Week 9 Notes

Dylan Ang

May 2021

Contents

1 Biogeochemistry

1.1 Carbon

1.1.1 The Global Carbon Cycle

The Global Carbon Cycle: Figure 1

- Boxes represent carbon pools
  - A carbon pool is a specific area in the ecosystem where carbon can exist.
  - Pools with a higher number store more carbon mass, the largest being Rock Components and Fossil Fuels. However, there are no arrows coming off of these, so the largest pool that is active is Ocean Waters.
- Arrows represent Fluxes.
  - Fluxes represent processes that cause movement of carbon from one pool to another.
  - Fluxes with a higher number transfer more carbon mass. The largest being photosynthesis.

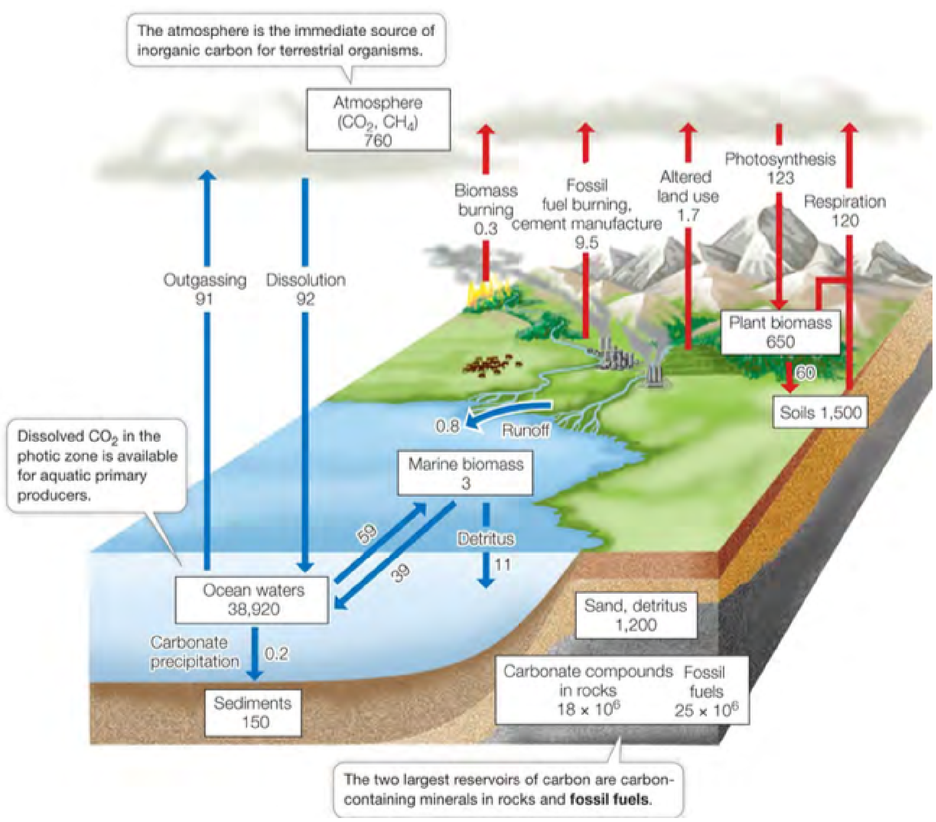


Figure 1: The Global Carbon Cycle

1.1.2 Atmospheric CO_2 Levels

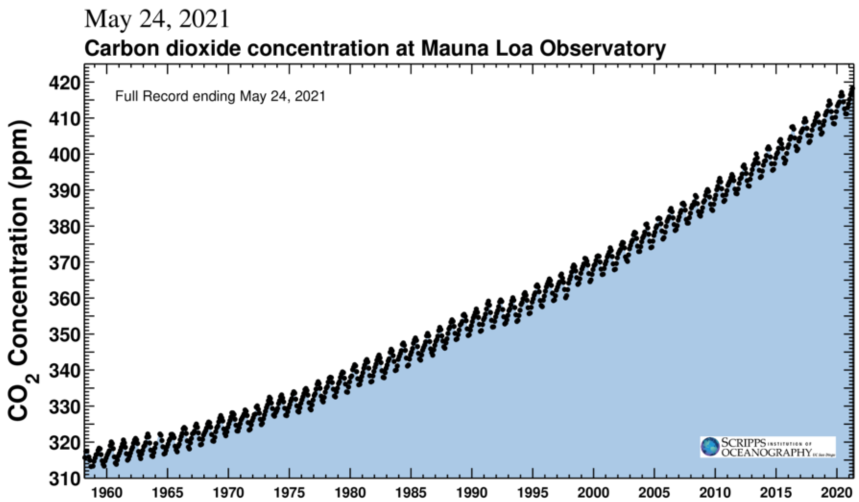


Figure 2: The Keeling Curve

Questions: in Figure 2

- What process drives the overall increase in CO_2 levels?
  - Anthropogenic greenhouse emissions: fossil fuels.
- What process drives the annual oscillation in CO_2 levels?
  - Global photosynthesis absorbs more CO_2 than Respiration creates when plants are growing, i.e., May to September.
  - Global photosynthesis absorbs less CO_2 than Respiration creates when plants are not growing.
- Highly seasonal, highly productive ecosystems like boreal forests will experience the most oscillation of CO_2 levels, because the carbon they absorb in Spring and Summer is not offset enough by the Southern hemisphere's Fall and Winter.
  - Global CO_2 level oscillations are mainly driven by the boreal forest.
  - Locations such as Mauna Loa or the South Pole will also see oscillations, although these are actually residual effects of the boreal forest.
  - Locations that are not highly seasonal or highly productive will not be able to contribute to global CO_2 level oscillations.

Ocean Acidification Example

- Higher Acidity (lower pH) and warming of ocean bleaches coral.
- Coral have an mutualistic relationship with zooxanthellae.
  - Coral get sugar from photosynthesis of zooxanthellae.
  - Zooxanthellae gets place to live, and nutrients from coral.
  - Also obligate relationship for coral. Coral can not survive without the relationship.
- Higher acidity or warming of the ocean acts as a stressor, killing zooxanthellae.
- Without the presence of zooxanthellae, the coral will lose its color (Coral Bleaching) and eventually die if prolonged. If conditions improve after bleaching but before death, the coral can recover by recruiting new zooxanthellae.

1.2 Water and Nitrogen

1.2.1 The Global Hydrological Cycle

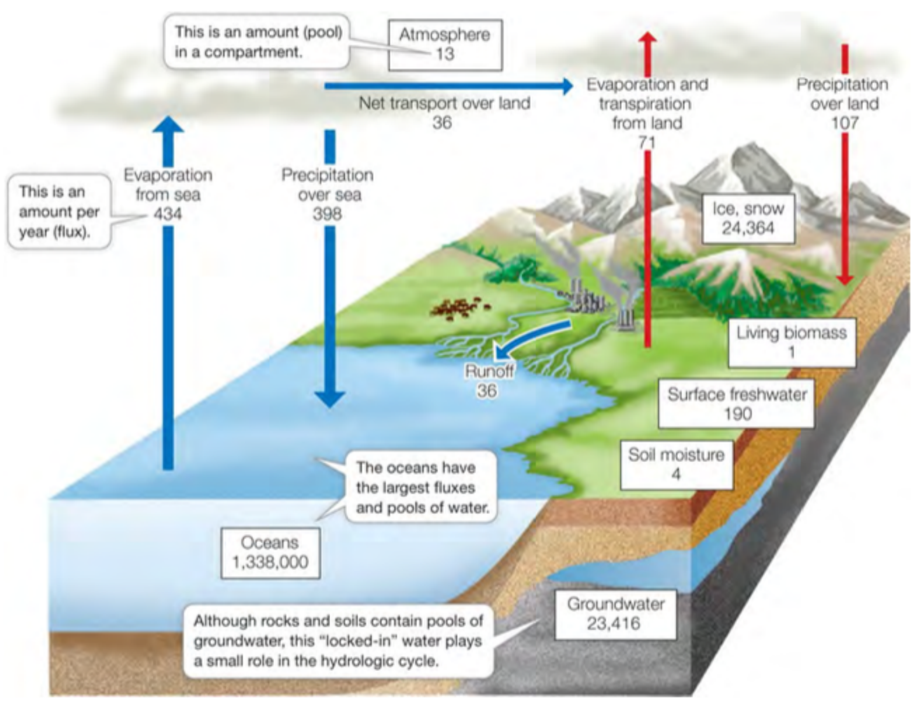


Figure 3: The Global Hydrological Cycle

The Global Hydrological Cycle: Figure 3

- Fluxes are processes by which water moves from one pool to another.
  - Evaporation
  - Transpiration
  - Rain
- Pools are locations that store water.
  - Oceans
  - Lakes
  - Groundwater
- Largest
  - Flux: Evaporation from oceans
  - Pool: Oceans
- Anthropogenic Fluxes
  - Groundwater does not naturally connect to the rest of the hydrological cycle.
  - Humans can, through irrigation and aquifers, access groundwater and thus connect it to the cycle.

The Global Nitrogen Cycle: Figure 4

- Largest
  - Flux: Denitrification - gaseous loss of nitrogen from the soil converting into N_2 gas in the atmosphere.
  - Pool: Atmospheric N_2
- Anthropogenic fluxes
  - Agricultural/Industrial Nitrogen fixation
  - Fossil fuels, biomass burning, livestock

1.3 Linking Cycles

1.3.1 Runoff

- Runoff as a flux: being dissolved in water adds that compound to the water cycle, helping to move it around. All 3 cycles experience runoff.
- Watersheds: Patterns of runoff across land.

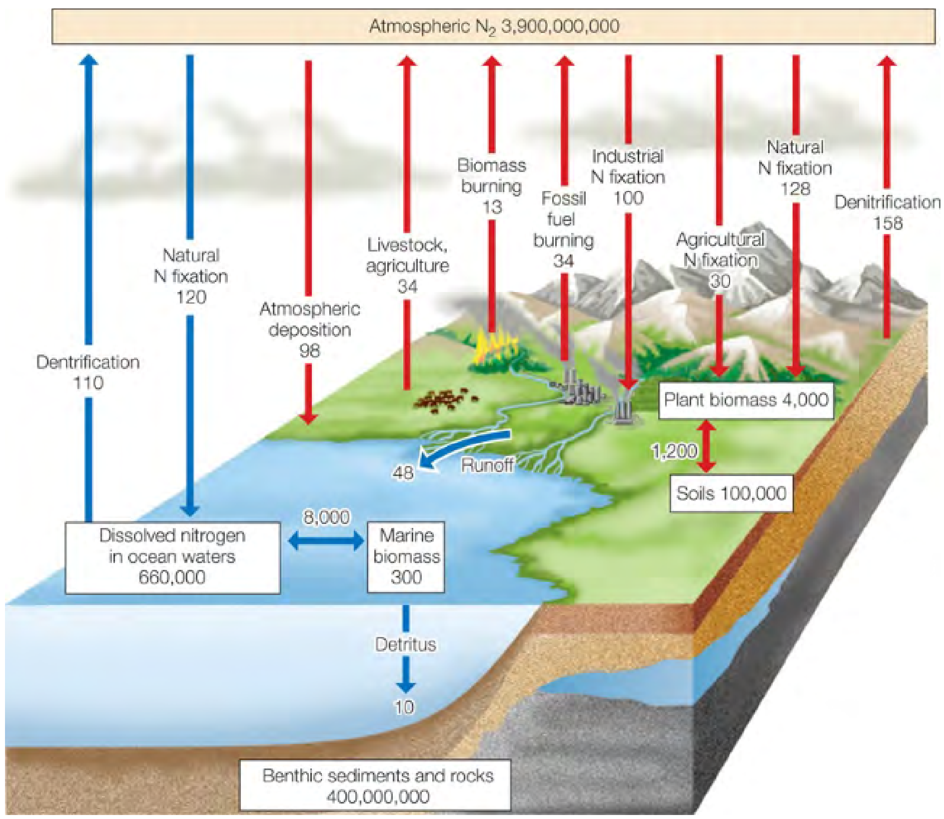


Figure 4: The Global Nitrogen Cycle

The gulf of Mexico Dead Zone

- Cause
  - Large portion of the Midwest is one watershed, runs off into the Gulf of Mexico.
  - Chemical runoff: Municipal waste (poo), fertilizer (also poo)
  - Nitrogen is often a limiting resource, so the nitrogen runoff from fertilizer and other poo causes an algal bloom.
  - When the algae die, the decomposition of their bodies uses all of the oxygen in the water column.
  - Low oxygen levels in water column along the coast of the Gulf of Mexico.
- Reducing the Dead Zone
  - Hurricanes/windstorms mix up water and infuse oxygen.
- Impacts of Dead Zone
  - Female fish in hypoxic locations have lower fecundity/smaller ovaries.
  - Male fish have smaller testes and lower sperm production.

1.3.2 How the Carbon cycle connects to the Nitrogen Cycle

- Photosynthesis takes CO_2 out of the atmosphere and turns it into sugars.
- *Rubisco* is the protein that actually picks up the CO_2 from the atmosphere.
- *Rubisco* is made up of a lot of nitrogen.
- Plants require lots of nitrogen to capture CO_2.

2 Energy and Trophics

2.1 Ecosystem Energy

2.1.1 Terms

- Gross Primary Production = rate of photosynthesis
- Net Primary Production = GPP - rate of respiration
- Food chains are usually simplified, they are more linear.
- Food webs better represent reality. Each species may have multiple predators and prey.

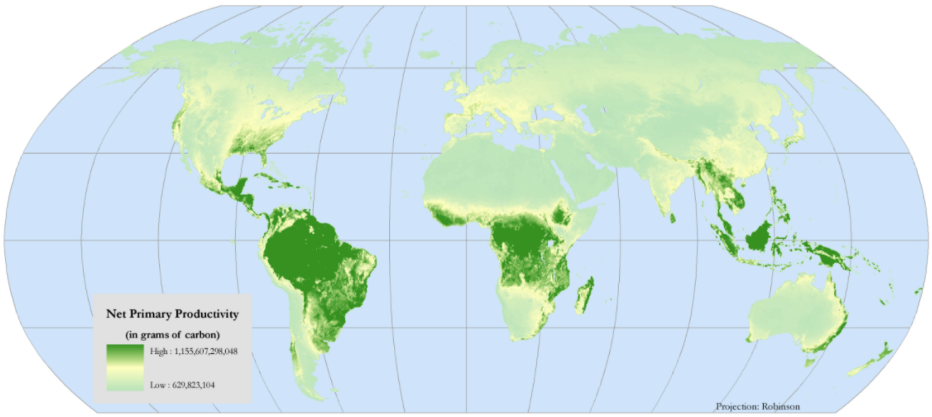


Figure 5: Global Net Primary Productivity

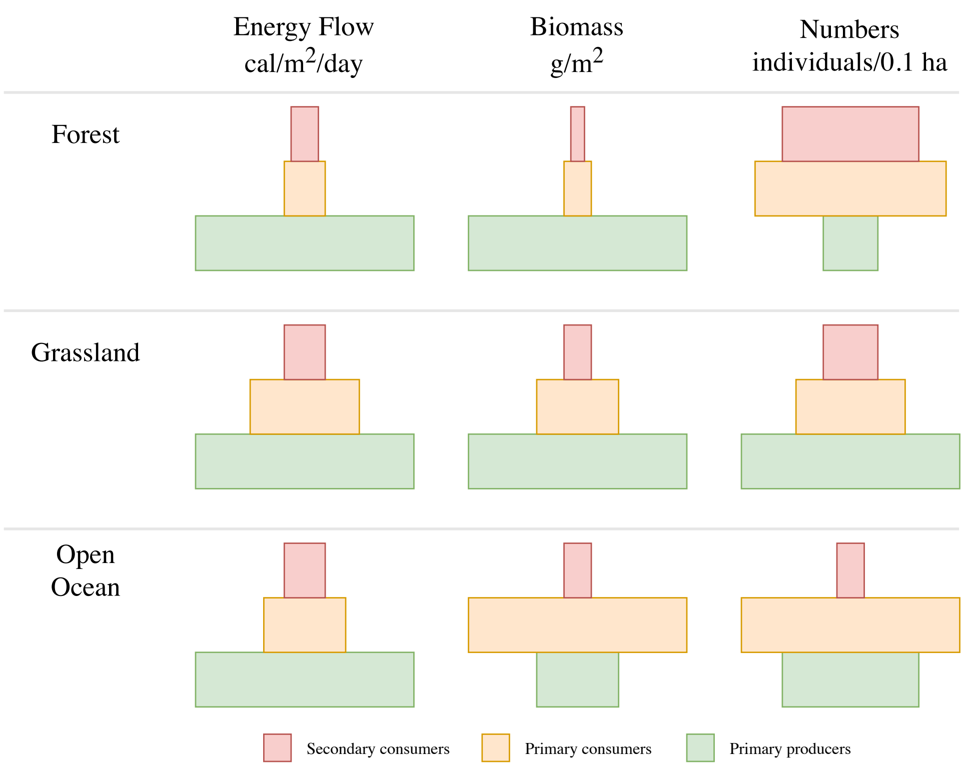


Figure 6: Trophic Pyramids

2.1.2 Trends in NPP maps: Figure 5

- Higher productivity in tropics. Generally speaking higher temperatures.
- Lower productivity in low temperatures and extremely hot temperatures (Sahara)

2.1.3 Trends in Trophic Pyramids: Figure 6

- Energy flow is always decreasing from primary producers upwards.
  - All energy in the system must come from the producers, and it can only be lost from there.
- Why is the biomass decrease more drastic in forests than in grasslands?
  - The primary consumers in forests are trees, and the primary consumers in grasslands are grass. Grass is edible by the secondary consumers, but trees are rarely eaten. The secondary consumers are likely only eating the leaves, not the wood (save for termites and decomposers). Therefore the energy that went to growing the wooden trunk and branches will not pass on to the next trophic level.
- Explain the difference in numbers between forests and grasslands.
  - One tree provides more food than one unit of grass. So, less tree individuals are required to support the primary consumers than grass individuals.
- How does the open ocean support more primary consumers than primary producers both in number and biomass?
  - The primary producers (mainly algal communities and phytoplankton) have high rates of reproduction. One individual producer can support multiple consumers just through reproducing quickly.

2.1.4 Energy Efficiency and Lindeman's Law

In Figure 7

- On average about 10% of energy available at one trophic level is transferred to the next trophic level.
- Most energy was lost when organisms died.

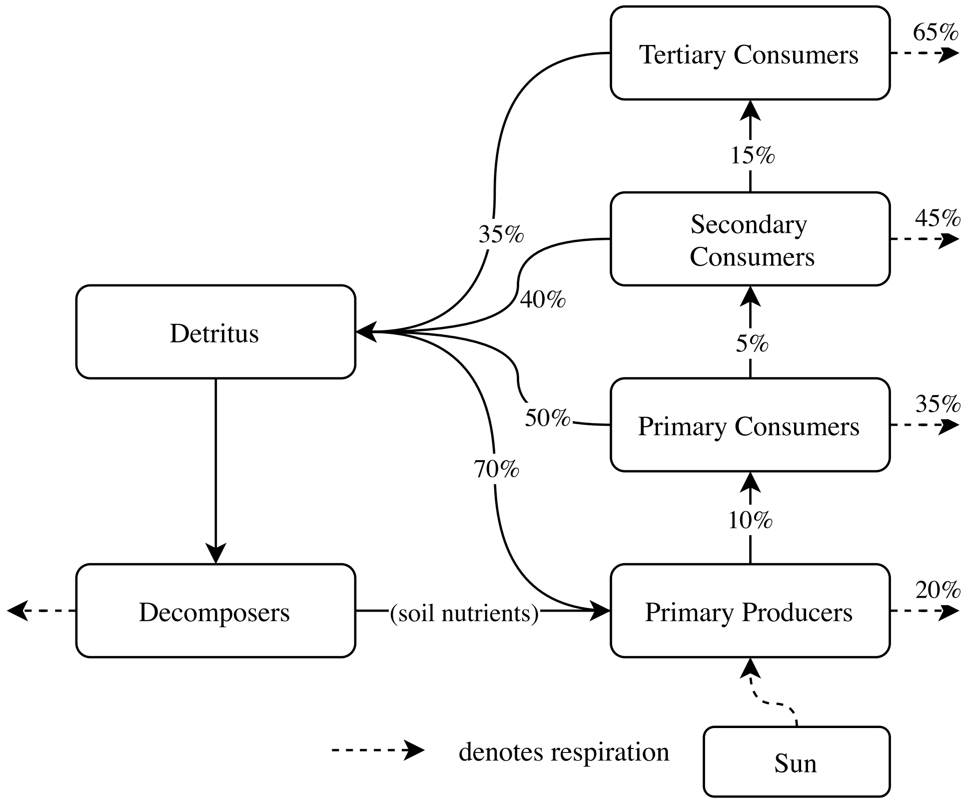


Figure 7: Lindeman

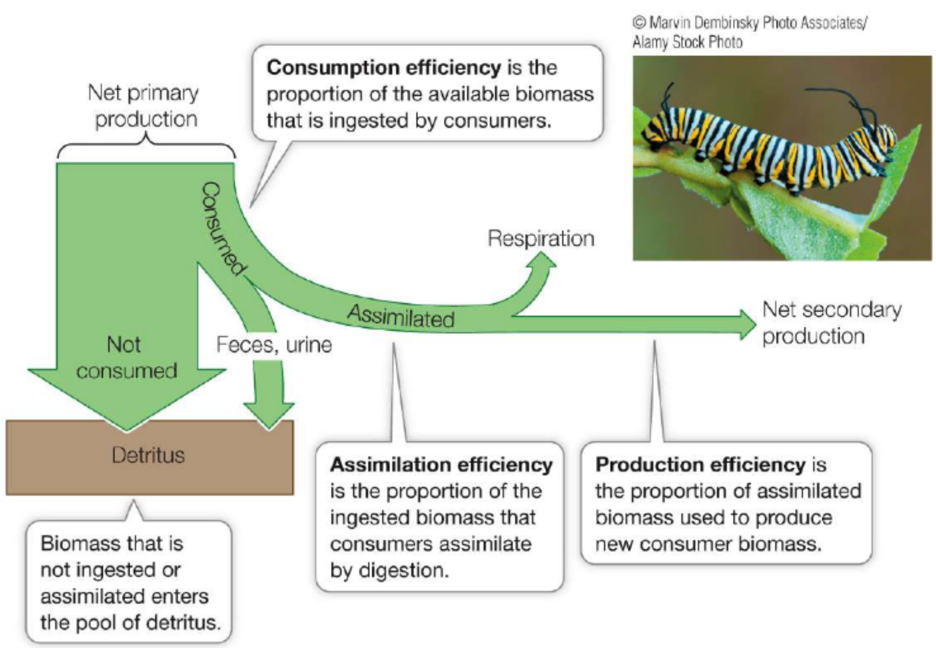
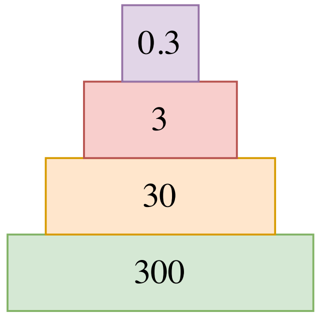


Figure 8: Efficiency within a trophic level

2.1.5 Efficiency Problems



Ecological efficiency of 10%

Primary production of 300 gC/m^2/day

Notice how primary production is the amount of energy at the lowest trophic level, and each successive level is 10% of its parent value.

2.1.6 Determinants of trophic level count

- The number of trophic levels in an ecosystem is limited by
  - Available energy (primary productivity)
  - Efficiency of energy transfer across trophic levels

2.2 Trophic Roles and Interactions

2.2.1 Important Role

- Keystone species
  - Species that is important for the structure of a given ecosystem. By definition they are not very common within the ecosystem.
- Foundation species
  - The most common species. They often physically provide a foundation upon which other organisms operate.
- Ecosystem engineer species
  - Alters the physical structure of the habitat to benefit itself and others.

2.2.2 Examples

Keystone Species

- Pisaster Starfish
  - Removal of Pisaster starfish dramatically reduced diversity.

  - The Pisaster starfish fed on multiple different species, keeping their populations in check.
  - Competition increased, top competitor won.

- Prairie Dogs
  - Prairie dogs serve as prey for higher trophic levels. They burrow holes that provide shelter for other animals, and disturb grazing patterns.
  - Removal of prairie dogs would have a drastic effect on many different species.

Foundation Species

- Corals
  - Coral reef provides habitat for many different species.
  - Without coral, all of the coral reef residing animals must find a new place to live.
- trees
  - The tree is a habitat for other organisms.

Ecosystem Engineers

- Beavers
  - Beavers chew down trees and build dams.
  - Alter the plant community and flow patterns downstream.
  - Beaver activity leads to higher diversity across the entire ecosystem.

2.2.3 Overlapping Roles

- A single species can not be both a keystone species as well as a foundation species.
  - This is because keystone species are by definition, rare and impactful. Whereas foundation species are by definition, frequent and impactful.

2.2.4 Top Down and Bottom Up Effects

Definition

- Top Down
  - Change begins in predator species and the effects trickle down to the trophic levels.
- Bottom Up
  - Change begins in lower trophic levels and the effects trickle up into higher trophic levels.

Examples

- Sea Otter: Top Down
  - Sea Otter populations decline ⇒ Sea Urchin populations increase ⇒ Kelp forest biomass declines.
- Algae: Bottom up
  - Nutrient rich water ⇒ Algal bloom ⇒ Less oxygen in water column as algae die ⇒ Fish have less oxygen and die out.

3 History of Life

3.1 Types of Major Events

Major Geophysical Events	Major Biological Events
Tectonics	Origin of Life
Changes in Earth's magnetic field	Evolution of photosynthesis
Atmospheric change	Evolution of eukaryotes and multicellularity
Changes in Earth's orbit	The Cambrian Explosion
Climate change	Colonizing land
Sea level change	Mass Extinctions
Asteroid impacts	Major radiations
	Evolution and migration of humans

3.2 Earth's History in One Giant Graph

In Figure 9 The bottom right of the graph represents the beginning of Earth. Chronology is bottom to top, right to left.

3.3 Origins of Life to the Cambrian Explosion

1. **Origin of Life (3.8 bya)** Precambrian/Archean/Eoarchean
   - It is believed that life originated 3.8 billion years ago.
   - Thought to be single celled organisms, bacteria
   - Lived at the bottom of the ocean in hydrothermal vents, which are places on the ocean floor where super hot, toxic water shoots out at high speed.
   - These vents are caused by magma near the surface of the ground which boils the water. This water is carrying toxic compounds, metals.
   - *Chemoautotrophs* in this region use metal compounds and energy from the vents to produce food. They do not rely on sunlight.

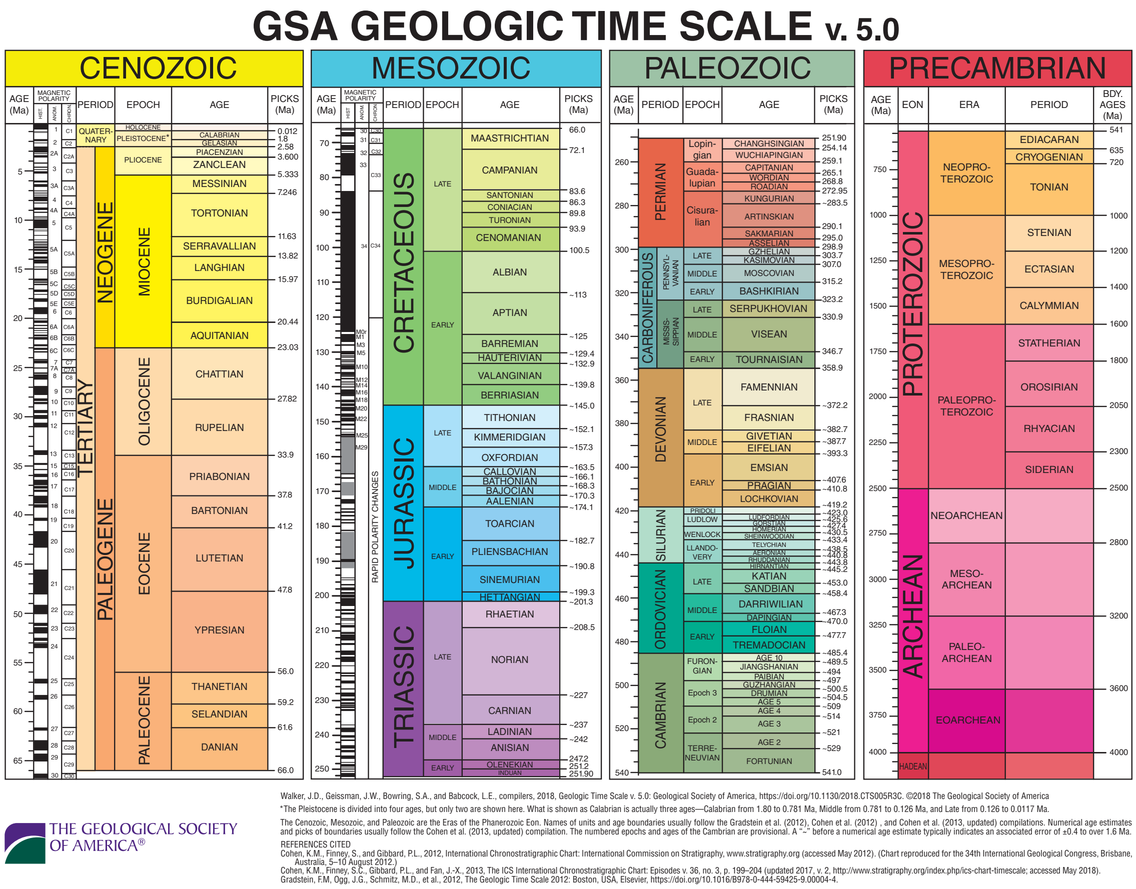
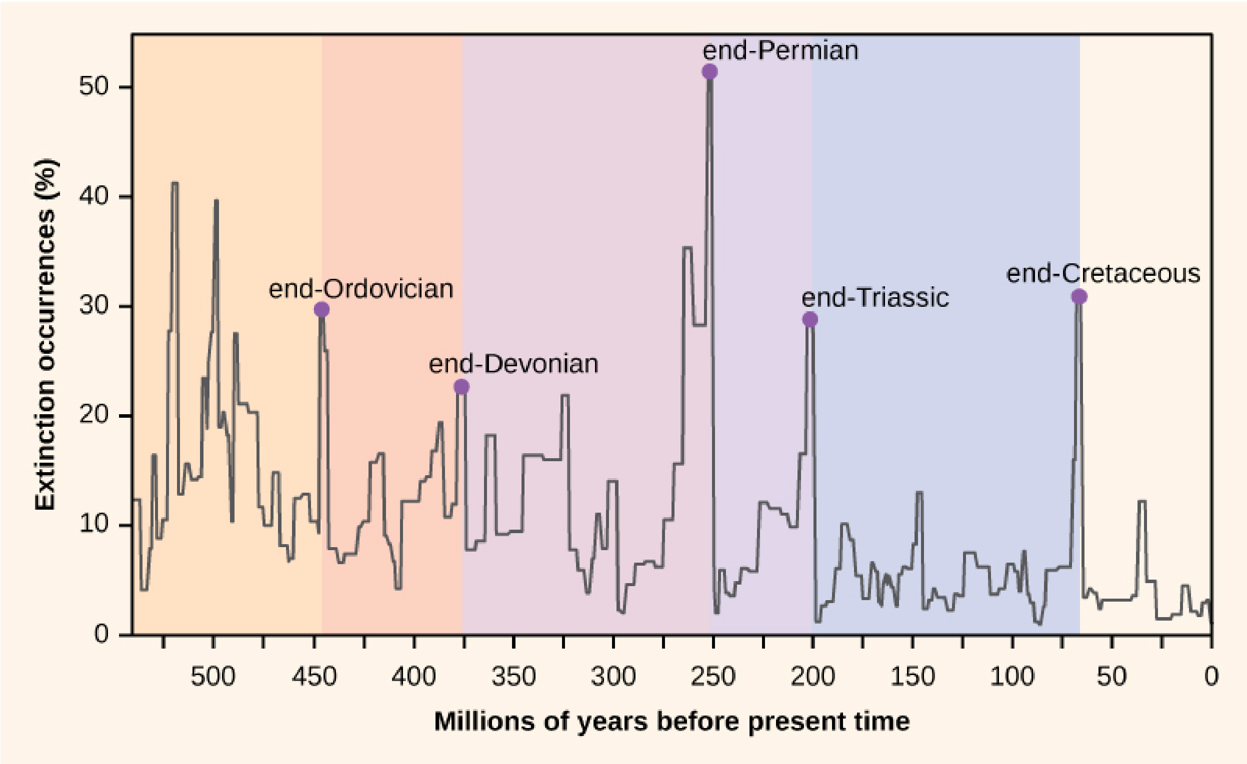


Figure 9: Geological Time Scale

2. **Photosynthesis (2.5 bya)** Precambrian, between Neoarchean and Paloproterozoic
   - Emergence of C_3 photosynthesis
   - First fossil evidence of life (cyanobacteria).
   - Production of oxygen $\rightarrow$ allows for aerobic bacteria.
3. **Ediacaran period (635-541 mya)** Precambrian/Neoproterozoic
   - Animals are mostly flat bodied filter feeders that reside at the bottom of the ocean.
4. **The Cambrian Explosion (542-488 mya)** Paleozoic/Cambrian/Epoch 2-3
   - Immense diversification of animal life in terms of species and niches.
   - Evidence of adaptations for predation and defense.
   - Most of the fossils from this era come from a location in British Columbia, Canada called the Burgess Shale.
   - Most of the major aquatic animal phyla begin here.

3.4 Mass Extinctions



Causes

- **Ordovician (444 mya):** global warming, anoxia, sea level rise?
- **Devonian (359 mya):** asteroid, reduced speciation?
- **Permian (252 mya):** volcanoes, glaciation, sea level drop?
- **Triassic (201 mya):** volcanic release of methane
- **Cretaceous (65 mya):** asteroid impact in Yucatan
- **Holocene (present):** humans

After Extinction

- **Silurian Period (444-419 mya):**
  - Origin of land plants
  - Origin of terrestrial fungi? (mycorrhizae)
  - Origin of terrestrial arthropods
- **Devonian Period (419-359 mya):**
  - The stem tetrapods: transitional fossils in the shift from fish to terrestrial tetrapod groups (amphibians, reptiles, mammals).
  - Eusthenopteron (fish) ⇒ Tiktaalik (transitional) ⇒ Icthyostega (tetrapod)
- **Carboniferous Period (359-304 mya):**
  - Massive forests, enormous plant diversity
  - Invasion of land by plants and tetrapods increases level of oxygen to the highest in Earth's history.
  - Giant insects due to high oxygen.
- **End Permian Mass Extinction (252 mya):**
  - Largest mass extinction
  - Large forests die out ⇒ oxygen level drops
  - Plant life dies, sinks to bottom of ocean/lakes, the pressure of sediments and water compresses this organic matter into oil and coal deposits.
  - Formation of Pangea

3.5 Dinosaurs to Modern Times

- **Triassic Period (252-201 mya):**
  - First Dinosaurs
  - First Mammals: mostly small and rodent-like
- **Jurassic Period (201-145 mya):**
  - Stegosaurus and Archaeopteryx
- **Cretaceous Period (145-65 mya):**
  - Tyrannosaurus rex, Triceratops, Velociraptor
- **End Cretaceous Mass Extinction (65 mya):**
  - Thick iridium (rare on earth, common in asteroids) layer at a particular age in the geological strata, which is good evidence of an asteroid impact.
  - The Chicxulub crater left behind by the asteroid.
- **Early Paleogene Period (65 mya):**
  - Mammals survive the End Cretaceous
  - 130 new mammal genera arise in about 10 mya
  - Radiation of Angiosperms (flowering plants)
    * Angiosperms perform evapotranspiration (water enters through the plant and exits through the leaves). As Angiosperms evopotranspirate, they alter the hydrologic cycle by adding water into the atmosphere.
    * They bring the oxygen level back up after the End Permian mass extinction.
    * Only fruit to produce nectar and fruit $\Rightarrow$ new animal niches
    * Radiation in Angiosperms caused by specialization into new methods of attracting pollinators.
- **Oligocene Epoch (34-23 mya):**
  - Expansion of grasslands and emergence of C_4 photosynthesis
  - Drives the presence of large herbivores that rely on grass diets
- **Prelude to the Pleistocene:**
  - Looks like modern life.
  - Climate comes into the life experience.

3.6 Life History Discussion

- Why do aerobic organisms arise after photosynthesis? How did pre-photosynthesis organisms perform respiration?
  - Aerobic respiration is very energy-efficient, but it requires oxygen. So when photosynthesis begins happening, there is a push towards aerobic respiration.
  - Pre-photosynthesis organisms performed either anaerobic respiration or fermentation.
- How did the first organisms get energy without photosynthesis?
  - Organisms at this time are Chemoautotrophs, gathering energy from chemical compounds in deep ocean vents.
- Why do we see an increase in O_2 levels following the invasion of land? What was the terrestrial landscape like at this time?
  - Photosynthetic plants invaded land, and the cycad forests begin to really develop and spread quickly.
  - This increases the oxygen level, supporting large insects.
- Why do O_2 levels drop so significantly 250 mya? Why do we not see similar drops at 444, 359, 201, or 65 mya?
  - At this time, 90% of life dies out, including the cycad forests that raised the oxygen to such high levels in the first place. Therefore there is a large drop in the oxygen as the forests no longer photosynthesize.
  - At this time, there is a major rise in plant growth, followed by a mass extinction event. This is unique to the Permian.
- The largest increase in genera is seen in the recent past, why then is the Cambrian Period considered an explosion of life?
  - The Cambrian saw the very first explosion of life.
  - Very important basic changes that set the stage for the future such as many of the genera we see today, as well as resource strategy niches like predation.
- What is the overall pattern? What does this indicate about the resilience of life on Earth?
  - Appears to fit an exponential growth curve.
  - Even when mass extinction events happen, something will survive.
  - Surviving organisms have reduced competition and radiate quickly.