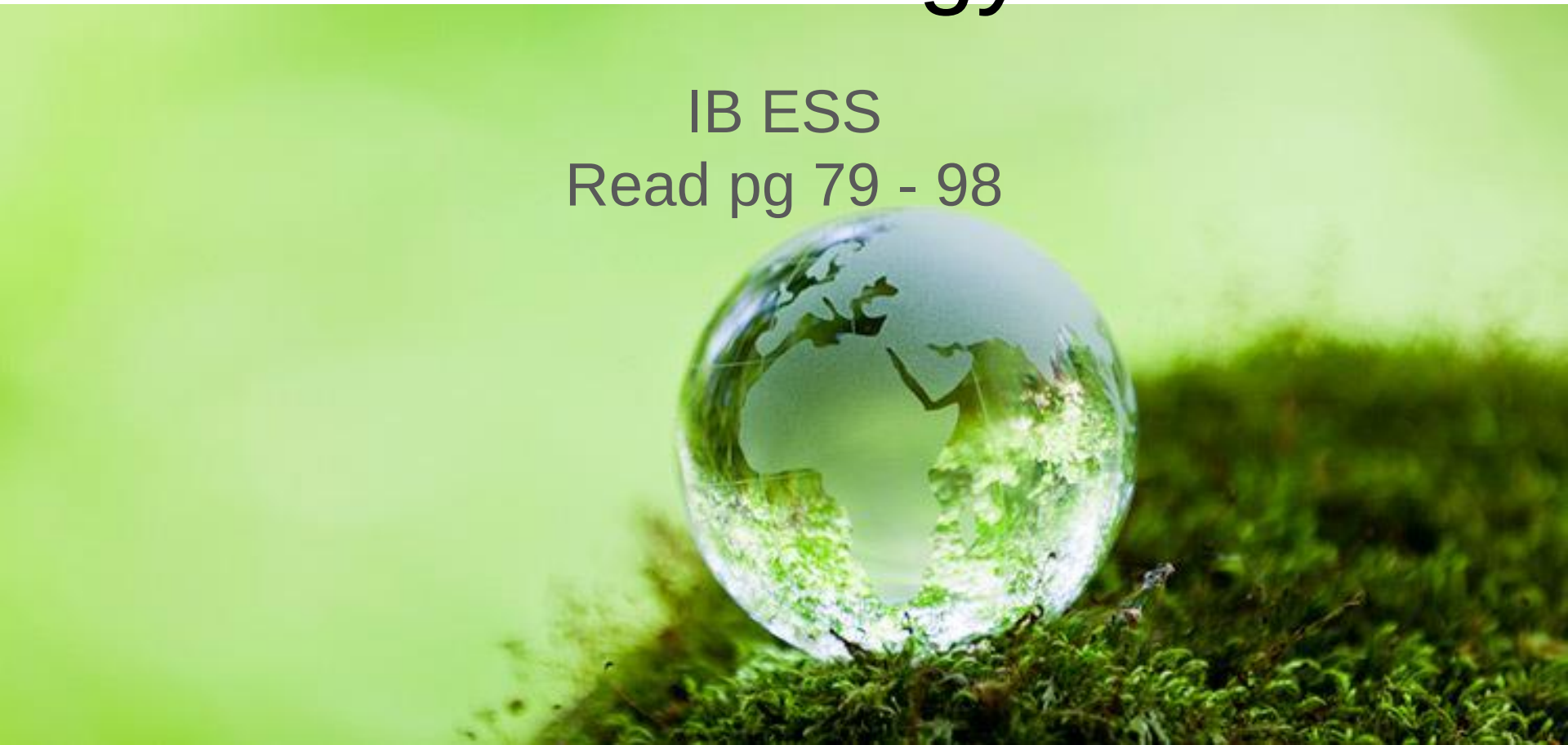
2.3 flows of energy & matter

IB ESS

Read pg 79 - 98



Significant Ideas & Skills

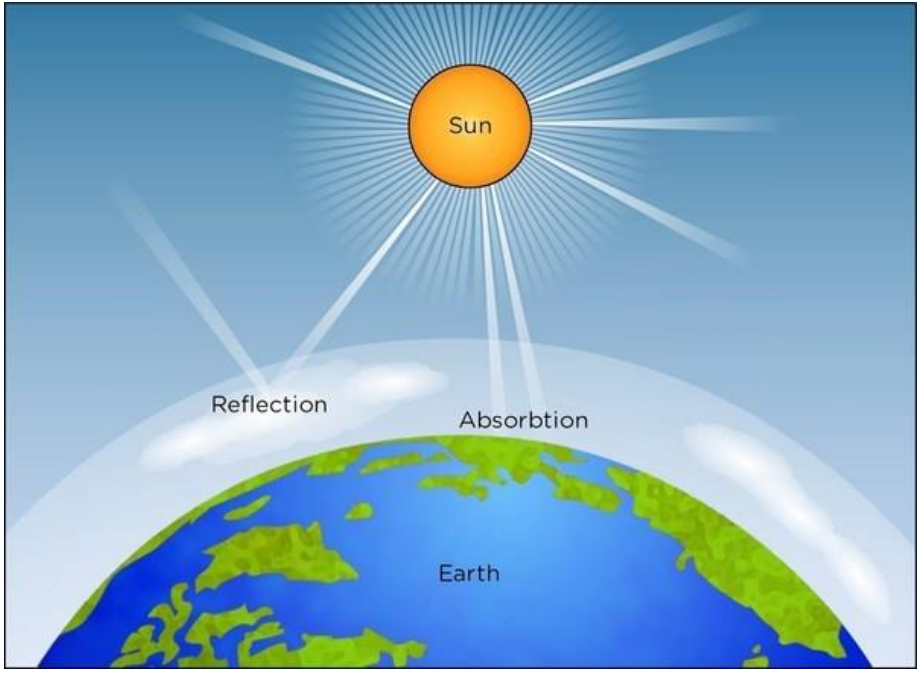
- Ecosystems are linked by energy and matter flows, driven by solar energy
- Analyze & Construct quantitative models of energy flows through ecosystems
- Define & calculate productivity, net primary productivity (NPP), gross primary productivity (GPP), gross secondary productivity (GSP), and net secondary productivity (NSP)
- Describe the flow & storage of matter through ecosystems, including the carbon and nitrogen cycles
- Outline the impact of human activities on energy flow and the carbon and nitrogen cycles

Key Questions

1. How are ecosystems linked together by the flow of energy and matter?
2. How are humans affecting the flow of energy and matter at a local and global levels?

Light from the sun

- Source of energy for life on Earth
- 30% reflected back into space (clouds, ice, snow, water & land)
- 69% absorbed (heat up land & sea)
- <1% available to plants



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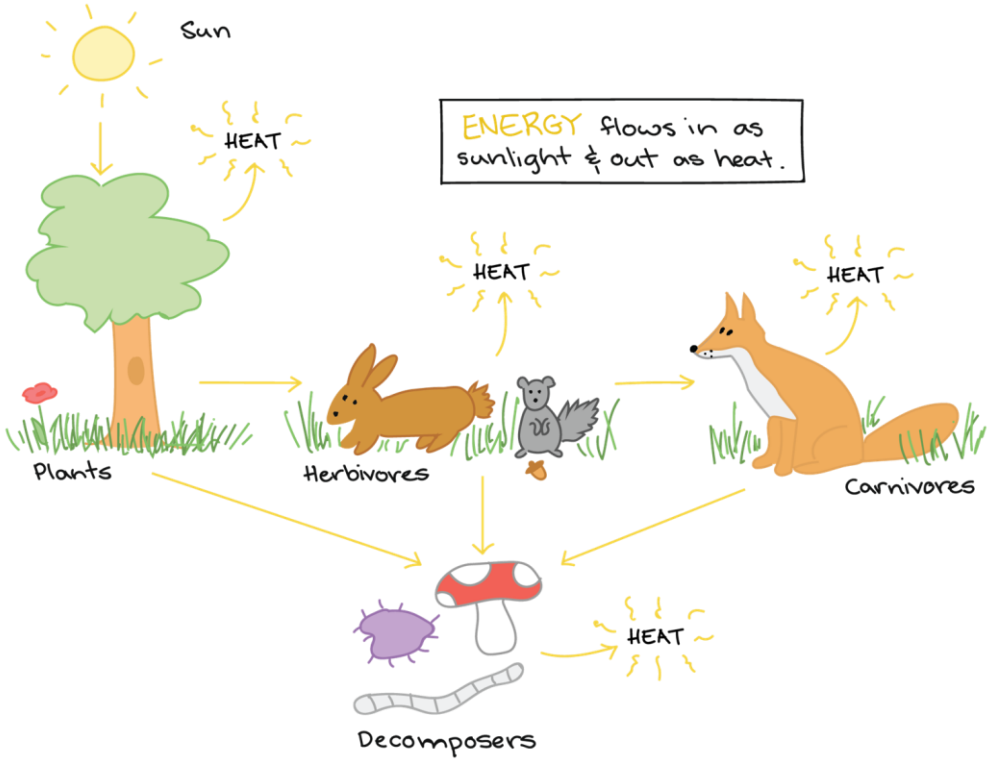
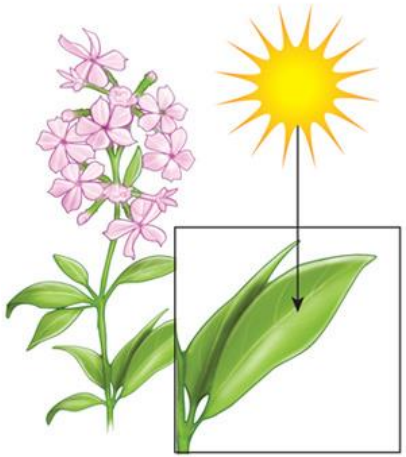
Energy that enters an ecosystem

- Converted from light to chemical energy by photosynthesis
- Transferred from 1 trophic level to next as organisms feed
- UV and visible light converted to heat in ecosystem
- Heat energy re-radiated into atmosphere



Very small fraction (<0.05%) of sunlight converted into plant biomass

- **Reflection**: from surface of leaves or passes through them without being captured
- **Wavelength**: chlorophyll only captures certain wavelengths (blue & red best and green least), the rest is reflected
- **Efficiency**: photosynthesis is inefficient & limited by temperature, carbon dioxide concentration & rate enzyme catalysts can work
- **Not being absorbed**: may not strike the chloroplasts



Productivity

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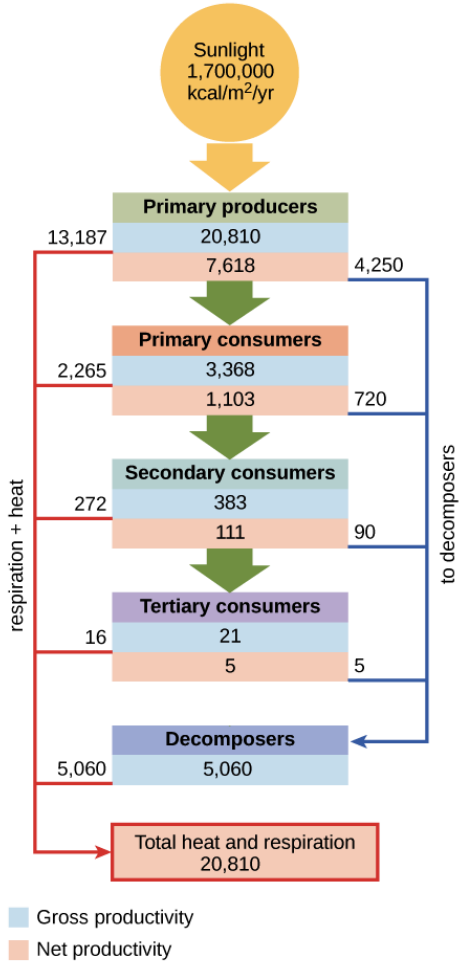
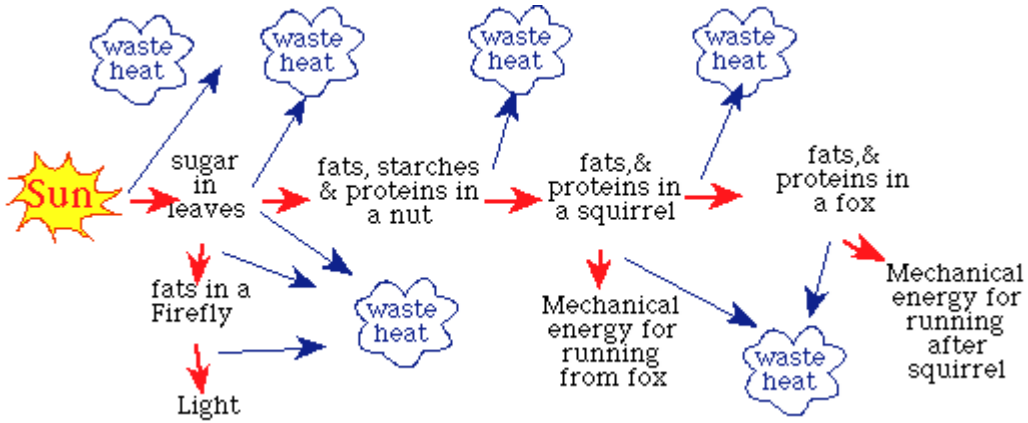
- Conversion of energy into biomass in a given period of time
  - Expressed per unit area per unit time
  - Photosynthesis converts light into glucose
  - Some glucose is respired & keeps plant alive
  - Remainder is converted to other compounds (starch & protein) stored in plant
    - Available to be passed onto consumers that eat it
  - Not all the energy transferred to consumers
    - Not efficient
    - Some energy used by organisms for respiration & lost to heat (not transferred to next trophic level)
    - Some energy lost in feces & other waste products not eaten (not transferred to next trophic level)
    - ONLY 10% energy assimilated in one trophic level available to the next

Ecological efficiency

- Recall from Topic 2.2 (p. 74, 92) only a small % of energy assimilated in one trophic level is available to be passed on to the next
- Causes biomass at higher trophic levels to be less than lower levels (pyramids)
- Energy eventually lost from all food chains as heat re-radiated back to atmosphere (2nd law of thermodynamics)





GPP & NPP p. 82-83

Energy flow diagrams

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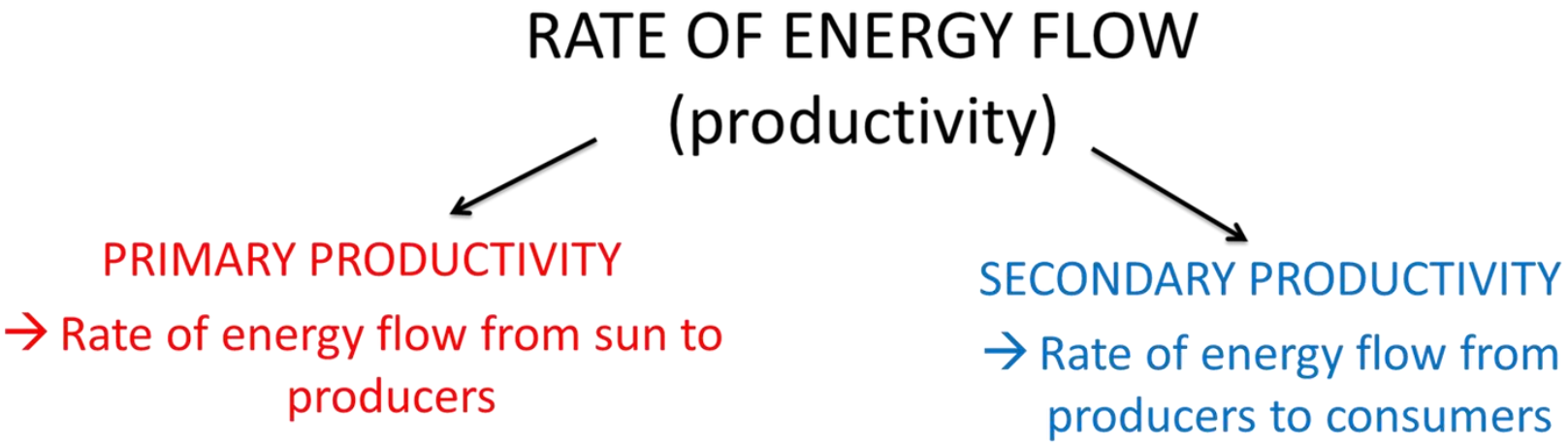
- Width of arrows represent quantities
- Arrows show how much energy is...
  - Passed in & out of each trophic level
  - Passed to decomposers or wasted
  - Lost through respiration



PRIMARY PRODUCTIVITY

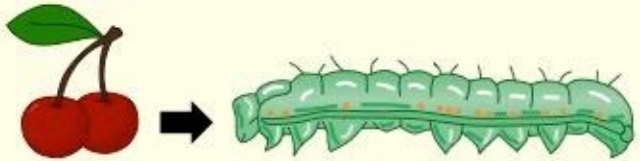
Gross Primary Production

300J

Net
Primary Production

Cell respiration or lost as heat
100 J

Tissue
200 J



SECONDARY PRODUCTIVITY

Gross
Secondary Production

200J

Net Secondary
Production

Faeces
100 J

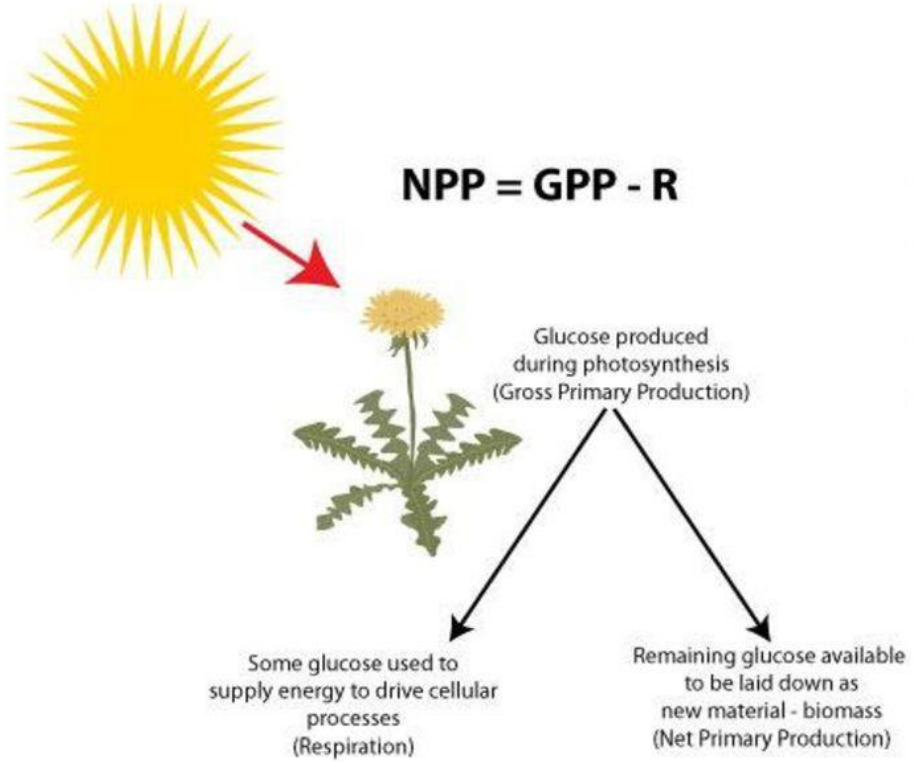
Tissue
33 J

Cell respiration or lost as heat
67 J

Primary Productivity

- Measure of the conversion of light energy into chemical energy in living organisms
- Production of chemical energy in organic compounds by autotrophs (producers)
- Usually measured as biomass per unit area per unit time
- EX. high in rainforests due to ample resources (sunlight, water, nutrients & temp)
- EX. low in desert due to scarce necessary resources

Gross/Net Primary Production



Only a small fraction of solar energy actually strikes photosynthetic organisms, and even less is of a usable wavelength

Gross primary productivity (GPP)

- Total energy converted by photosynthesis (rate at which photosynthesis occurs)
- Gain by producers in energy or biomass per unit area per unit time fixed by photosynthesis in green plants
- Not easy to measure directly
    - Net primary productivity (NPP) calculated instead from measurements of changes in biomass

Net primary productivity (NPP)

- Gain by producers in energy or biomass per unit area per unit time minus respiratory loss (R)

$$GPP = NPP + R \quad \text{(or)} \quad NPP = GPP - R$$

- Measurements used to estimate NPP vary
  - Many involve sampling plant material & drying it to estimate biomass
  - Difficult to account for productivity of every part of a plant so often estimates are too low
    - Roots, amounts eaten by herbivores & leaves lost in leaf litter
- Respiration (R) estimates come from amount of carbon dioxide produced
  - Obtained by measuring concentrations of the gas in atmosphere

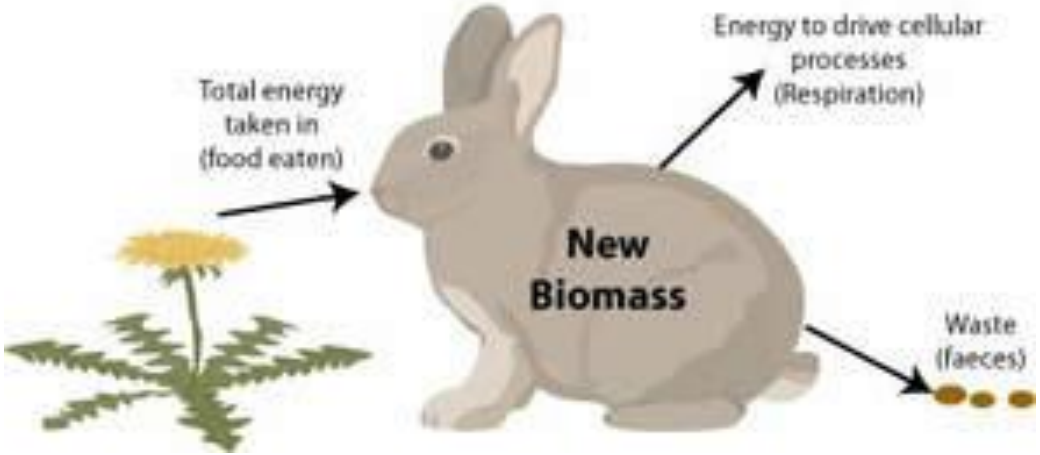
Secondary productivity

p. 84

- Measures feeding or absorption of stored energy
- Biomass gained by heterotrophs (consumers) as they feed
- Usually measured as biomass per unit area per unit time
- When productivity of consumers is considered, 2 losses are significant
  - 1. Loss in feces
    - Animals do not or cannot use all the biomass they eat
    - Feces contain food that cannot be digested by the animal
  - 2. Respiratory loss (R)
    - Energy that is assimilated but then used in respiration to maintain the animal's life processes

NSP = GSP - R

(Food eaten - Energy in faeces) - Respiration



Gross secondary productivity (GSP)

- Energy gained through absorption by consumers
- Energy or biomass gained by consumers through absorption

GSP = food eaten - fecal loss

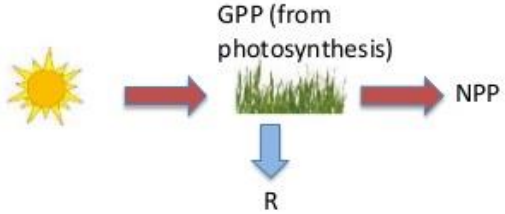
Net secondary productivity (NSP)

- Biomass that is available to the next trophic level
- Gain in energy or biomass per unit area per unit time remaining after the deduction of losses through respiration

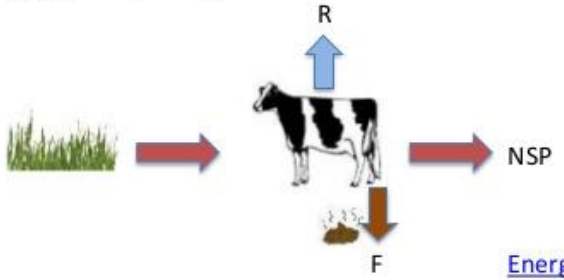
NSP = GSP - R

Calculations

NPP = GPP – R



NSP = GSP – F – R



Energy flow in ecosystems

Transfer & transformation of materials in an ecosystem

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- Energy cannot be recycled in an ecosystem (eventually lost has heat, not to return) BUT nutrients CAN
  - Nutrients absorbed from soil & pass along food chains until they return to the soil via decomposition
  - “Energy flows, but nutrients cycle”
- Important cycles:
  - Water cycle
  - Carbon cycle
  - Nitrogen cycle
  - Sulfur cycle
  - Phosphorus cycle

Carbon cycle

p. 86, 87

- Carbon present in ALL organic compounds
- **Organic compounds** - carbon-containing compounds excluding carbon dioxide and carbonates that are found in the bodies of living organisms
  - EX. macromolecules (lipids, proteins, carbohydrates, nucleic acids)
- **Inorganic compounds** - compounds of mineral origin
- Carbon storages:
  - organic (organisms)
  - Inorganic (atmosphere, soil & fossil fuels)
- Carbon flows:
  - Indicated by arrows
  - Feeding, death, photosynthesis & respiration

Nitrogen cycle

p. 88

- 80% of Earth's atmosphere is N_2 gas
  - Stable & cannot be used directly by living organisms
- Vital element found in proteins & nucleic acids of living organisms
- Recycled through ecosystems by microbes
  - Nitrogen fixing by bacteria - from air to intrates (taken in by plants)
    - 2 types in soil: *Azotobacter* & *Rhizobium*
    - *Rhizobium* found in nodules on roots of legumes (peas, beans & clover)
    - Symbiotic relationship between bacteria & plant roots
      - Bacteria receive sugars from plant, plant receives nitrates from bacteria
  - Nitrogen fixing by lightning
    - Combines nitrogen gas with oxygen to nitrates into the soil
  - Nitrogen fixing by humans
    - Haber process used to manufacture fertilizers

Nitrogen cycle

- Nitrifying bacteria (*Nitrosomonas & Nitrobacter*)
  - *Nitrosomonas* convert ammonia from wastes into nitrites
  - *Nitrobacter* convert nitrites into nitrates
  - Nitrates= soluble compound that can be absorbed by plants via roots & assimilated into their biomass
  - Ammonium compounds & nitrites cannot be taken in directly by plants
- Denitrifying bacteria
  - Convert nitrates to nitrogen gas back to atmosphere in anaerobic conditions
  - Live in waterlogged soils (depleted of nitrates & not useful for cultivation)

Anthropogenic influence on energy flow & nutrient cycling

- Humans convert biomass like wood into fuel
  - Energy lost as heat
  - Energy that would have passed along the food chain or to decomposer food chain no longer available
- Cycling of carbon & nitrogen
  - Storages are being removed
    - EX carbon in fossil fuels added to atmosphere
  - Flows being interrupted
    - EX flows of nitrogen modified by use of fertilizers adding nitrates to agricultural areas in disproportionate amounts
- Deforestation for both urban and agricultural development
  - In nature, biomass is used in a food chain & dead material is recycled
  - In agriculture, biomass is removed for human food & natural cycling cannot take place
  - Urbanization leads to near permanent loss of ecological productivity

Trophic Efficiency

p. 92

- Ratio of secondary productivity to primary productivity consumed; generally “10%”
- Rationale: uneaten biomass, fecal loss, respiration/heat loss, reproductive/other life processes
- Reasonable variations from 0.1% to 20%

Maximum Sustainable yield (MSY)

p. 95

- The rate of increase in biomass that can be exploited without preventing the organisms being taken from replenishing themselves

SY = (annual growth & recruitment) - (annual death & emigration)

- Examples:
  - Forestry: SY = largest amount of wood that can be harvested without reducing the productivity of the remaining trees
  - Fishing: SY = amount of fish that can be caught on a regular basis without compromising the ability of the species to reproduce & maintain its population
- Can vary over time with needs of ecosystem
  - Example: forest that recently suffered a fire require more of its own productivity to sustain & re-establish a mature forest.
    - Sustainable yield may be much less than in previous years