Ecosystem Ecology

Energy Flows and Nutrient Cycles

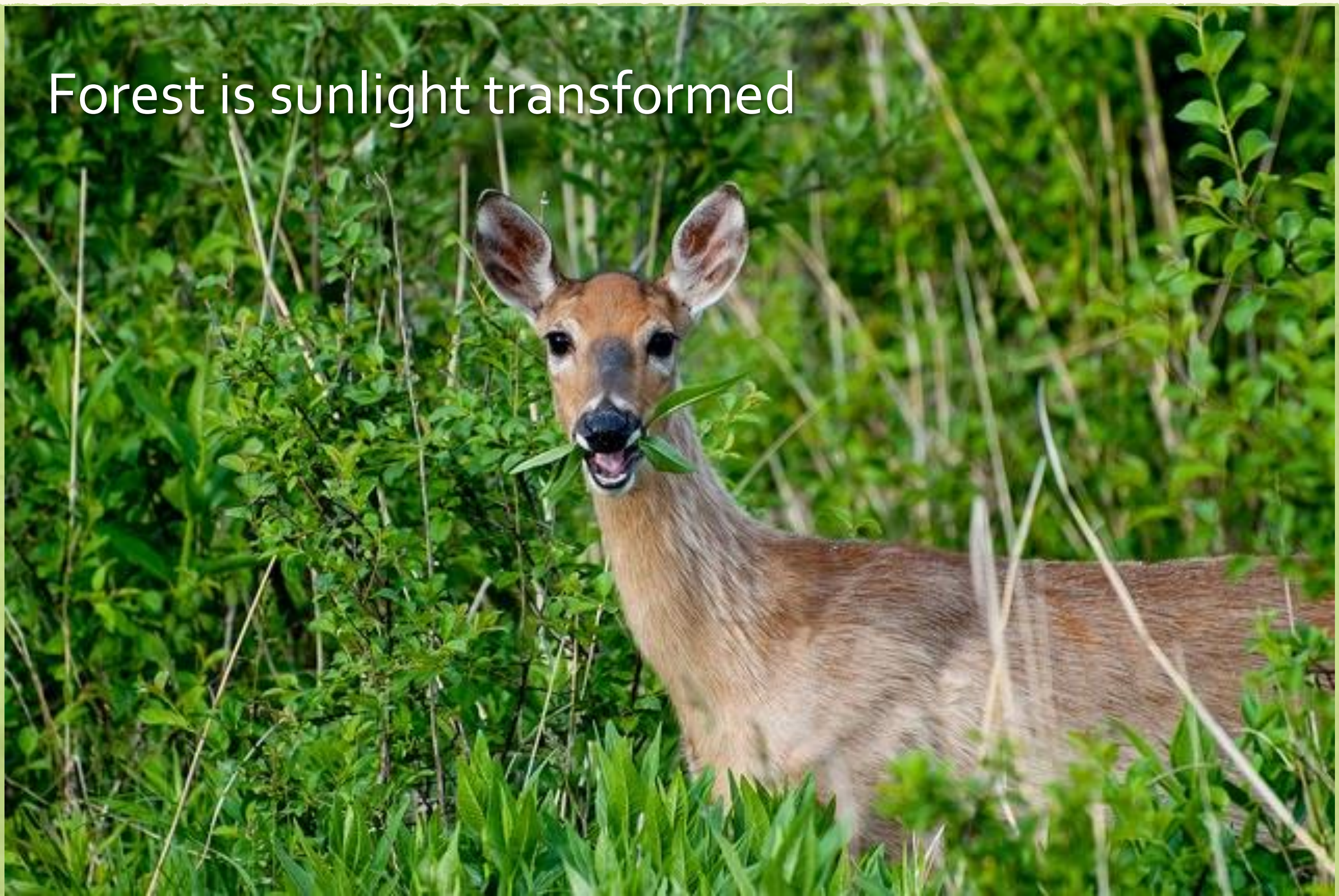
Introduction to Ecosystems

- Some reflected
- Some converted to heat
- Some absorbed PSN
- Some absorbed by organisms, soils, water

Introduction to Ecosystems

- Plants use solar energy to synthesize sugars
  - Plant growth
  - Storage

Introduction to Ecosystems



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

Definition

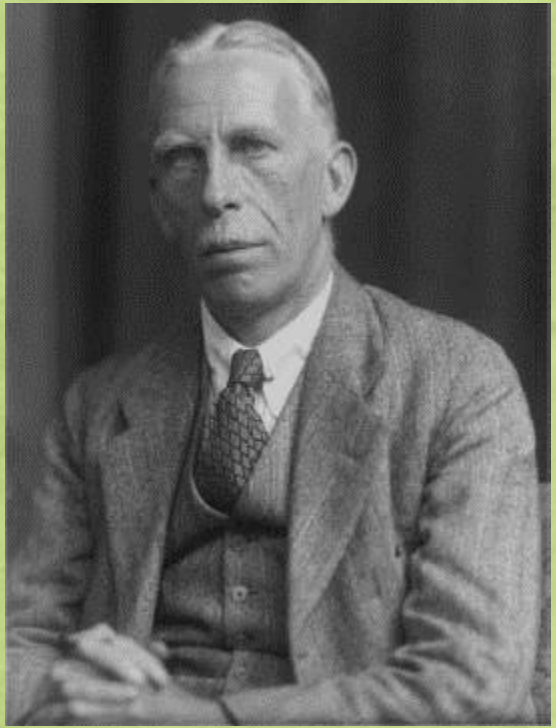
Forest can be viewed as a system –

- Absorbs
- Transforms
- Stores

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

= biological community plus all abiotic factors influencing the community

Definition



Arthur Tansley
(1871 – 1955)

Concept 1st 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"

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)

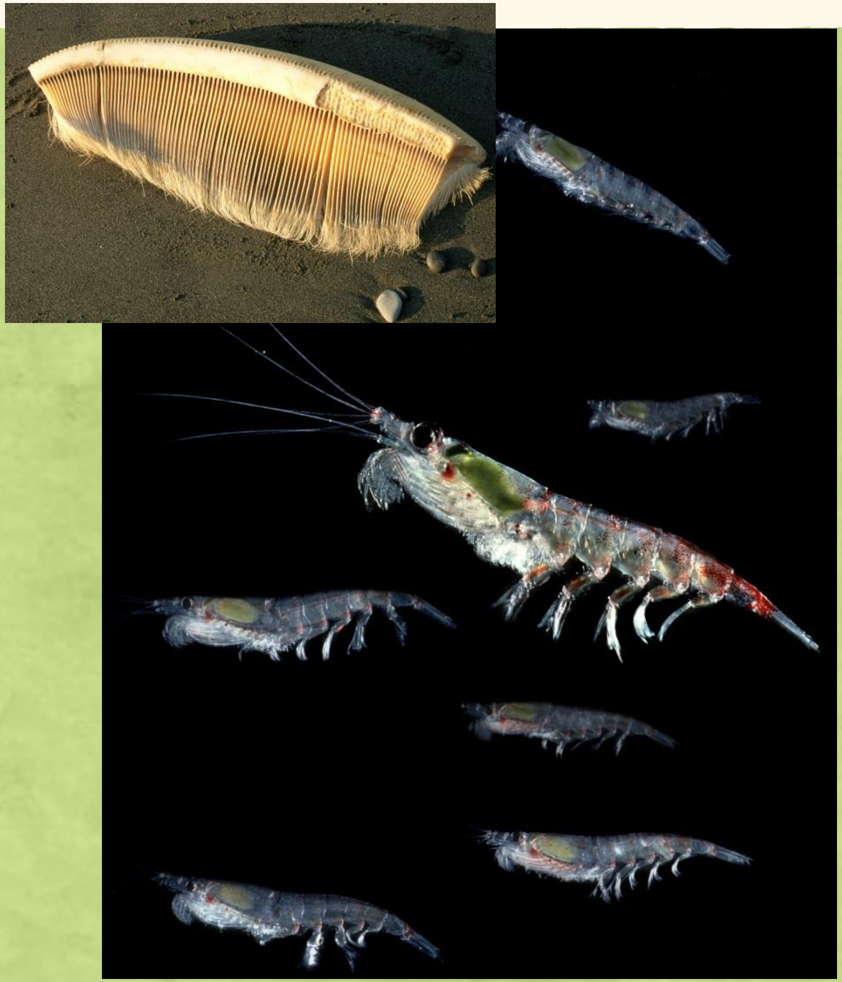
Energy

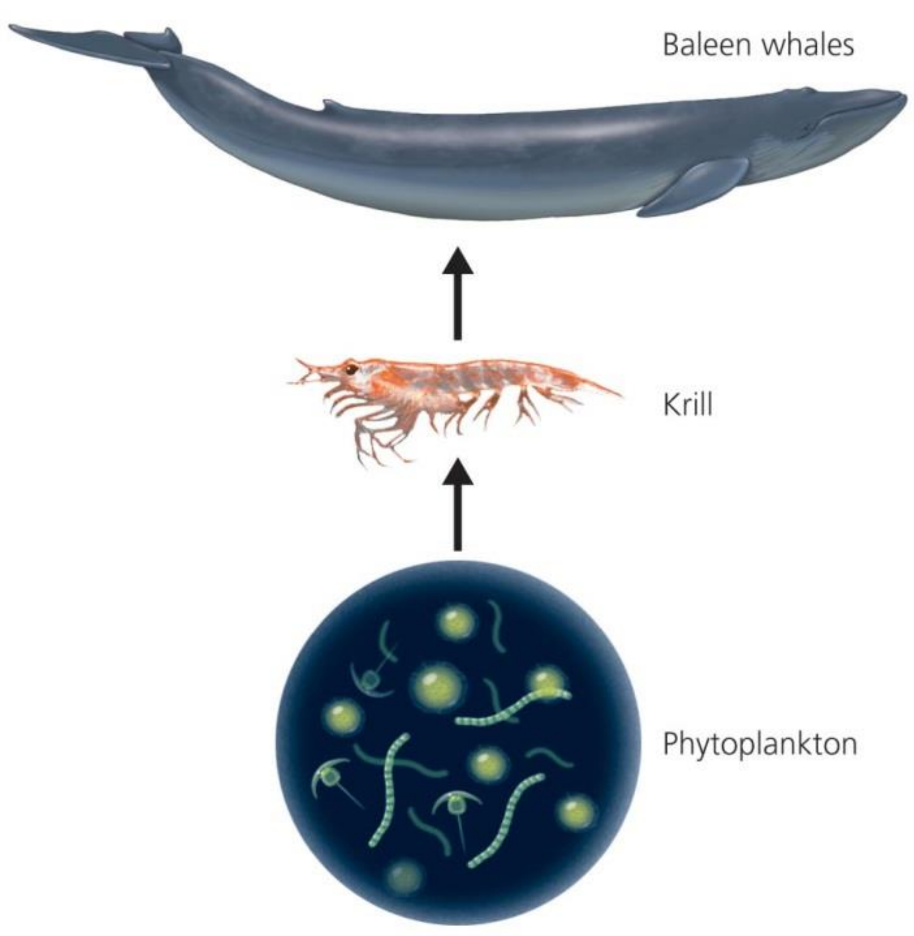
- Ability to do work
  - Kinetic -- energy now doing work
  - Potential -- energy stored (e.g., in chemical bonds within living organisms)
- Consequence of entropy
  - material moves spontaneously down a concentration gradient
  - the reverse requires expenditure of energy
  - Organisms move matter up 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 tropic 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)

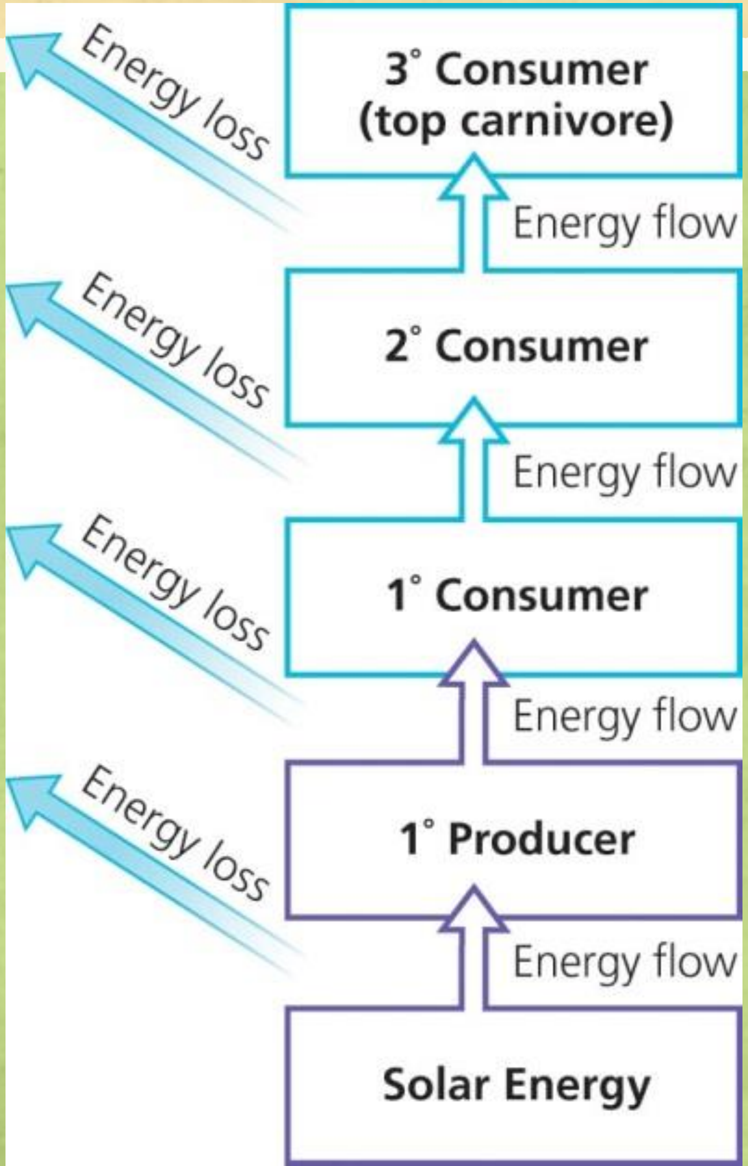
Energy Sources in Ecosystems

- **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.

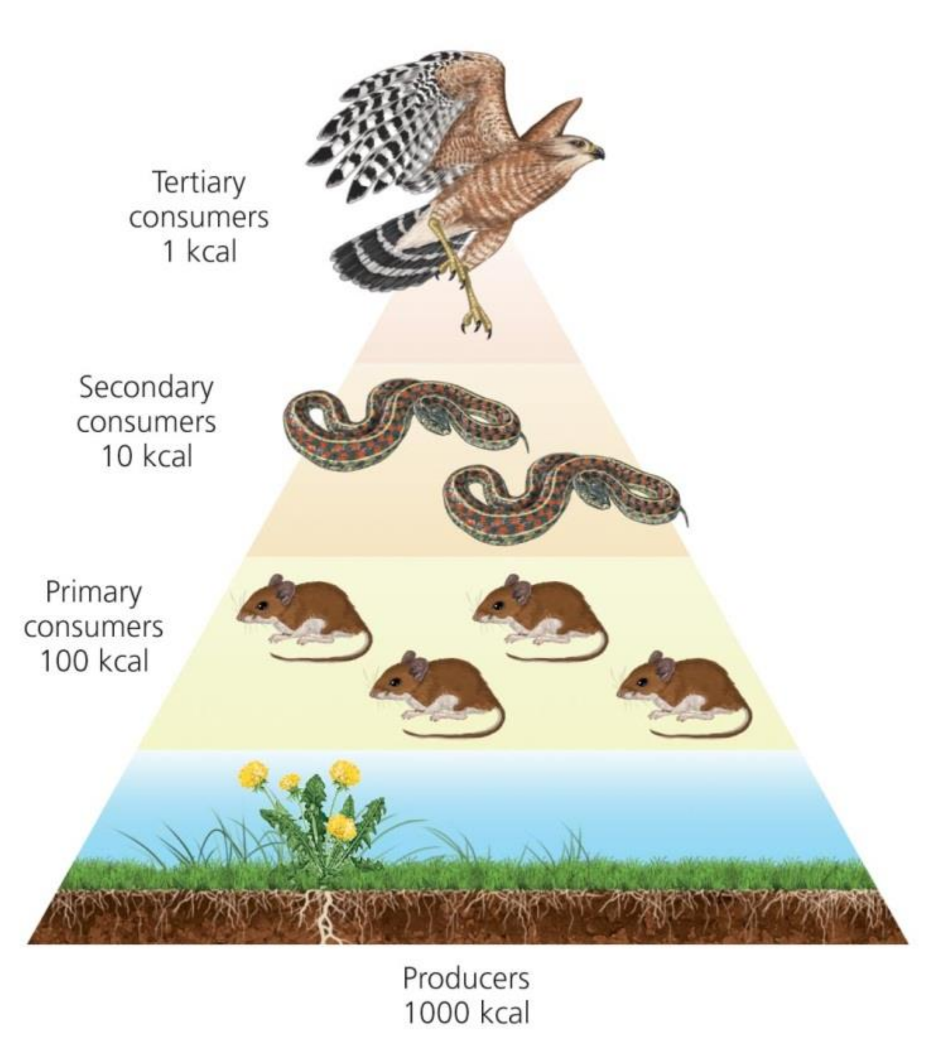
The Inorganic Sources of Energy

- Chemoautotrophs (eubacteria and archaea) derive energy from the oxidation of electron donors in the environment.
  - E.g. hydrogen H_2, hydrogen sulfide (H_2S), or methane (CH_4).
- Photoautotrophs derive energy from sunlight through photosynthesis.

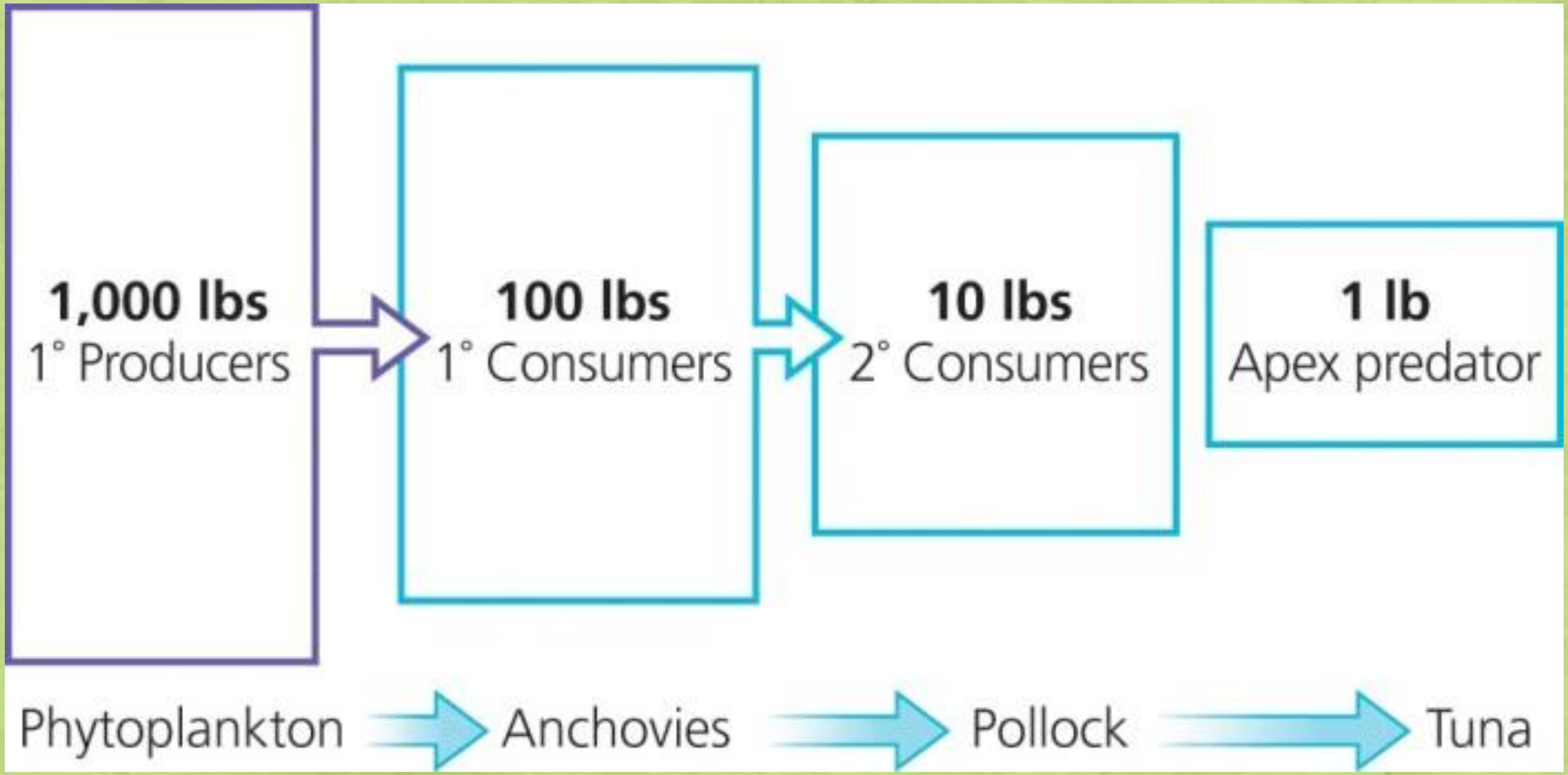
Energy Flow Through Ecosystems



Energy Pyramid in Ecosystems



Energy Loss Along the Food Chain Affects Which Species Can Be Sustainably Harvested



Primary Production

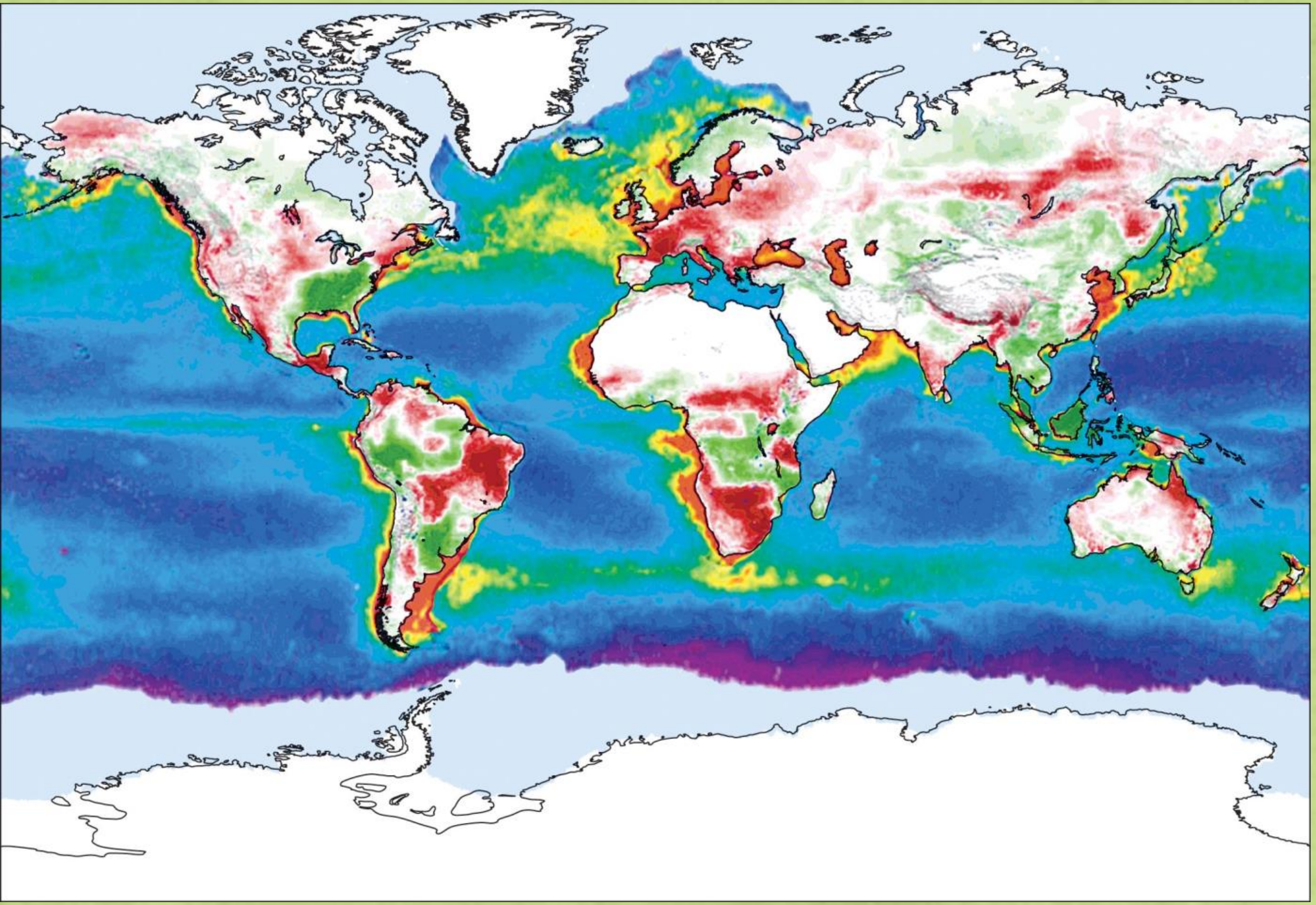
Net = Gross – Respiration

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 1 ecosystem to another – study factors that control rates

Patterns of natural variation can provide clues to environmental factors that control the process

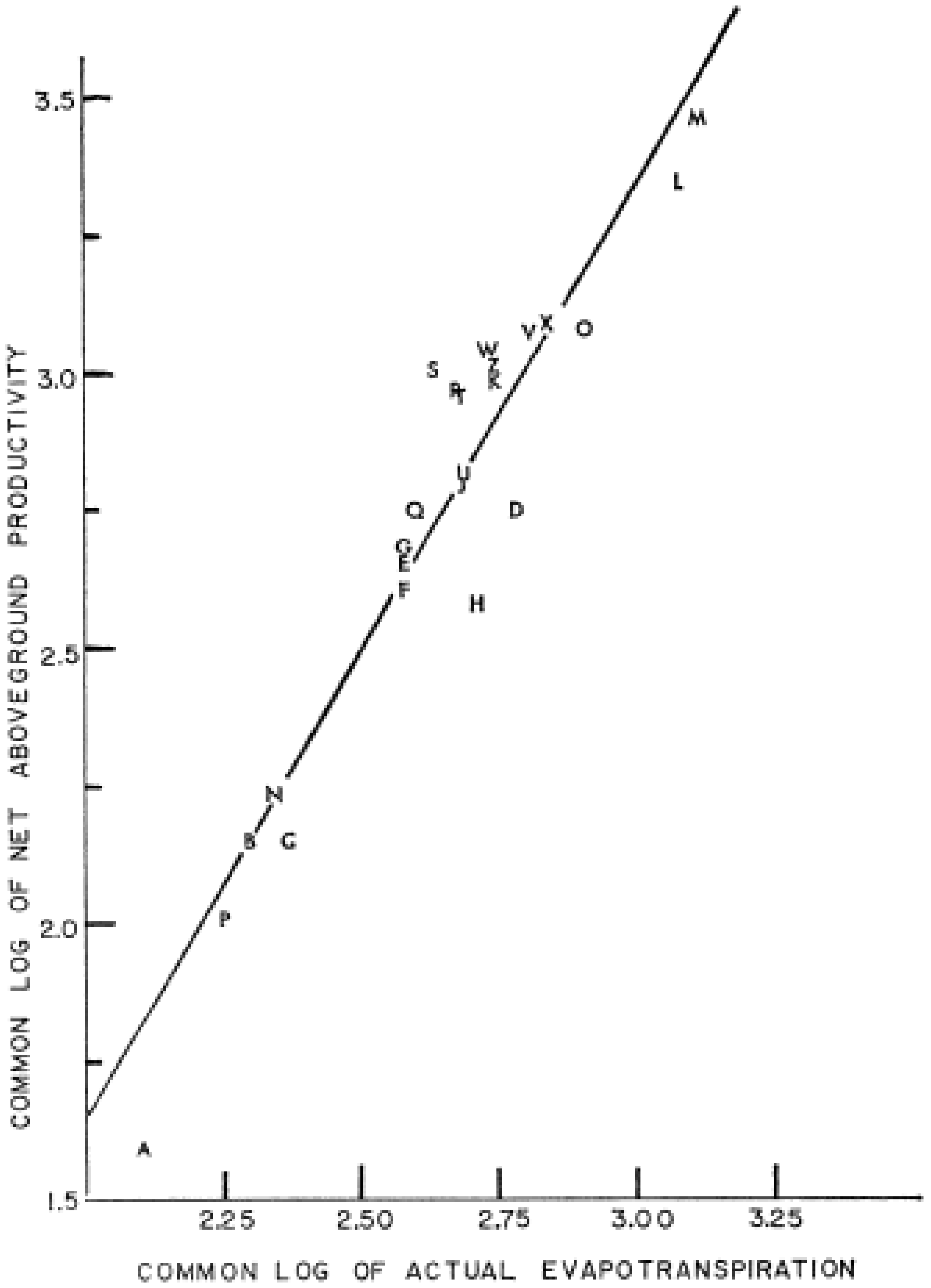


FIG. 1.—Net above-ground productivity in grams of dry matter per square meter graphed against actual evapotranspiration in millimeters. The regression line (see text) is included. See Table 1 for identities of coded points.

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.

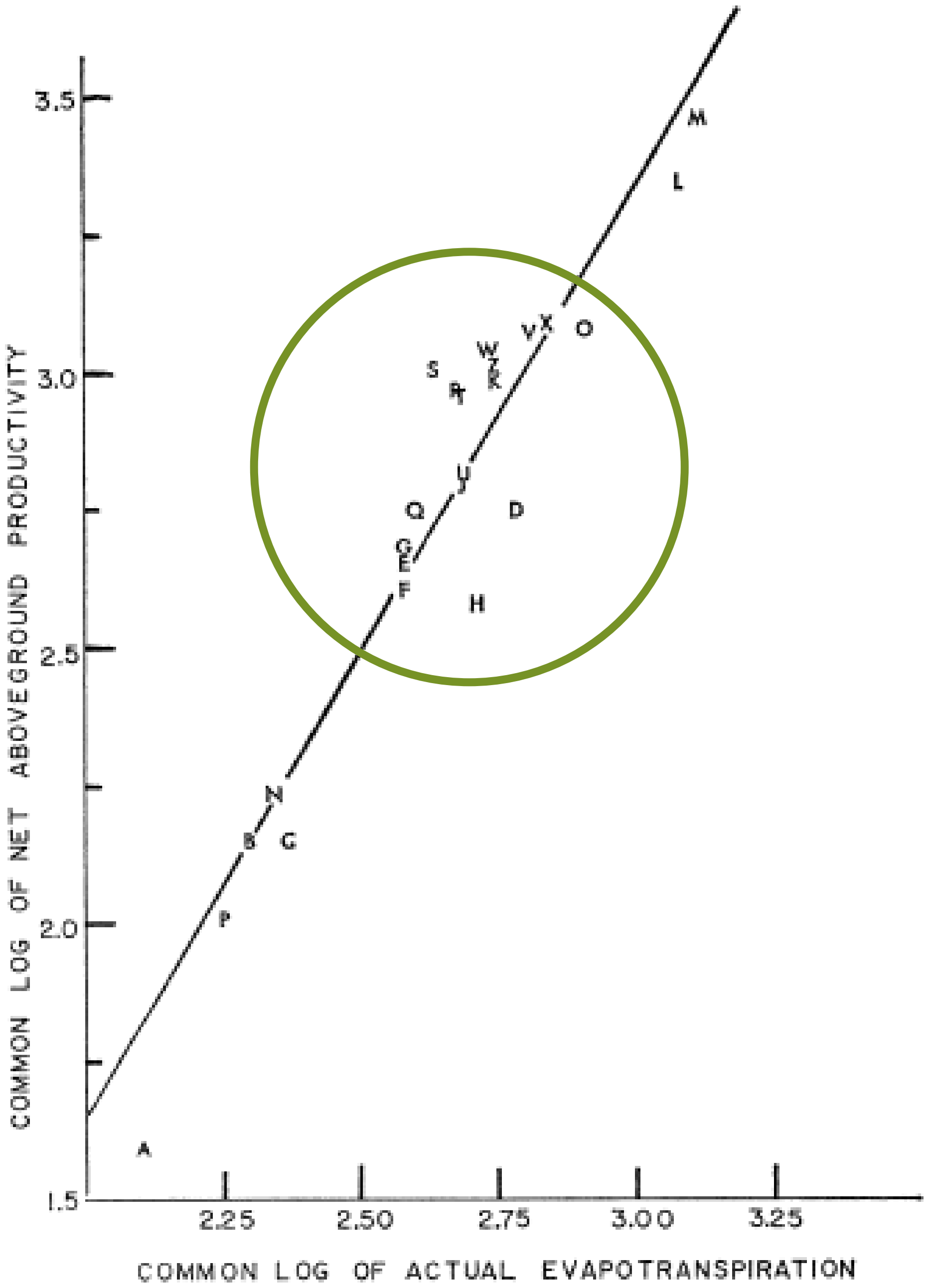


FIG. 1.—Net above-ground productivity in grams of dry matter per square meter graphed against actual evapotranspiration in millimeters. The regression line (see text) is included. See Table 1 for identities of coded points.

What does this tell us?

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

But…

Primary Productivity

Rosenzweig attempts to explain variation in primary productivity **across** terrestrial ecosystems but what about **within** ecosystems?

Primary Productivity

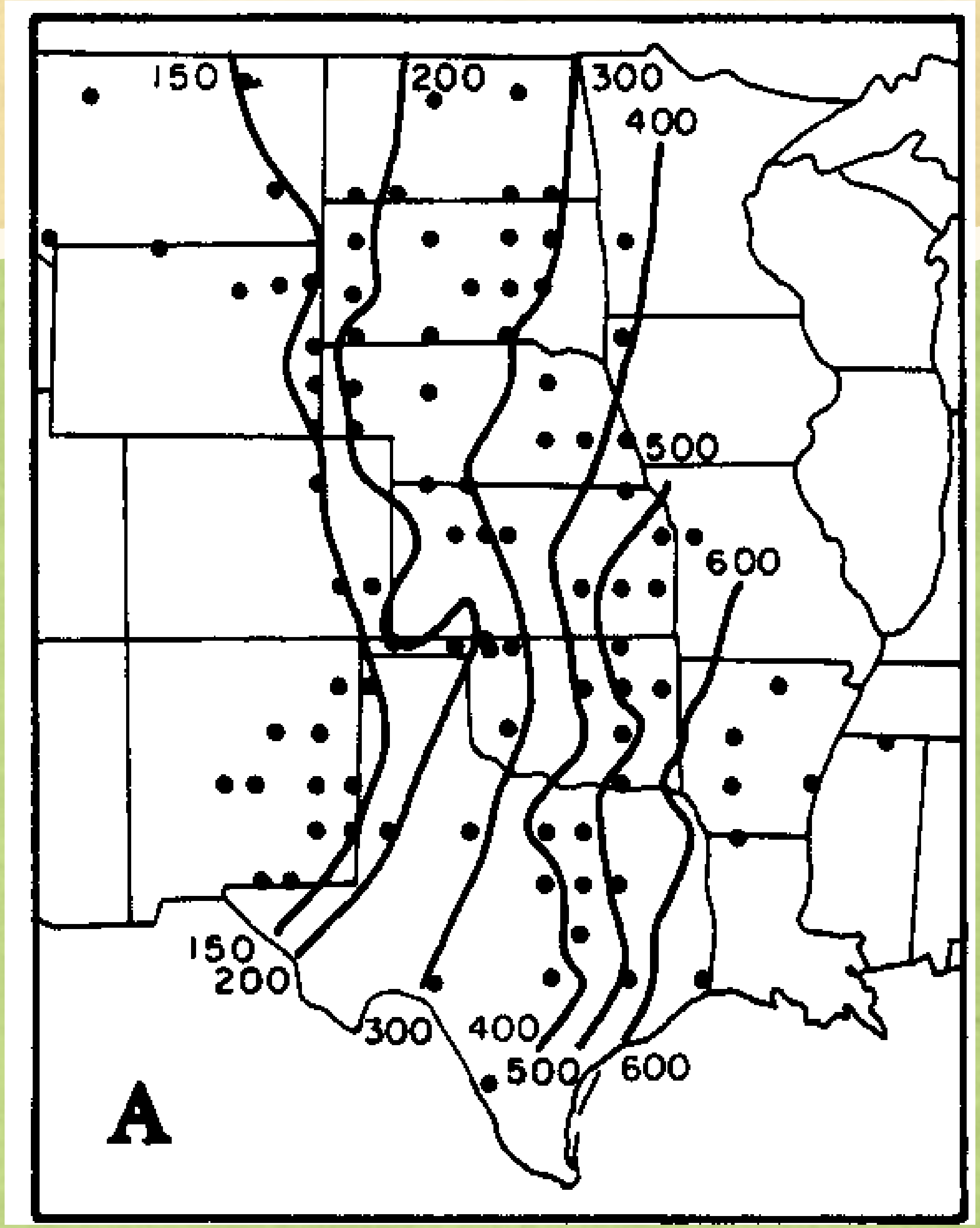
O.E. Sala – Colorado State University explored factors controlling primary productivity in central grasslands of North America

9498 sites grouped into 100 representative study areas

Mississppi/Arkansas → New Mexico/Montana

Primary Productivity

- Highest in eastern grasslands → lowest in west
- Corresponds to change from tallgrass to shortgrass prairie



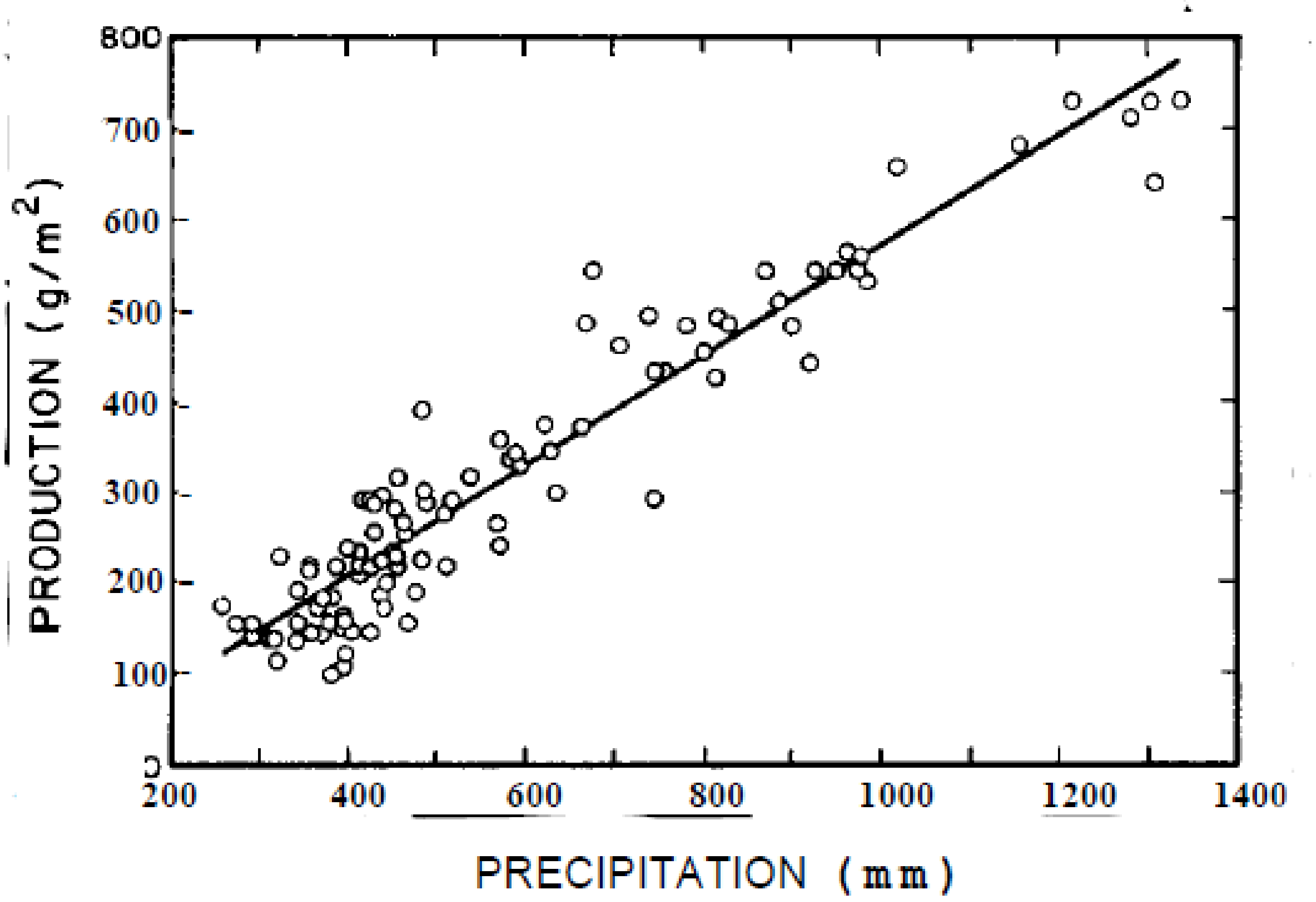


FIG. 2. Relationship between mean annual precipitation and mean aboveground net primary production (ANPP) for 100 major land resource areas across the Central Grassland region. ANPP = -34 + 0.6·APPT; $r^2 = 0.90$.

- Significant relationship with precipitation
- If temperature added no improvement in "fit"

Why?

Warm temperatures occur at all grasslands during the growing season.

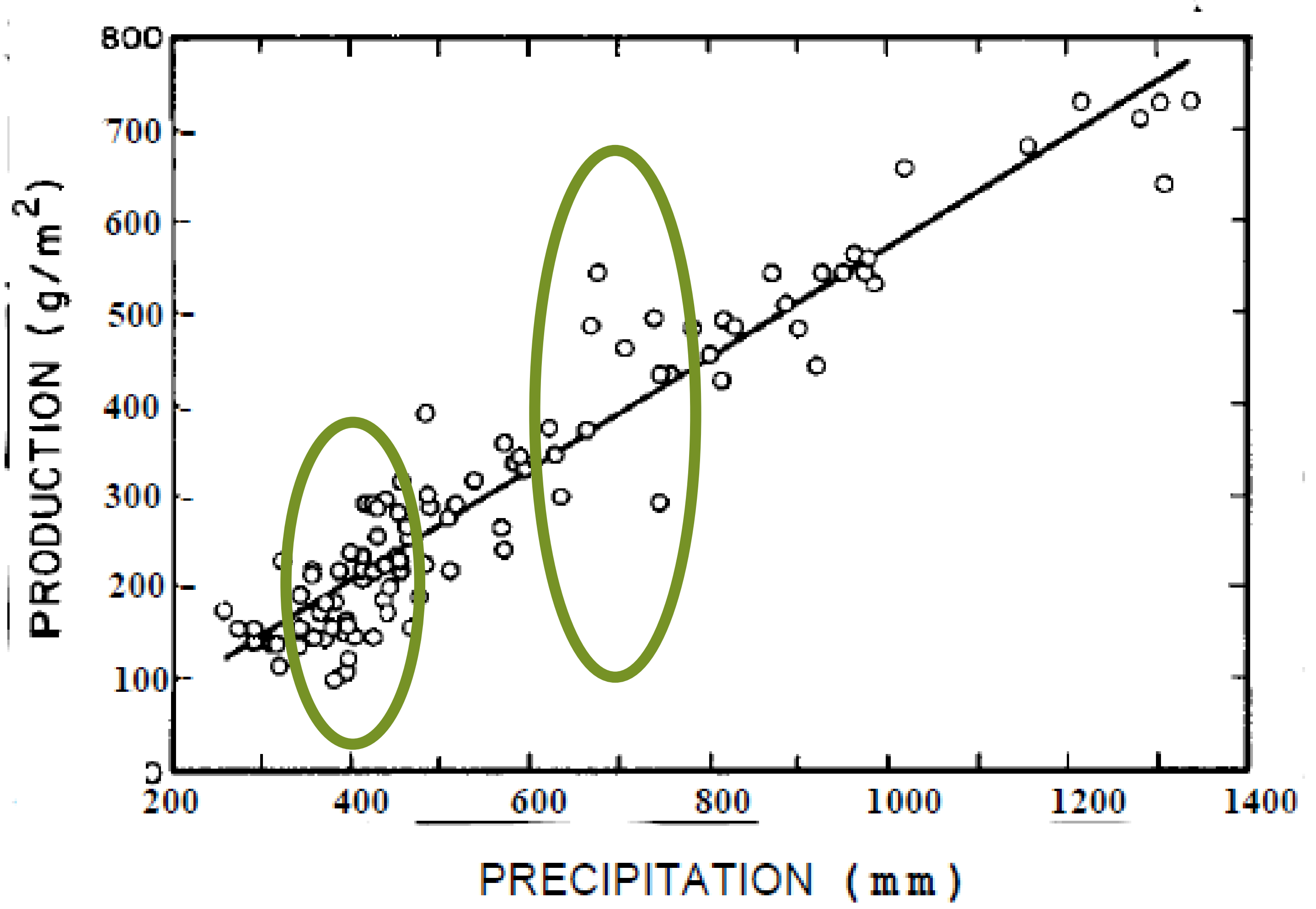


FIG. 2. Relationship between mean annual precipitation and mean aboveground net primary production (ANPP) for 100 major land resource areas across the Central Grassland region. ANPP = -34 + 0.6·APPT; $r^2 = 0.90$.

- 500 – 600 mm shows production ranging from 300 – 1000 g/m²

Why?

Differences challenge ecologists for explanation

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

Owensby et al. Journal of Range Management 23:341-346

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 → +68% ANPP, in burned sites but only +9% in burned sites

NO_3 – availability higher in unburned sites

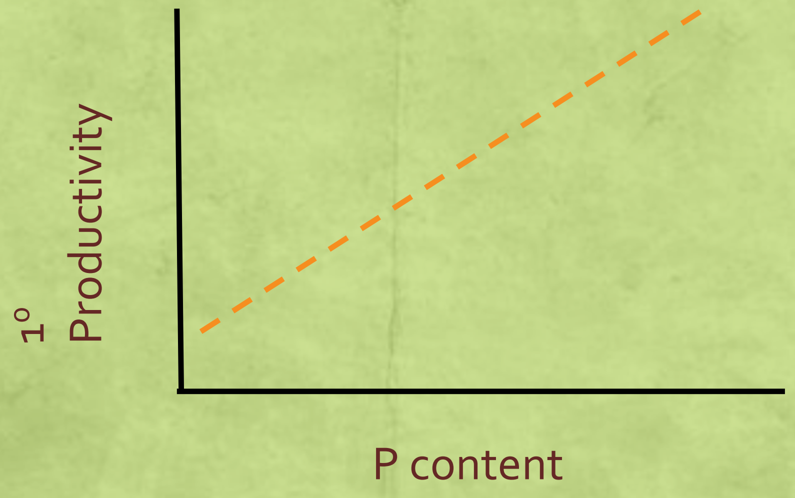
Primary Productivity

Despite major influence of temperature and moisture on ANPP, variation in nutrient availability can also have measureable affect.

Primary Productivity – Aquatic Systems

Significant positive relationships with nutrient availability and primary productivity

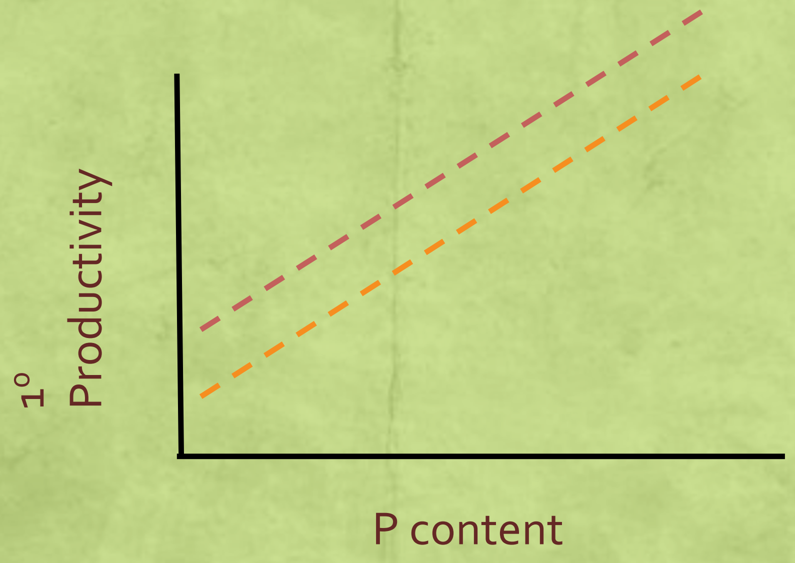
1^{st} studies P & phytoplankton biomass – Japanese lakes (1950's – 60's)



Primary Productivity – Aquatic Systems

Later similar relationship seen with lakes in Northern Hemisphere

Slopes in both studies nearly identical!



Nutrients – particularly P, control phytoplankton biomass

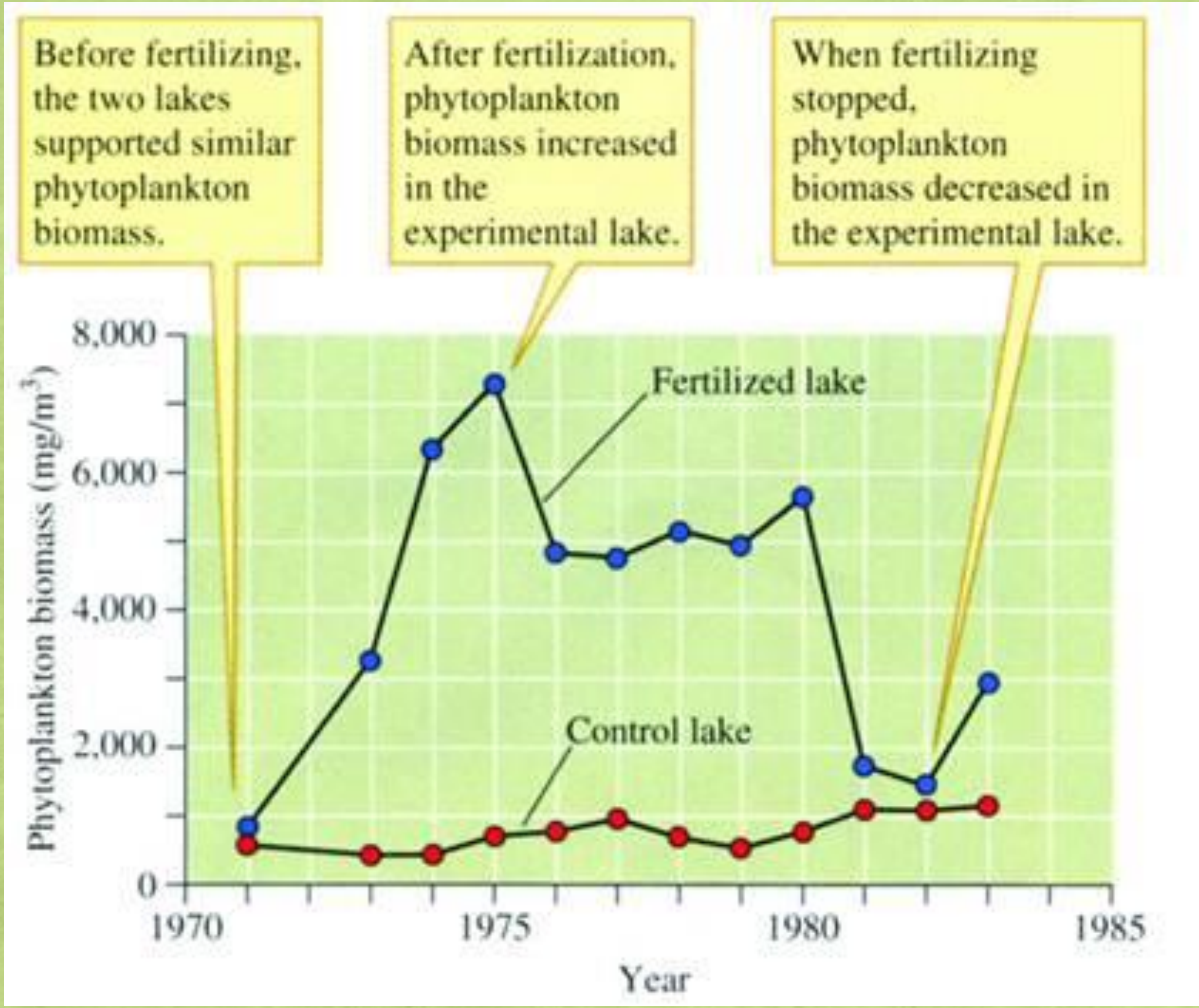
Primary Productivity – Aquatic Systems

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.
Fertilized lake
Control lake
Phytoplankton biomass (mg/m³)
8,000
6,000
4,000
2,000
0
1970
1975
1980
1985
Year

Primary Productivity – Aquatic Systems

Freshwater systems – P additions have a much larger effect

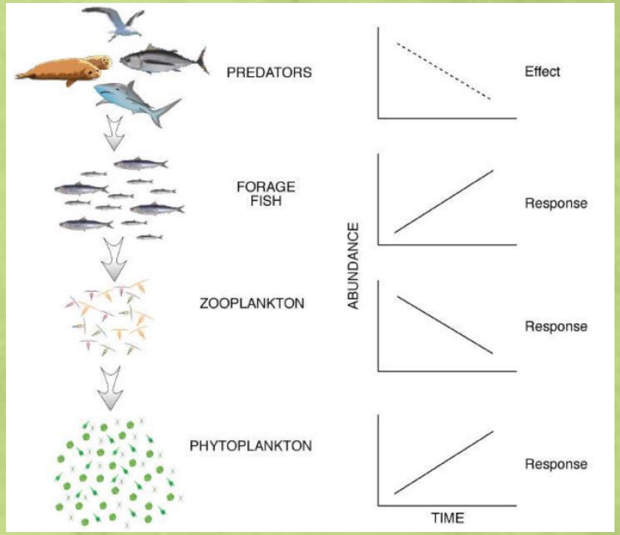
Marine systems – N additions have a much larger effect on hard bottom substrates (coral reefs, rocky intertidal, open ocean)

Trophic Cascades

Chemical controls on 1^{o} productivity = bottom up controls

But… consumers may also influence 1^{o} productivity =

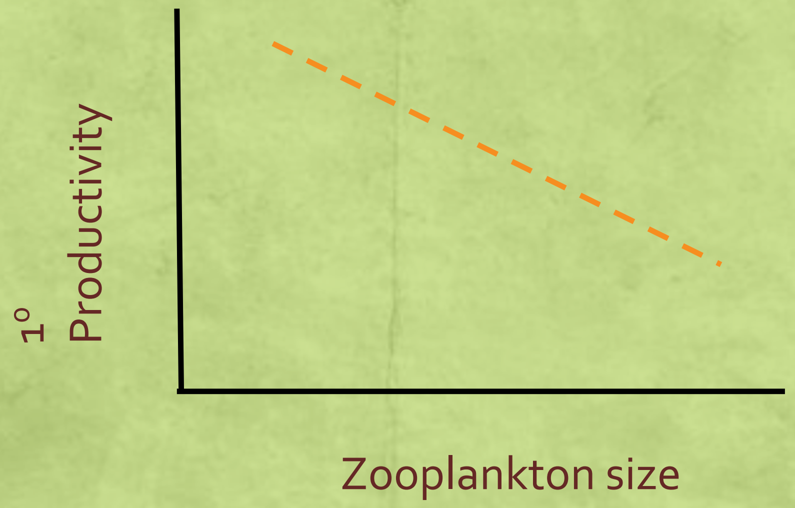
top down controls



Trophic Cascades

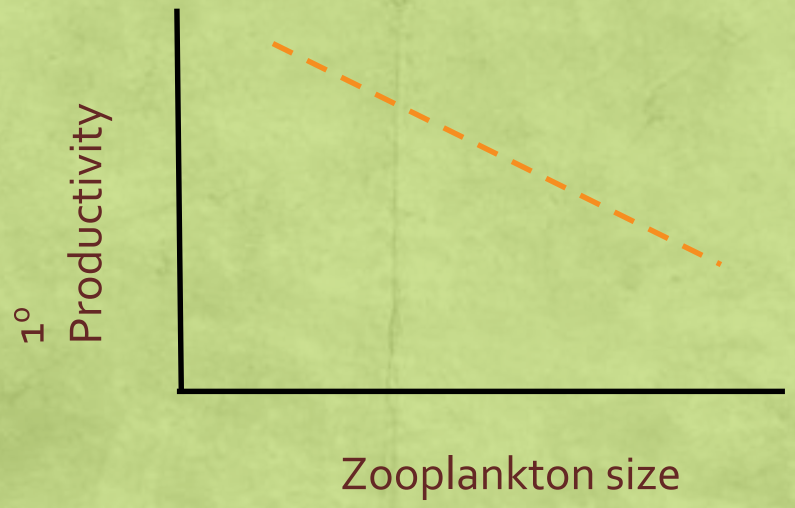
Carpenter, Kitchell and Hodgosn – Bioscience 35:634-639

Althoght nutrients determine 1° productivity in lakes, piscivorous and planktivorous fish can cause significant deviations



Trophic Cascades

Proposed influence of consumers on lake 1º productivity propagate through food web



Trophic Cascades

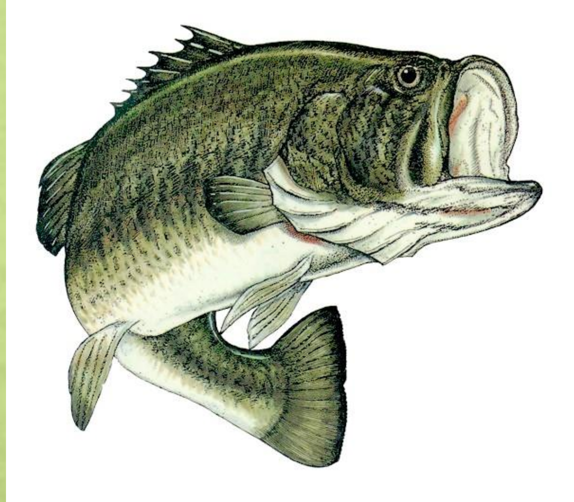
Visualized effects of consumers coming from top of food web to base → Trophic Cascade Hypothesis

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

Trophic Cascades

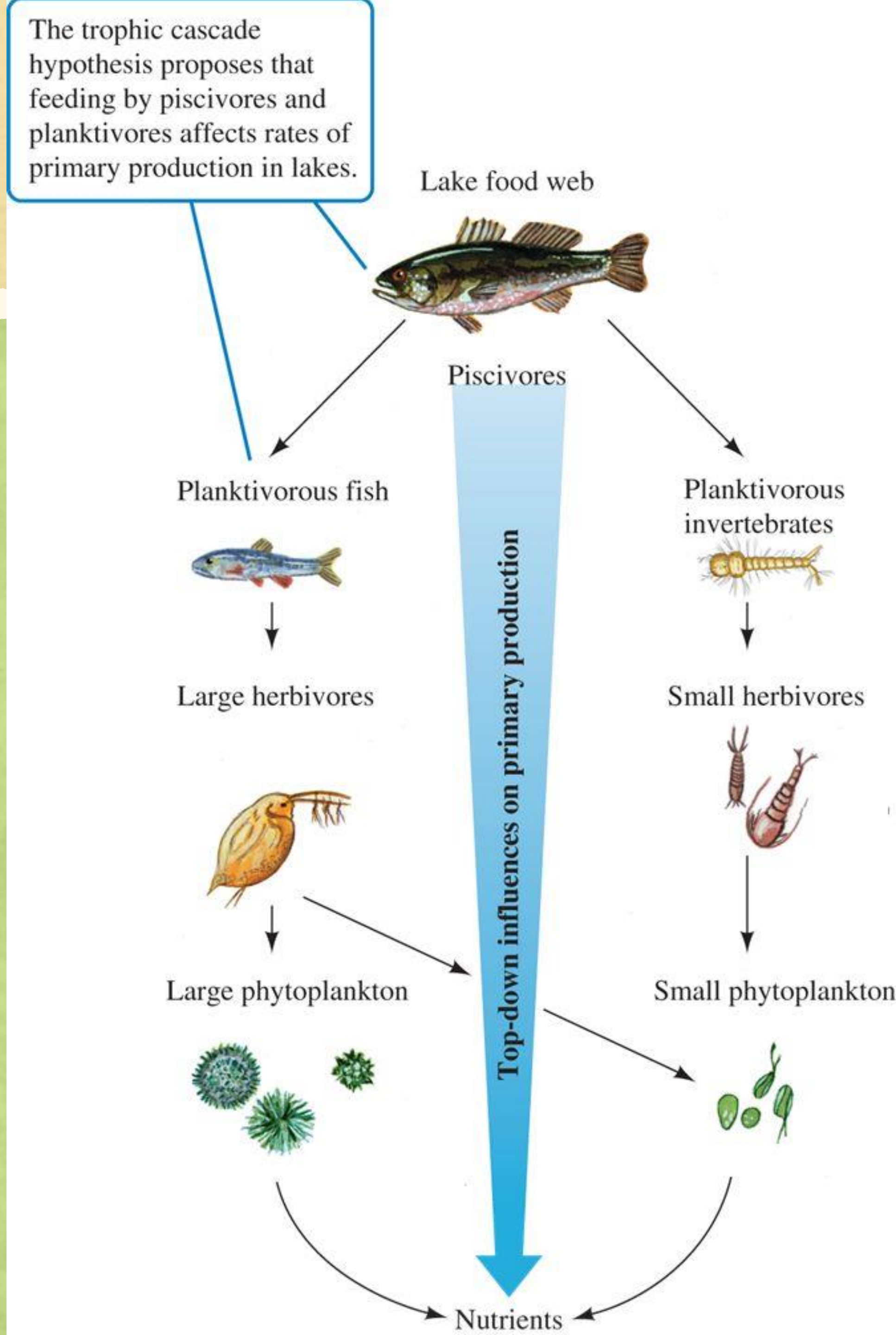
1. Piscivorous fish (LMB) feed on plankivorous fish & inverts
2. Because of their influence on planktivorous fish, LMB indirectly effect populations of zooplankton

By reducing plankivorous fish, LMB reduce feeding pressure on zooplankton



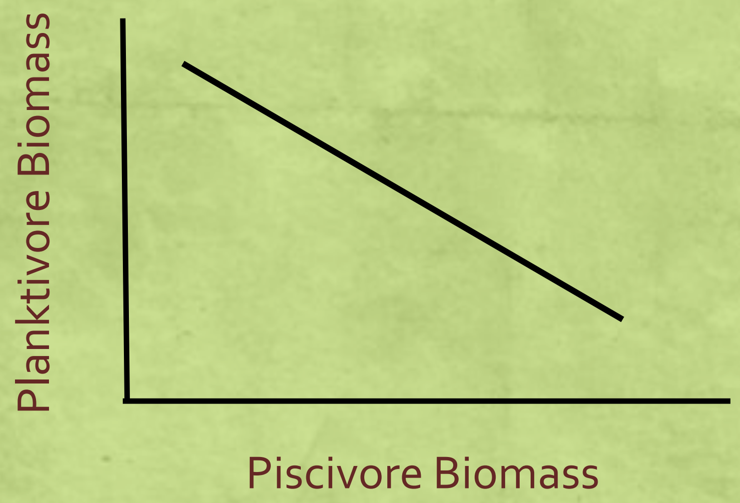
Trophic Cascades

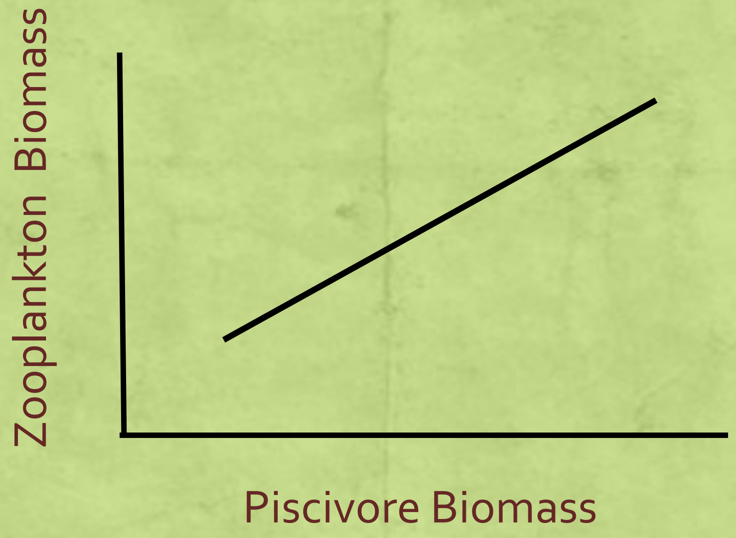
3. Large bodied zooplankton dominate zooplankton community
4. Dense population of zooplankton reduces phytoplankton biomass and rate of 1° productivity

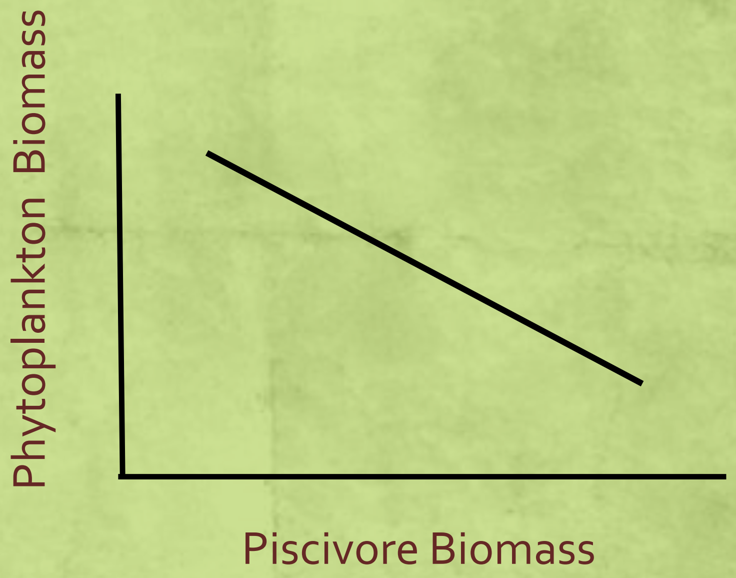


Trophic Cascades

Hypothesis predictions







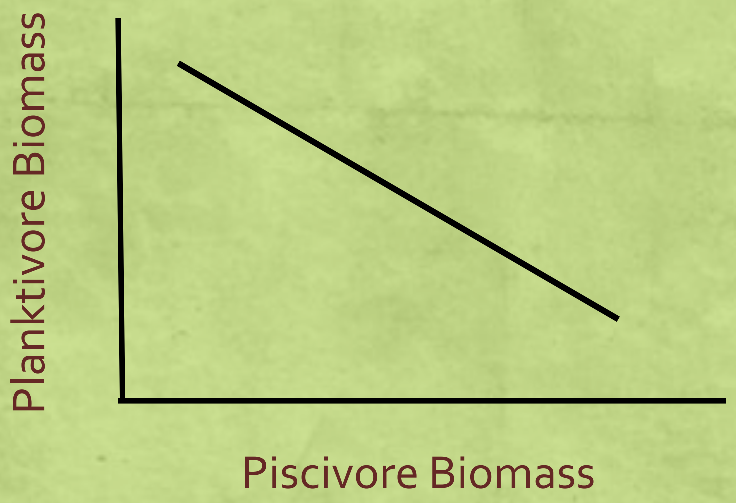
Trophic Cascades

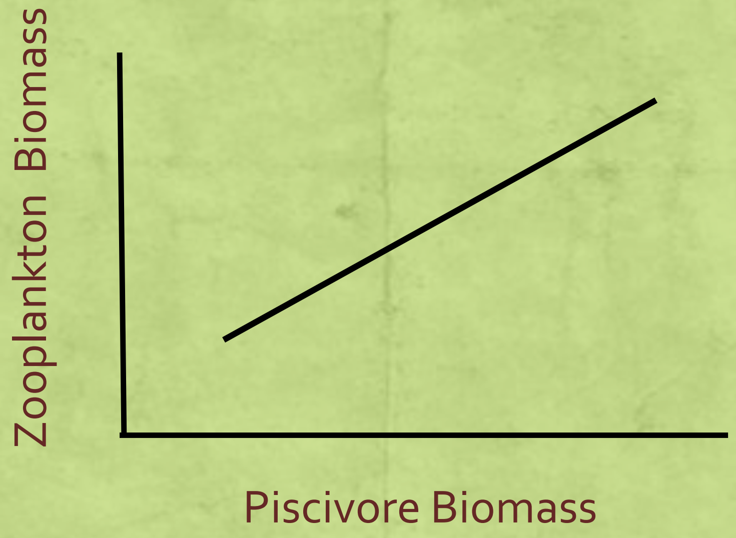
By manipulating fish communities in 2 lakes can test predictions

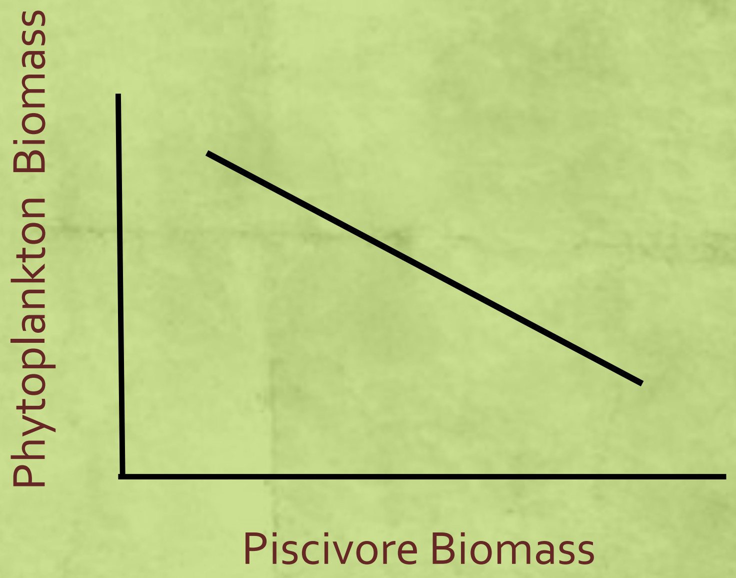
1. Increased LMB / reduced Planktivores
2. Increased Planktivores / reduced LMB
3. Control

Trophic Cascades

Hypothesis predictions







Trophic Cascades

Results

1. Reducing planktivorous fish → ↓ 1° productivity - in absence of minnows, predaceous inverts fed heavily on smaller herbivorous zooplankton
2. Increasing plankivorous fish / reduce LMB → ↑ 1° 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

Strong 1992 Ecology 73:747-754

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

Trophic Cascades

Serengeti – Mara 25,000 km^2
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…

Trophic Cascades

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 Flow

Energy is lost with each transfer between trophic levels

- Assimilation efficiency
- Respiration by consumers
- Heat production

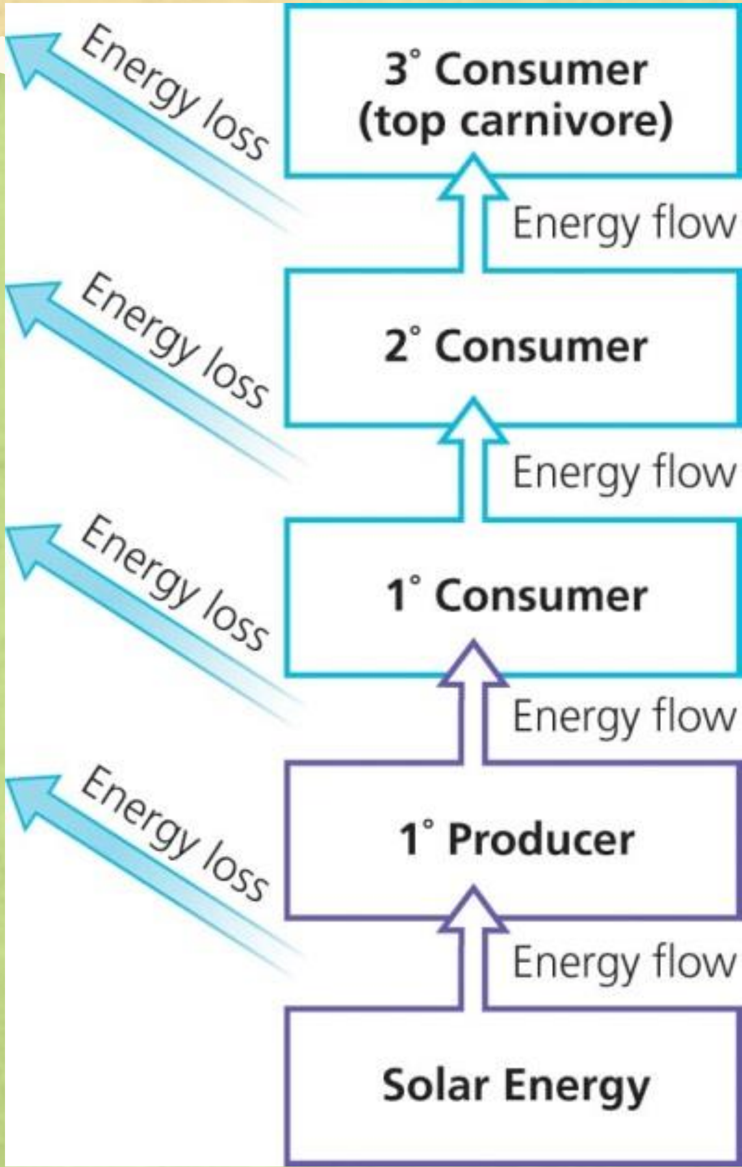
Energy Flow

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