Energy flow in the ecosystem

Educational Goals

• History and fundamental concepts pertaining to energy flux in ecosystems
• Ecosystem Concept and thermodynamic underpinnings
• Primary production and its measurement, limiting factors, and global patterns
• Secondary Production
• Intratrophic transfers of energy
• Ecological efficiency
Ecosystem Ecology

- Ecosystems as giant energy-transforming machines

Background: Organizing Concepts

- Charles Elton – 1920’s revolutionary concept:
  - Organisms living in the same place have similar tolerances of physical factors AND
  - Feeding relationships link organisms
Food Webs

Conceptual Organization
Focus on **compartments** and **fluxes** of energy and materials
A Simple Compartment Example

- Pool size
- Flux rate (input = output)
- Residence Time
- Turnover Rate

Ecosystem Concept

A.G. Tansley (1935) – built on Elton’s
- Coined the word “ecosystem”
A.J. Lotka and Thermodynamics

The ecosystem as an energy-transforming machine:

- Set of equations representing exchanged of matter and energy

First law of thermodynamics
Second Law of Thermodynamics

Synthesis – Lindeman (1942)

• Elton – food web structure
• Tansley – fundamental unit
• Lotka - thermodynamics
Lindeman’s Foundations of Ecosystem Ecology

- The **ecosystem** is the fundamental unit of ecology.
- **Food chain**
- **Trophic level**
- **Pyramid of energy**

Trophic Structure

Functional Classification:
- **Producers** (autotrophs)

- **Reducers** (heterotrophs)
Trophic Pyramids

Odum’s Energy Flux Model

- Used energy as currency in compartment analysis
Primary Production

- Primary producers capture light and transform it to energy
  - $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$
  - for each g of C assimilated, 39 kJ energy stored

Components of Primary Production

- gross primary production

- net primary production

- gross - net = respiration
Components of Primary Production

Measurement of Primary Production

- harvest techniques

- gas exchange techniques

- Radioactive carbon ($^{14}$C) may also determine net uptake of carbon by plants
Application of Odum’s Approach

Gas Exchange in Aquatic Systems
Limits to primary productivity?

• Photosynthetic efficiency – 1-2%

• Limits:
  – Light
  – Temperature
  – Water
  – Nutrients

Photosynthesis and Temperature
Water limits primary productivity

Nutrients stimulate primary production

• Terrestrial systems may be nutrient limited

• Aquatic systems often strongly nutrient limited
Primary Production varies among ecosystems
Global Primary Productivity

Global Productivity
More terminology…..

• Herbivore, carnivore, omnivore

• Trophic link

• Decomposers

Ecological Efficiency
• Ingestion
• Egestion
• Assimilation
• Excretion (a)
• Respiration
• Production
Fundamental Energy Relationships

Limits to Secondary Production?

- Correlated with Primary Production

- Biotic interactions - Predation, etc.
Net Ecosystem Production

Is there anything left over?

Ecosystems support two parallel food chains

**herbivore-based** (relatively large animals feed on leaves, fruits, seeds)

**detritus-based** (microorganisms and small animals consume dead remains of plants and indigestible excreta of herbivores)

- herbivores consume:
  - 1.5-2.5% of net primary production in temperate forests
  - 12% in old-field habitats
  - 60-99% in plankton communities
Energy moves through ecosystems at different rates.

Indices of energy cycling speeds
- residence time

Energy moves through ecosystems at different rates.

Indices of energy cycling speeds
- biomass accumulation ratio
Ecosystem Energetics

Compare systems with different inputs:

• Autochthonous – produced within the system

• Allochthonous – produced outside the system

Biomass Accumulation Ratios

• Become larger as amount of stored energy increases:
  – humid tropical forests have net production of 1.8 kg/m²/yr and biomass of 43 kg/m² = 23 yr

  – forested terrestrial communities >20 yr

  – planktonic aquatic ecosystems <20 days
Residence Time for Litter

- Decomposition of litter is dependent on

- **Residence time**

  - humid tropics: ~3 mos
  - dry and montane tropics: ~1-2 yr
  - southeastern US: ~4-16 yr
  - boreal ecosystems: ~>100 yr

Stream study.....

- Assimilation of energy by herbivores indicates subsidy
  - autochthonous
  - allochthonous