Introduction to Ecosystems

- Some reflected
- Some converted to heat
- Some absorbed PSN
- Some absorbed by organisms, soils, water
Plants use solar energy to synthesize sugars.
- Plant growth
- Storage
Introduction to Ecosystems

Forest is sunlight transformed

- Portion consumed by herbivores
- Consumed by detritivores
- Soil organic matter
Definition

Forest can be viewed as a system –

- Absorbs
- Transforms
- Stores

Physical, chemical and biological structures and processes are inseparable -> Ecosystem

= biological community plus all abiotic factors influencing the community
Definition

Concept 1\textsuperscript{st} proposed in 1935

“though the organism may claim primary interest...we cannot separate them from their special environment with which they form on physical system”

Arthur Tansley
(1871 – 1955)
Definition

- Ecosystems process matter and energy
- Distinctly different approach from individual, population, & community ecology
  - mostly non-evolutionary
  - more non-biological processes (chemistry, physics)
  - Laws of physics determine a lot of what goes on in ecosystems
Definition

Ecosystem Ecologists study flows of energy and nutrients

Areas of interest include

- Primary Production
- Energy Flow
- Nutrient Cycling
Definition

- What Are the Energy Sources in Ecosystems?
- What Limits Primary Production?
- What Controls Energy Flow Through Consumers?
- How Does Energy Flow Structure Ecosystems?
Simple laws of physics

- **Conservation of matter** -- matter is neither created nor destroyed, only changed in form

- **Conservation of energy** -- energy is neither created nor destroyed, only changed in form

- **Entropy** -- Any transfer or change of energy cannot be 100% efficient. Some energy is degraded to lower quality, less useful energy (=heat)
Energy

- Ability to do work
  - Kinetic -- energy now doing work
  - Potential -- energy stored (e.g., in chemical bonds within living organisms)

- Consequence of entropy
  - material moves spontaneously down a concentration gradient
  - the reverse requires expenditure of energy
  - Organisms move matter up concentration gradients by expending energy
Energy flows within ecosystems

- Energy moves one way within ecosystems
- No cycles
- Every transfer results in reduction in usable energy (production of some heat)
- Input is energy from nonliving sources, primarily the sun via photosynthesis
A Simple Food Chain: From the Plankton to the Largest Animal on Earth
Trophic levels: steps in energy transfer

- **1st trophic level -- Primary producers**
  - photosynthetic autotrophs, some chemosynthetic autotrophs

- **2nd trophic level -- Primary consumers**
  - heterotrophs consume primary producers (herbivores)

- **3rd trophic level -- Secondary consumers**
  - heterotrophs consume primary consumers (carnivores)

- **4th trophic level -- Tertiary consumers**
  - heterotrophs consume secondary consumers (carnivores)

- **Decomposers -- mostly bacteria & fungi**
  - heterotrophs that consume dead organisms (detritivores)
Energy Sources in Ecosystems

- **Autotrophs**—organisms that obtain energy from inorganic sources, such as by photosynthesis.
  - Autotrophs are the ultimate biological source of energy for ecosystems.
  - Primary production is the energy autotrophs acquire from the inorganic environment.
  - Gross primary production (GPP)—the total rate of energy capture by autotrophs.
  - Net primary production (NPP)—the total rate of energy capture by autotrophs minus energy lost in their respiration.

- **Heterotrophs** are organisms that obtain energy from organic compounds, generally from other organisms, living or dead.
  - Secondary production—the acquisition of energy by heterotrophs.
The Inorganic Sources of Energy

- Chemoautotrophs (eubacteria and archaea) derive energy from the oxidation of electron donors in the environment.
  - E.g. hydrogen $\text{H}_2$, hydrogen sulfide ($\text{H}_2\text{S}$), or methane ($\text{CH}_4$).
- Photoautotrophs derive energy from sunlight through photosynthesis.
Energy Flow Through Ecosystems

- **3° Consumer (top carnivore)**
  - Energy flow
- **2° Consumer**
  - Energy flow
- **1° Consumer**
  - Energy flow
- **1° Producer**
  - Energy flow
- **Solar Energy**
  - Energy loss
Energy Pyramid in Ecosystems

- Producers: 1000 kcal
- Primary consumers: 100 kcal
- Secondary consumers: 10 kcal
- Tertiary consumers: 1 kcal

The pyramid illustrates the flow of energy through different trophic levels in an ecosystem.
Energy Loss Along the Food Chain Affects Which Species Can Be Sustainably Harvested
Primary Production

Net = Gross – Respiration

Amount of energy available to consumers in the ecosystem

Measured by

- Rate of carbon uptake
- Amount of biomass
- $O_2$ produced
Global Patterns of Primary Production

Terrestrial systems: high productivity - green; low productivity - red.

Marine systems: high productivity - red, moderate productivity - yellow, low productivity - blue.
Primary Production

Because rates vary from one ecosystem to another – study factors that control rates.

Patterns of natural variation can provide clues to environmental factors that control the process.
Rosenzweig 1968 – estimated influence of moisture and temperature on rates

Annual net primary productivity

Annual actual evapotranspiration (AET) – total amount of water that evaporates and transpires off of landscape during course of year.
What does this tell us?

AET (temperature and precipitation) accounts for significant proportion of variation in annual net primary productivity

But...
Rosenzweig attempts to explain variation in primary productivity across terrestrial ecosystems but what about within ecosystems?
Primary Productivity

O.E. Sala – Colorado State University explored factors controlling primary productivity in central grasslands of North America

9498 sites grouped into 100 representative study areas

Mississippi/Arkansas → New Mexico/Montana
Primary Productivity

- Highest in eastern grasslands → lowest in west
- Corresponds to change from tallgrass to shortgrass prairie
- Significant relationship with precipitation
- If temperature added no improvement in “fit”

Why?

Warm temperatures occur at all grasslands during the growing season.

FIG. 2. Relationship between mean annual precipitation and mean aboveground net primary production (ANPP) for 100 major land resource areas across the Central Grassland region. ANPP = -34 + 0.6·APPT; \( r^2 = 0.90 \).
500 – 600 mm shows production ranging from 300 – 1000 g/m²

Why?

Differences challenge ecologists for explanation

FIG. 2. Relationship between mean annual precipitation and mean aboveground net primary production (ANPP) for 100 major land resource areas across the Central Grassland region. ANPP = -34 + 0.6·APPT; $r^2 = 0.90$. 
Primary Productivity

Can it be explained by differences in soil fertility?
N & P

Do nutrients explain differences in rates of primary productivity?

Experiments conducted to enhance nutrients
Primary Productivity


Tallgrass prairie fertilization with N & P

- Large production responses with N → 46%
- Not with P

Why?
Primary Productivity

- Lack of response may be due to efficient mutualistic relationship with mycorrhizal fungi and plants
- Latter studies confirm findings

Avg increase with N $\rightarrow$ +68% ANPP, in burned sites but only +9% in burned sites

NO$_3^-$ – availability higher in unburned sites
Primary Productivity

Despite major influence of temperature and moisture on ANPP, variation in nutrient availability can also have measurable affect.
Primary Productivity – Aquatic Systems

Significant positive relationships with nutrient availability and primary productivity

1st studies P & phytoplankton biomass – Japanese lakes (1950’s – 60’s)
Primary Productivity – Aquatic Systems

Later similar relationship seen with lakes in Northern Hemisphere

Slopes in both studies nearly identical!
Primary Productivity – Aquatic Systems

Whole lake experiments – NW Ontario, Canada 1968

Vinyl curtain divided lake into 8 ha basins 1973 - 1980

- C & N
- C & N & P
- Both sides responded to nutrient additions
- Phytoplankton biomass ↑ reference lakes
Before fertilizing, the two lakes supported similar phytoplankton biomass.

After fertilization, phytoplankton biomass increased in the experimental lake.

When fertilizing stopped, phytoplankton biomass decreased in the experimental lake.
Primary Productivity – Aquatic Systems

Freshwater systems – P additions have a much larger effect

Marine systems – N additions have a much larger effect on hard bottom substrates (coral reefs, rocky intertidal, open ocean)
Trophic Cascades

Chemical controls on $\text{1}^{\circ}$ productivity = bottom up controls

But... consumers may also influence $\text{1}^{\circ}$ productivity = top down controls
Trophic Cascades

Carpenter, Kitchell and Hodgson – Bioscience 35:634-639

Although nutrients determine $1^\circ$ productivity in lakes, piscivorous and planktivorous fish can cause significant deviations.

![Diagram showing the relationship between Zooplankton size and productivity](image-url)
Trophic Cascades

Proposed influence of consumers on lake $1^\circ$ productivity propagate through food web
Trophic Cascades

Visualized effects of consumers coming from top of food web to base → Trophic Cascade Hypothesis

Similar to Keystone Species but... Trophic Cascade model focused on effects of consumer on ecosystem processes and not on species diversity
Trophic Cascades

1. Piscivorous fish (LMB) feed on plankivorous fish & inverts
2. Because of their influence on planktivorous fish, LMB indirectly effect populations of zooplankton

By reducing plankivorous fish, LMB reduce feeding pressure on zooplankton
3. Large bodied zooplankton dominate zooplankton community
4. Dense population of zooplankton reduces phytoplankton biomass and rate of $1^o$ productivity
Trophic Cascades

Hypothesis predictions

- Planktivore Biomass vs. Piscivore Biomass
- Zooplankton Biomass vs. Piscivore Biomass
- Phytoplankton Biomass vs. Piscivore Biomass
Trophic Cascades

By manipulating fish communities in 2 lakes can test predictions
1. Increased LMB / reduced Planktivores
2. Increased Planktivores / reduced LMB
3. Control
Trophic Cascades

Hypothesis predictions

- Planktivore Biomass vs. Piscivore Biomass
- Zooplankton Biomass vs. Piscivore Biomass
- Phytoplankton Biomass vs. Piscivore Biomass
Trophic Cascades

Results
1. Reducing planktivorous fish $\rightarrow$ ↓ 1º productivity - in absence of minnows, predaceous inverts fed heavily on smaller herbivorous zooplankton
2. Increasing plankivorous fish / reduce LMB $\rightarrow$ ↑ 1º productivity
Reproductive rates of LMB increased 50x

Trophic activities of few species can have large effects on ecosystem processes
Trophic Cascades

Majority tests of Trophic Cascades have been done in aquatic systems


Are Trophic Cascades all Wet?

- Most likely to occur in ecosystems with lower species diversity and reduced spatial and temporal complexity
- Characteristic of many aquatic ecosystems
Trophic Cascades

Some terrestrial systems consumers have been found to have significant effects

Serengeti Grassland Ecosystem
Serengeti – Mara 25,000 km²
Grassland ecosystem

- 1.4 million Wildebeest
- 600,000 Thompson’s Gazelle
- 200,000 Zebra
- 52,000 Buffalo
- 60,000 Topi
- 20 + additional grazing mammals
Trophic Cascades

- Grazers consume 66% of ANPP
- Potential for effect on ecosystem
- Complex interrelations of biotic and abiotic factors
Trophic Cascades

- Soil fertility and rainfall stimulate primary productivity and thus distribution of grazing mammals
- Grazing mammals affect
  - Water balance
  - Soil fertility
  - Plant productivity
Trophic Cascades

McNaughton – positive relationship primary productivity and precipitation but grazing also increased primary productivity

Plant growth rates increased - Compensatory Growth
• Lower rates of respiration (lower biomass)
• Reduced self-shading
• Improved water balance (reduced leaf surface area)
Trophic Cascades

Serengeti now considered exceptional ecosystem but not always so...
North American Grasslands was likely comparable.

60 million bison grazed grasslands up until middle of 19th century.

Research suggests they may have had similar affects on grasslands.
Energy is lost with each transfer between trophic levels

- Assimilation efficiency
- Respiration by consumers
- Heat production
Energy Flow

Research at Lake Mendota, WI Demonstrated ~ 10% of available energy is transferred to next trophic level – **Rule of thumb**

This limits # of trophic levels within ecosystems!
Energy Flow

Eventually there is insufficient energy to support viable populations
Nutrient Cycles