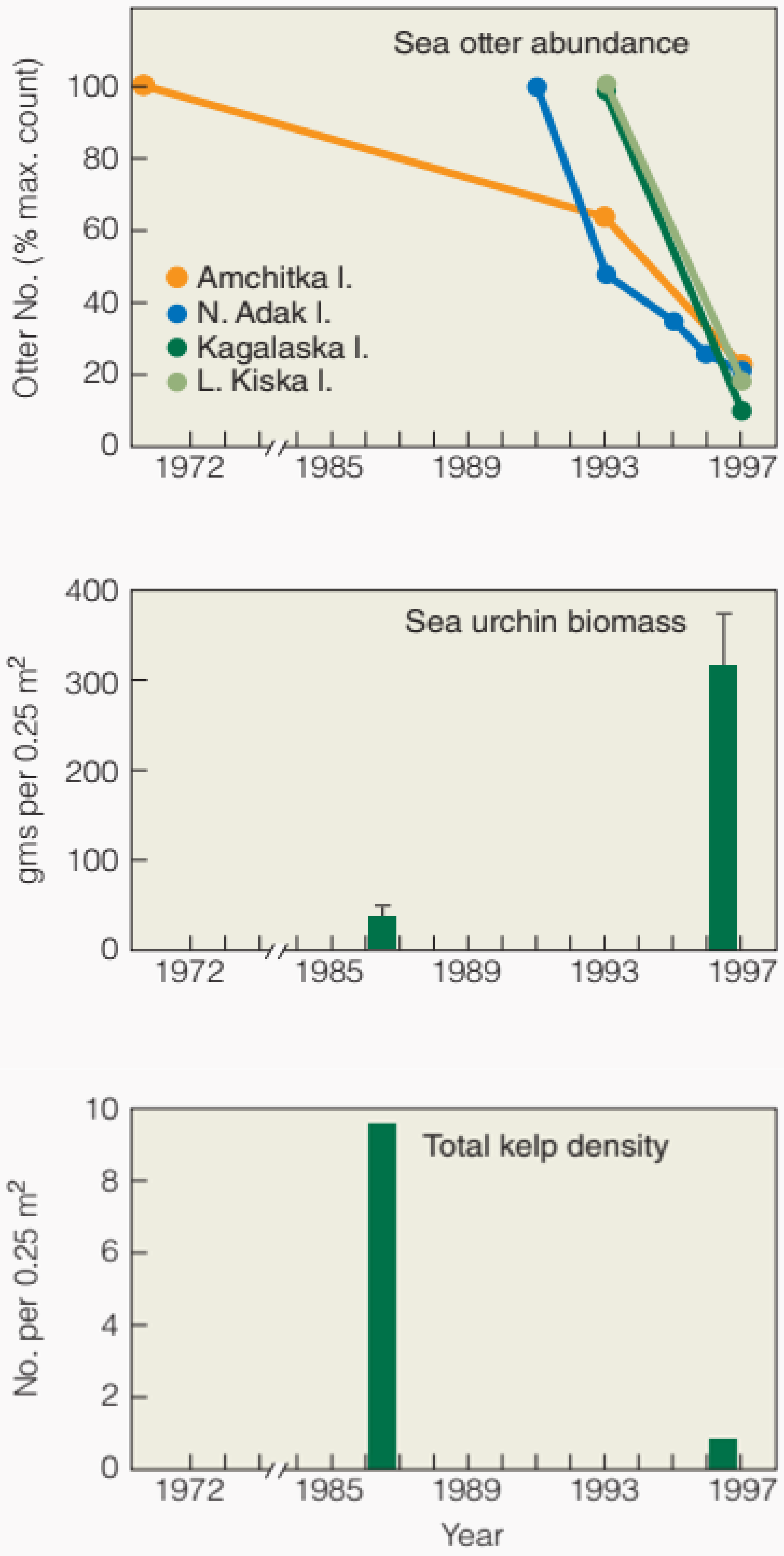
Sea otter function as a keystone predator species in the coastal kelp communities of the North Pacific.

Disturbed state of the food web

Increased predation of otter by killer whales in the 1990s.

Sea otter abundance declined in the Aleutian

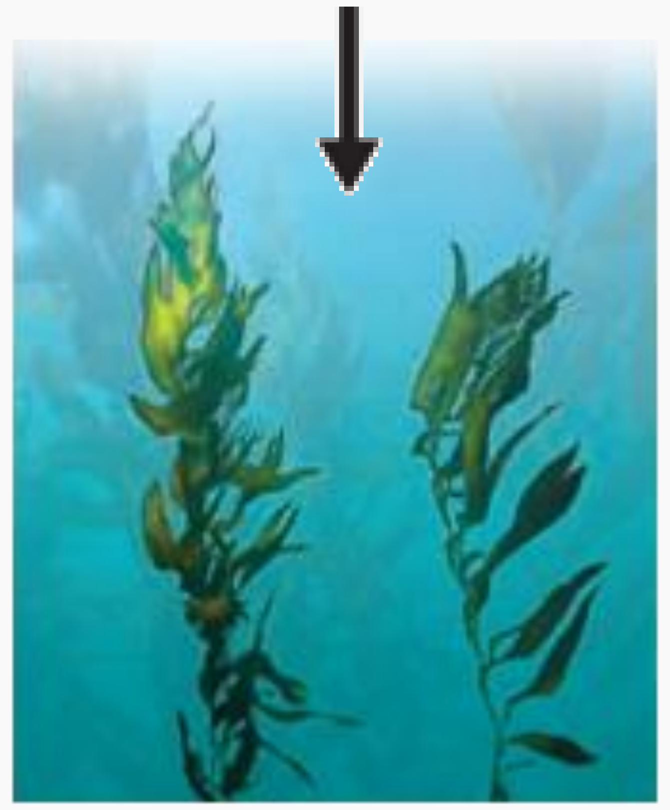
[Figure 16.6, with modifications], Smith TM & Smith RL, 2015, Elements of Ecology, 9th ed., Pearson Education Ltd. Used under a Fair Use rationale.



Killer whales prey on sea otters, reducing populations

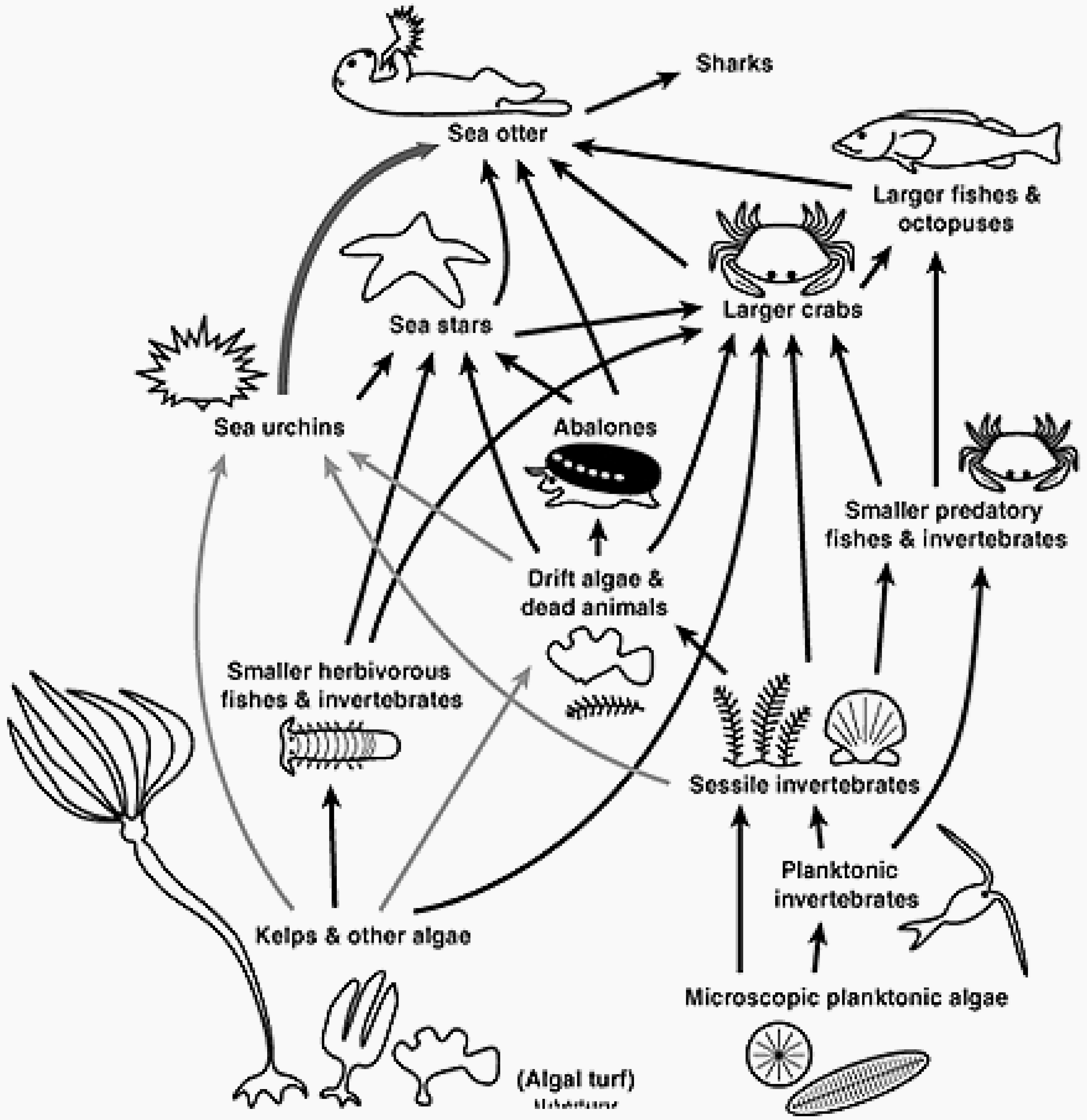
Reduced sea otter populations result in increase in sea urchin populations

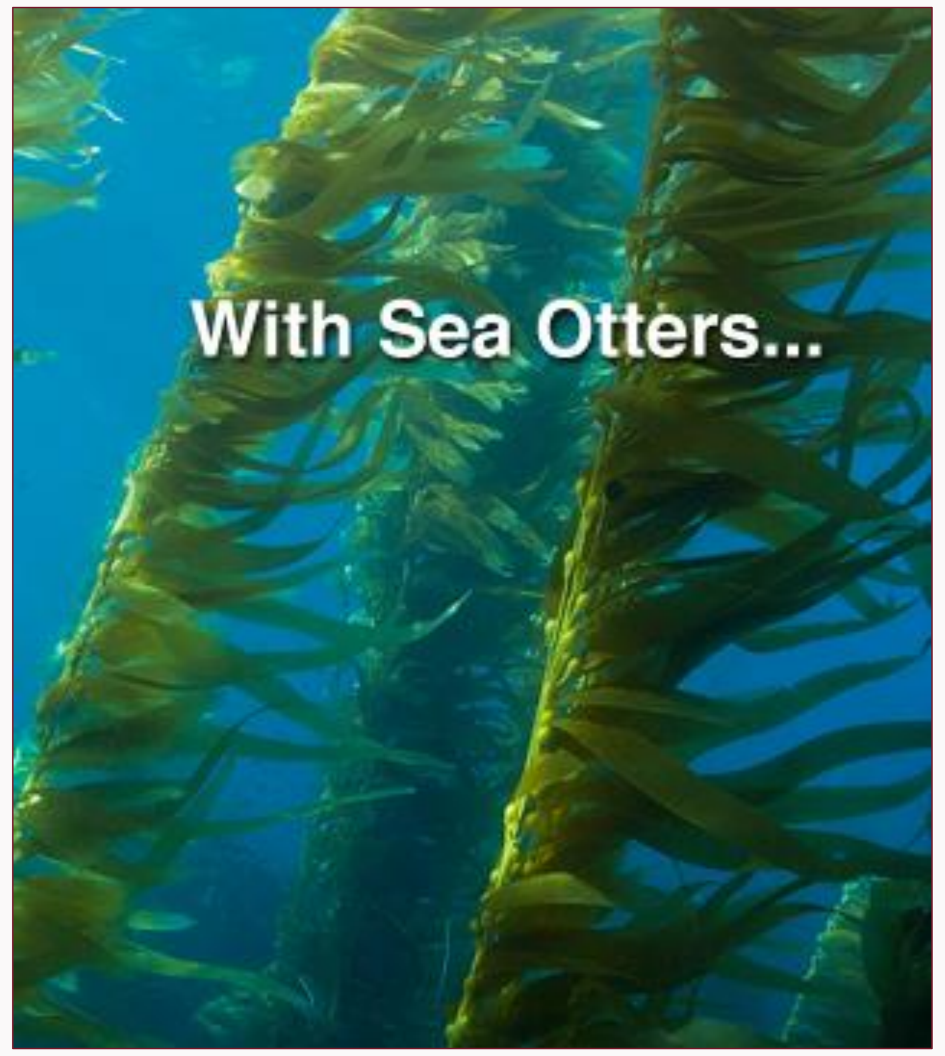
Increased sea urchin populations reduce biomass of kelp on which they feed

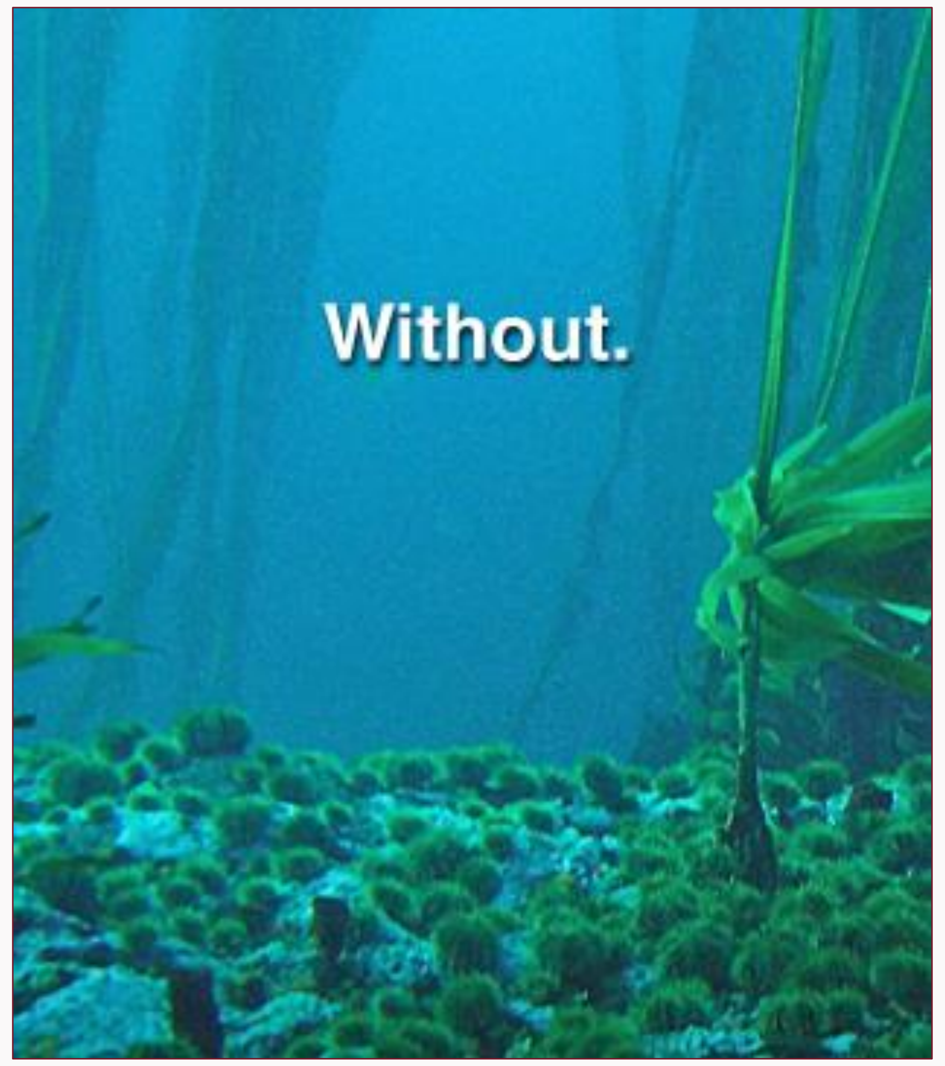


Sea otters in the kelp forest food web

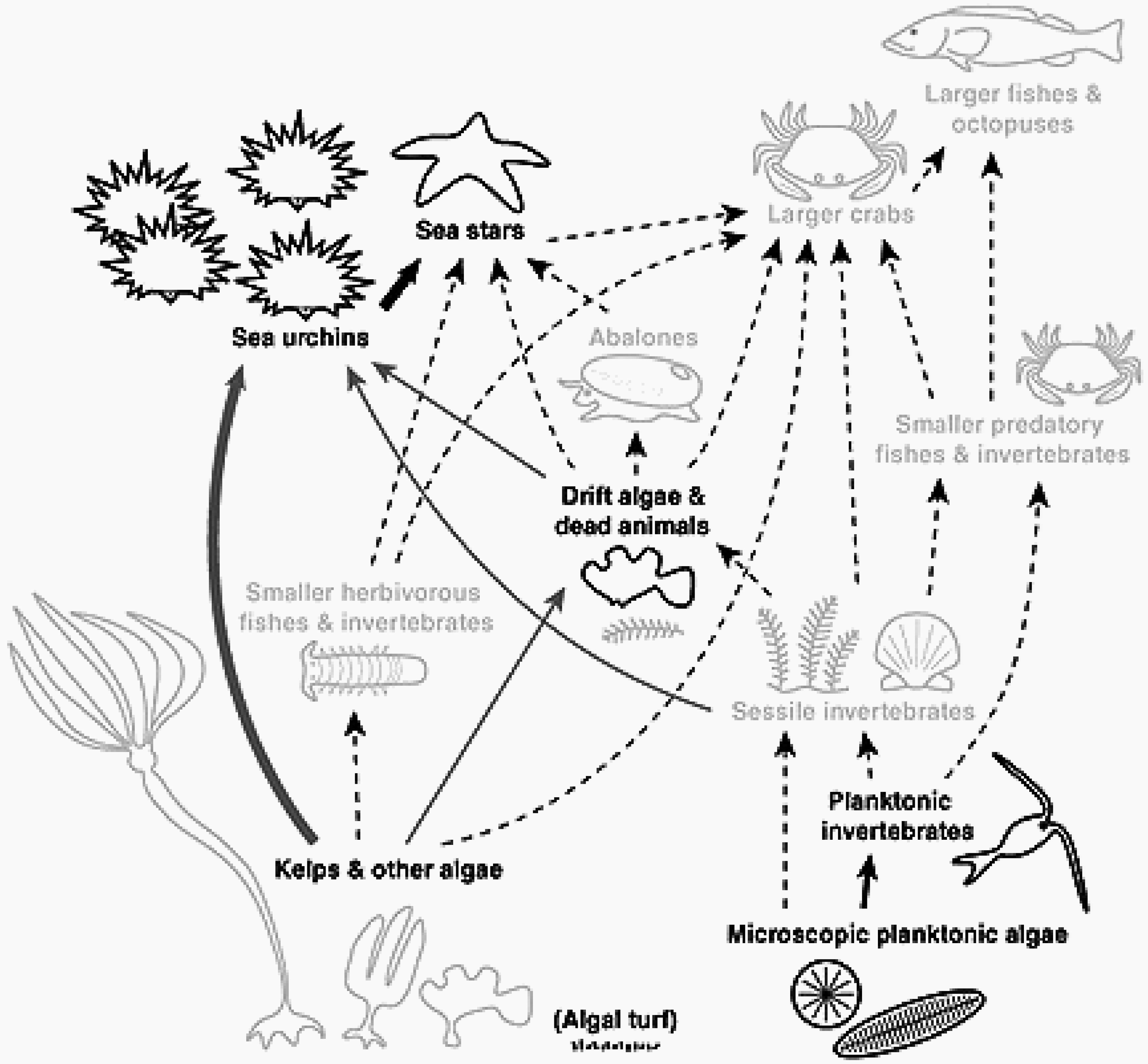
A. With sea otters, kelp forest food web





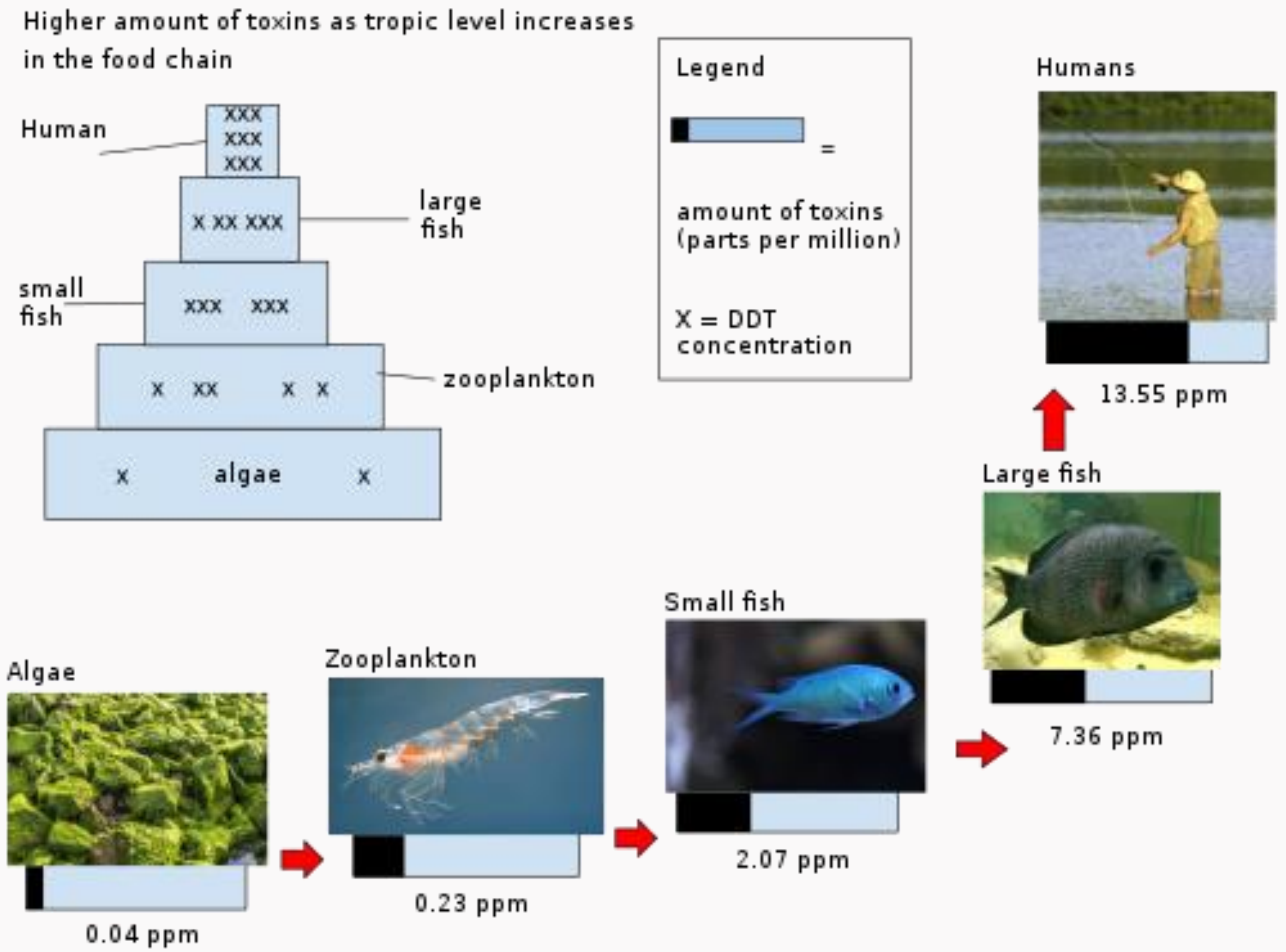


B. Without sea otters, urchin barren food web



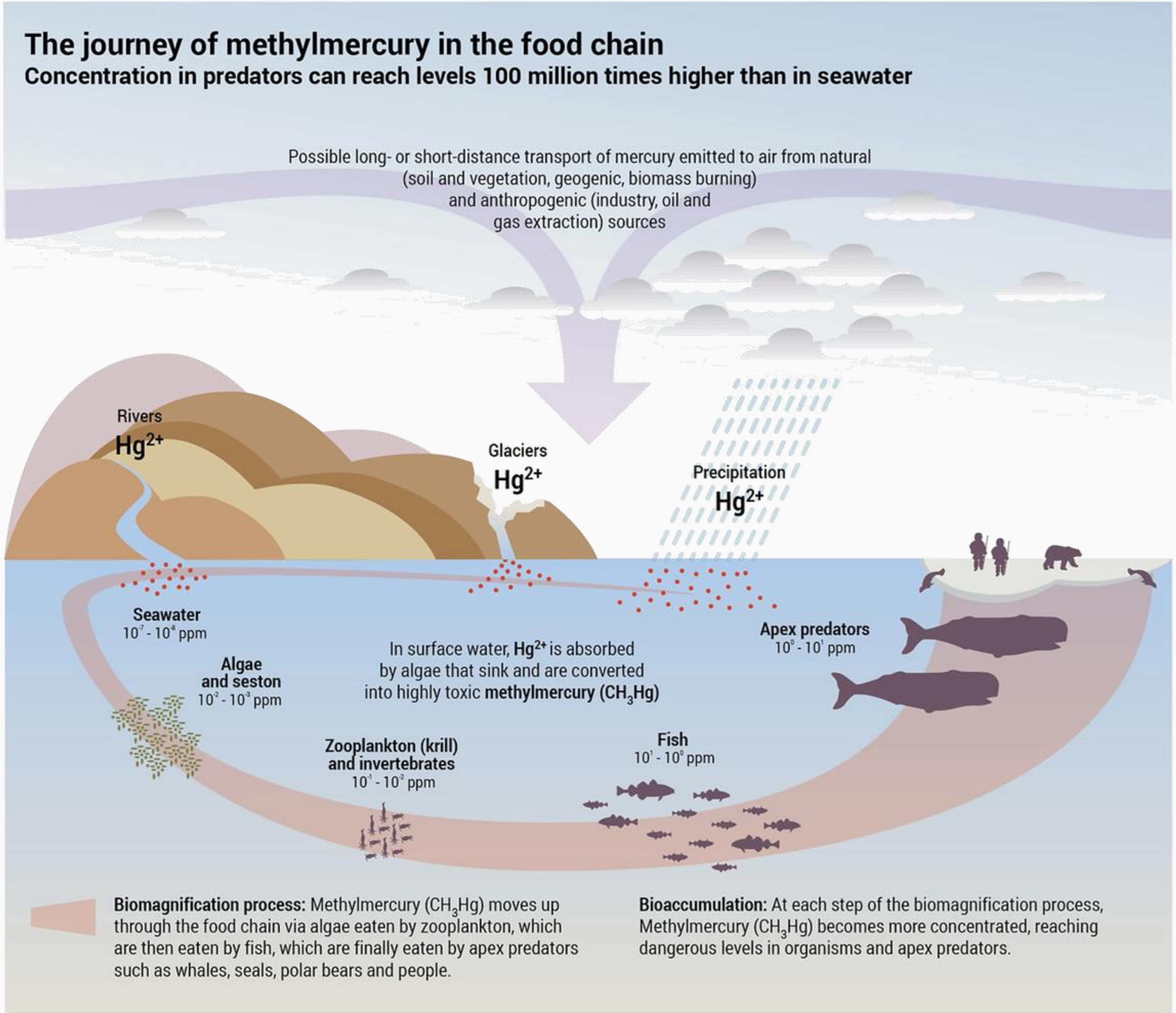
Biomagnification: consequences of food webs

- The increasing concentration of persistent, toxic substances in organisms at each successive trophic level.
  - Fat soluble substances that are stored in the fat reserves of each organism.
- Biomagnifiable substances e.g.: DDT, PCB, heavy metals.



Biomagnification of methylmercury

- A very poisonous form of mercury.
- Was used to preserve grain fed to animals.
- Examples:
  - Minamata tragedy (Japan)
  - Basra poison grain disaster (Iran).



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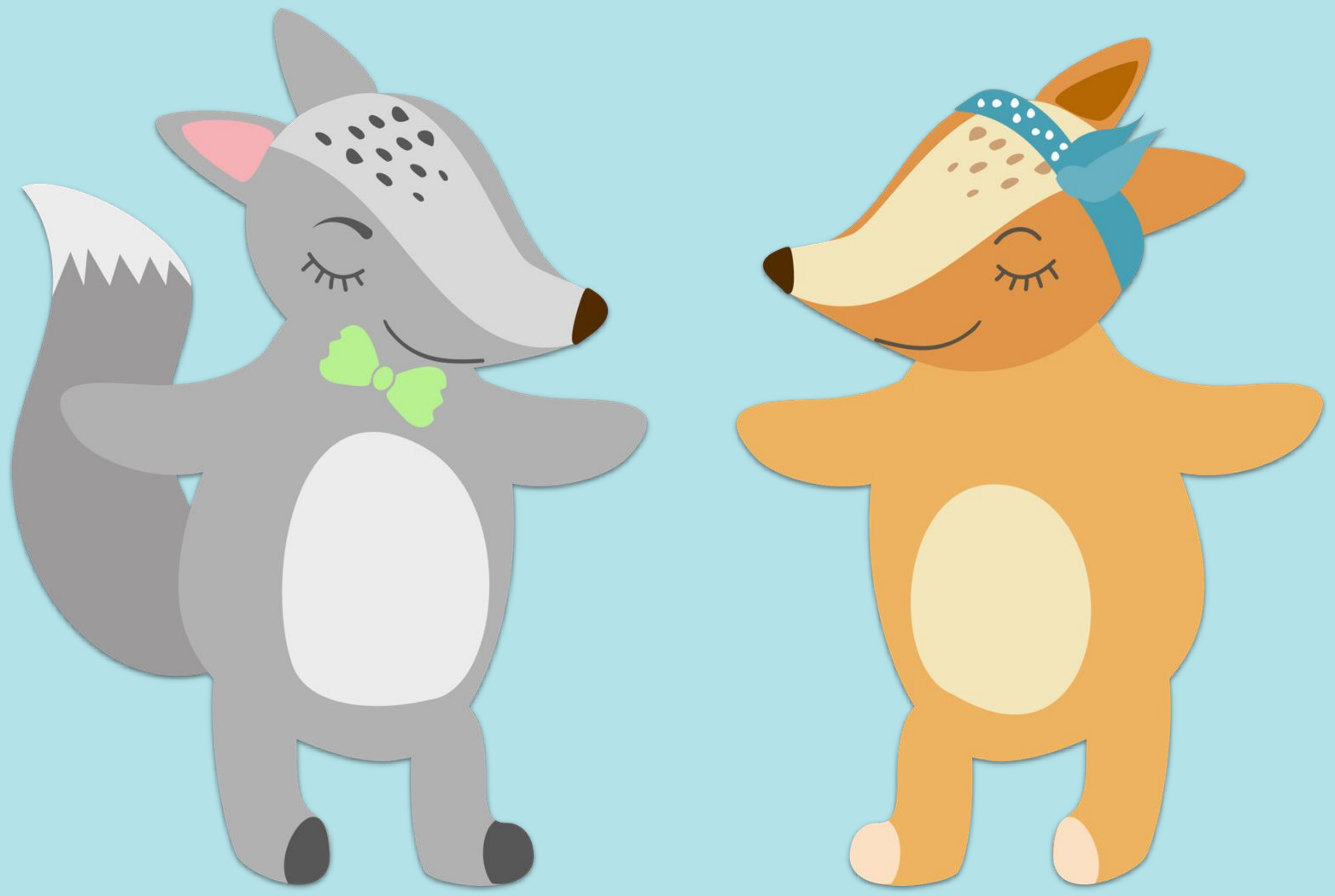

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