Ecosystem Ecotoxicology

Ecosystem processes and approaches for assessing ecosystem responses to contaminants

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INTRODUCTION

- **Definition:**

Ecotoxicology : study of the effects of toxic chemicals on biological organisms, especially at the population, community, ecosystem level

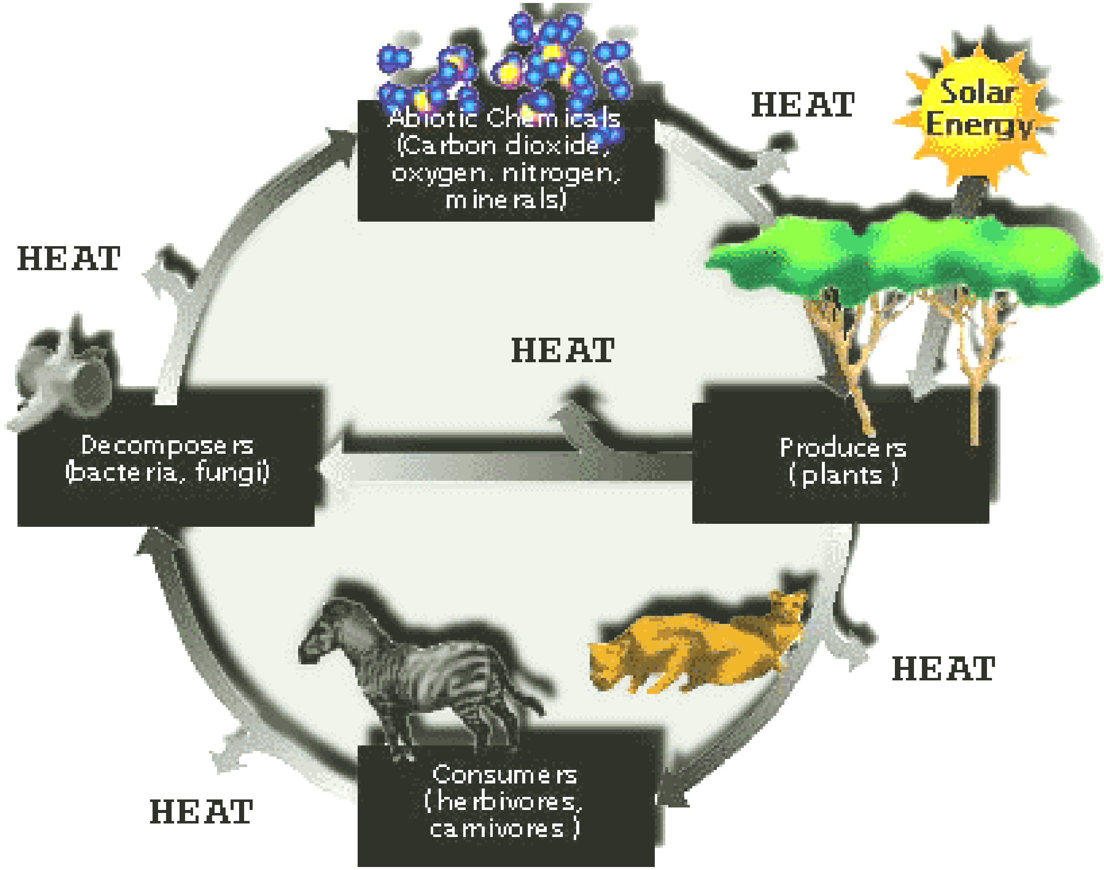
Ecosystem: biological system consisting of all the living organisms or biotic components in a particular area and the nonliving or abiotic component with which the organisms interact, such as air, mineral soil, water and sunlight

Ecosystem ecology : study of the movement of energy and materials through biotic and abiotic compartments of ecosystems

ABIOTIC COMPONENTS	BIOTIC COMPONENTS
Sunlight	Primary producers
Temperature	Herbivores
Precipitation	Carnivores
Water or moisture	Omnivores
Soil or water chemistry (e.g., P, NH_4+)	Detritivores
etc.	etc.

ENERGY FLOWS AND MATERIAL CYCLES

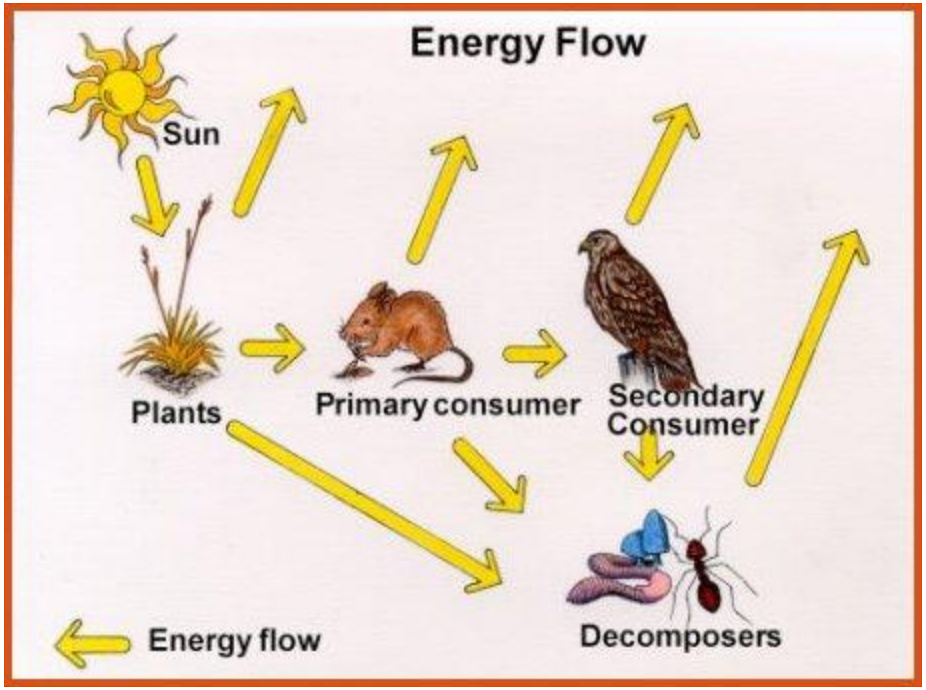
- Two main ideas about how ecosystems function: ***ecosystems have energy flows*** and ***ecosystems cycle materials***. These two processes are linked, but they are not quite the same



1) Ecosystem processes

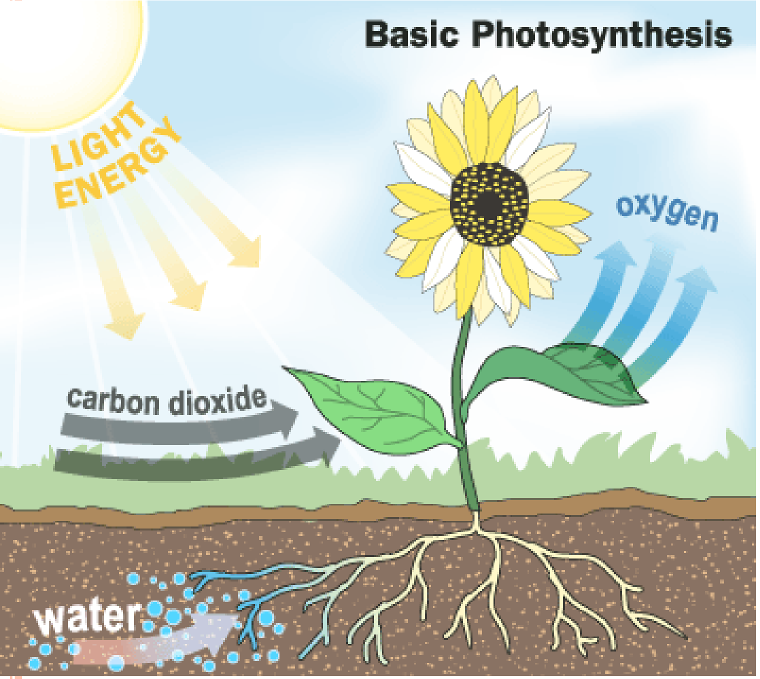
A) Bioenergetics and Energy Flow through Ecosytems

ecosystems = energy-transforming systems



PRIMARY PRODUCTION

- Energy enters the biological system as light energy is transformed into chemical energy in organic molecules by cellular processes (photosynthesis and respiration) and ultimately is converted to heat energy.



6CO2 + 6H2O + Light energy → C6H12O2 + 6O2

Inorganic carbon + Nutrients + Light energy → Biomass + Heat

(Sterner and Elser2002)

NPP = GPP – Respiration

GGP: gross primary production
NPP: net primary production

Methods for Measuring Net Primary Production:

$$B = B2 - B1$$

where $B2$ is the biomass at time 2 and $B1$ is the biomass at time 1.

Factors Limiting Primary Productivity :

- Light,
- Temperature,
- Nutrients,
- Moisture

SECONDARY PRODUCTION

- The rate of productivity of consumers such as herbivores and predators that obtain their energy from plant or animal biomass.

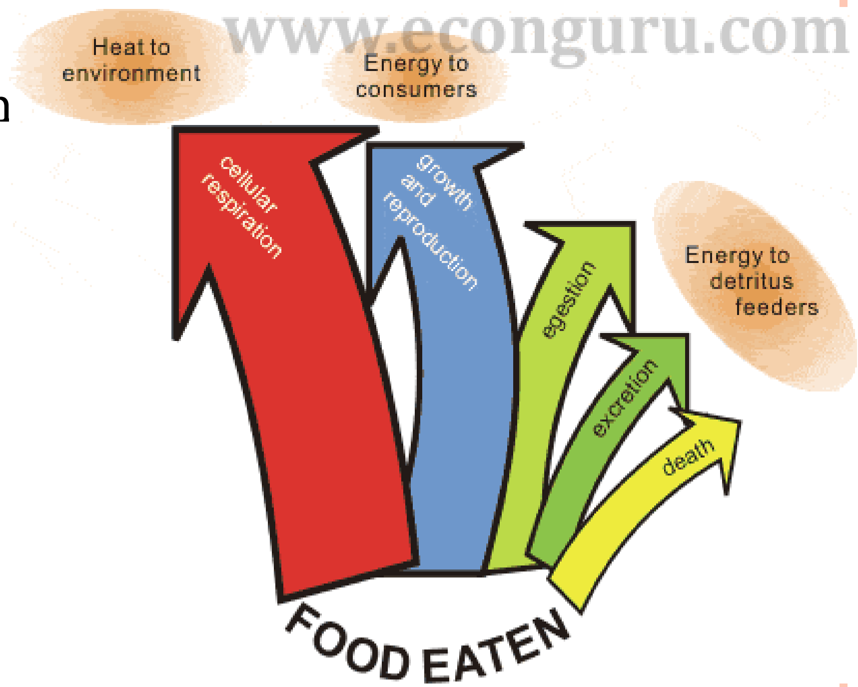
- Only a small fraction of the assimilated energy in consumers is available for growth and reproduction; the remaining is necessary for maintenance and respiration.

- Consumption = Respiration +Wastes + Growth

Difficulties quantifying the role of detritus and the imprecise assignment of organisms to different trophic groups are significant impediments to the quantification of secondary production.

Ecological Efficiencies
Energy transfer through the food chain is inefficient

- Only a small fraction of the assimilated energy in consumers is available for growth and reproduction The remaining is necessary for maintenance and respiration
- Less energy is available at the herbivore level than at the primary producer level, less yet at the carnivore level, and so on.



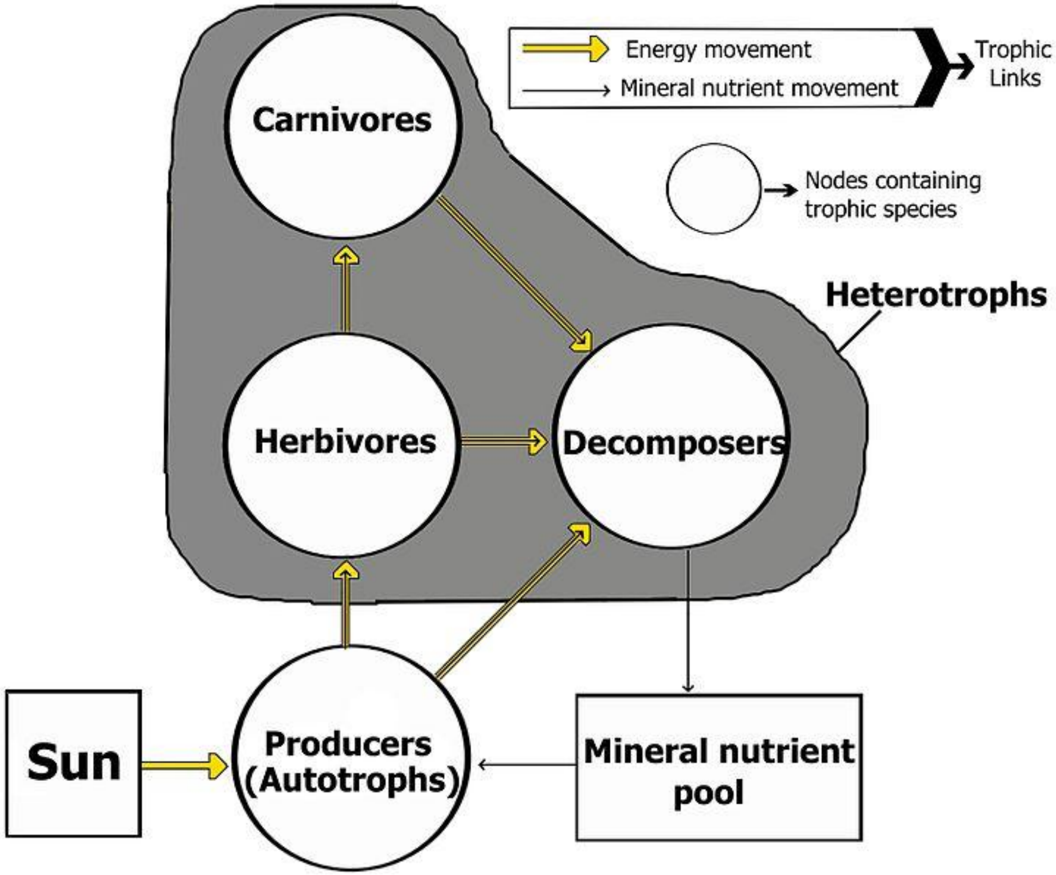
The result is a pyramid of energy

- Energy is dissipated, meaning it is lost to the system as heat; once it is lost it cannot be recycled.
- Without the continued input of solar energy, biological systems would quickly shut down.
- Thus the earth is an ***open system*** with respect to energy.

B) Nutrient cycling and Materials flow through ecosystems

- A **nutrient cycle** (or **ecological recycling**) is the movement and exchange of organic and inorganic matter back into the production of living matter. The process is regulated by food web pathways that decompose matter into mineral nutrients
- Ecosystems recycle locally, converting mineral nutrients into the production of biomass, and on a larger scale they participate in a global system of inputs and outputs where matter is exchanged and transported through a larger system of biogeochemical cycles.
- **Mineral cycles** include carbon cycle, sulfur cycle, nitrogen cycle, water cycle, phosphorus cycle, oxygen cycle, among others that continually recycle along with other mineral nutrients into productive ecological nutrition.

- The movement of mineral nutrients through the food chain, into the mineral nutrient pool, and back into the trophic system illustrates ecological recycling.
- The movement of energy, in contrast, is unidirectional and noncyclic



Simplified food web illustrating a three trophic food chain (producers-herbivores-carnivores) linked to decomposers

- During decomposition these materials are not destroyed or lost, so the earth is a ***closed system*** with respect to elements .
- The elements are cycled endlessly between their biotic and abiotic states within ecosystems.
- Many toxic chemicals have direct effects on ecosystems because they alter biogeochemical processes.

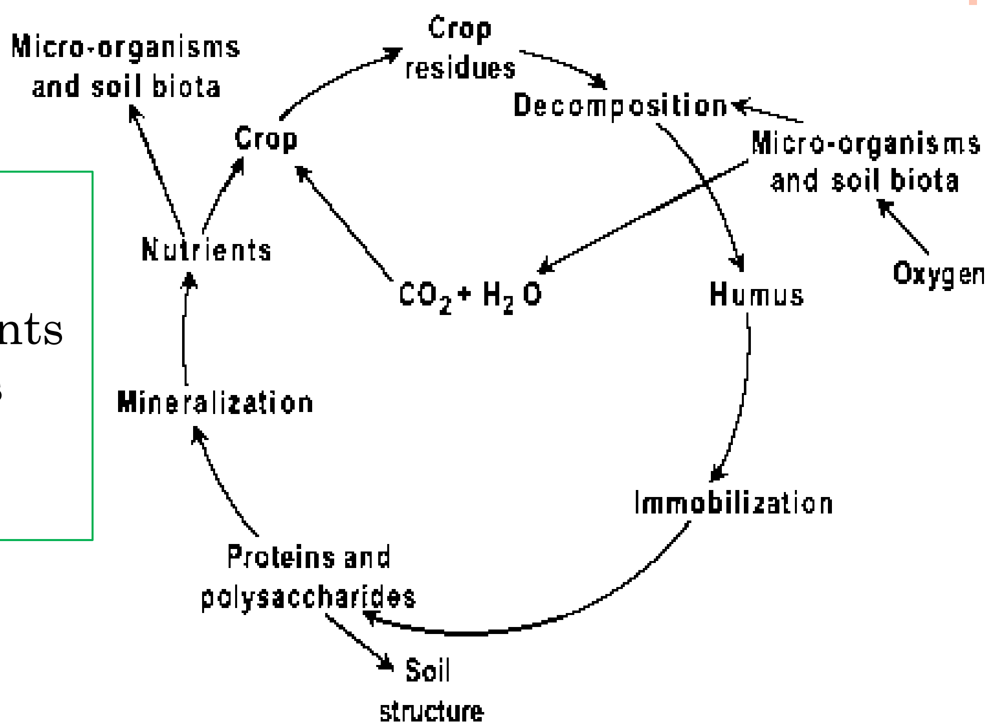
Stoichiometry

- Ecological stoichiometry, defined as the balance of multiple chemical substances in ecological interactions and processes (Sterner and Elser 2002), uses ratios of certain elements (C, N, and P) to characterize how composition of organisms and their prey affect nutrient cycling, production, and energy flow.

C) Decomposition and organic matter processing

- Decomposition is the process by which dead organic matter (detritus) is broken down to its component parts.
- Decomposition is a fundamental process of ecosystems that varies significantly with levels of disturbance
- During the decomposition process, microorganisms convert the carbon structures of fresh residues into transformed carbon products in the soil.

Carbon cycling is the continuous transformation of organic and inorganic carbon compounds by plants and micro- and macro-organisms between the soil, plants and the atmosphere



- In the decomposition process, different products are released: carbon dioxide (CO_2), energy, water, plant nutrients and resynthesized organic carbon compounds. Successive decomposition of dead material and modified organic matter results in the formation of a more complex organic matter called humus (Juma, 1998).

- Changes in mass (dry weight) or nutrient content of organic material over time is generally used as an indicator of decomposition rates.

Flow of energy, cycling of nutrients, and decomposition of litter are fundamental processes in all ecosystems. A basic understanding of these processes and how they vary spatially and temporally is necessary to predict how these systems may respond to anthropogenic stressors

Because pathways of energy flow and biogeochemical cycles in ecosystems are intimately coupled with the movement of contaminants, basic models developed by ecosystem ecologists may also help explain fate of xenobiotic chemicals.

2) Descriptive approaches for assessing ecosystem responses to contaminants

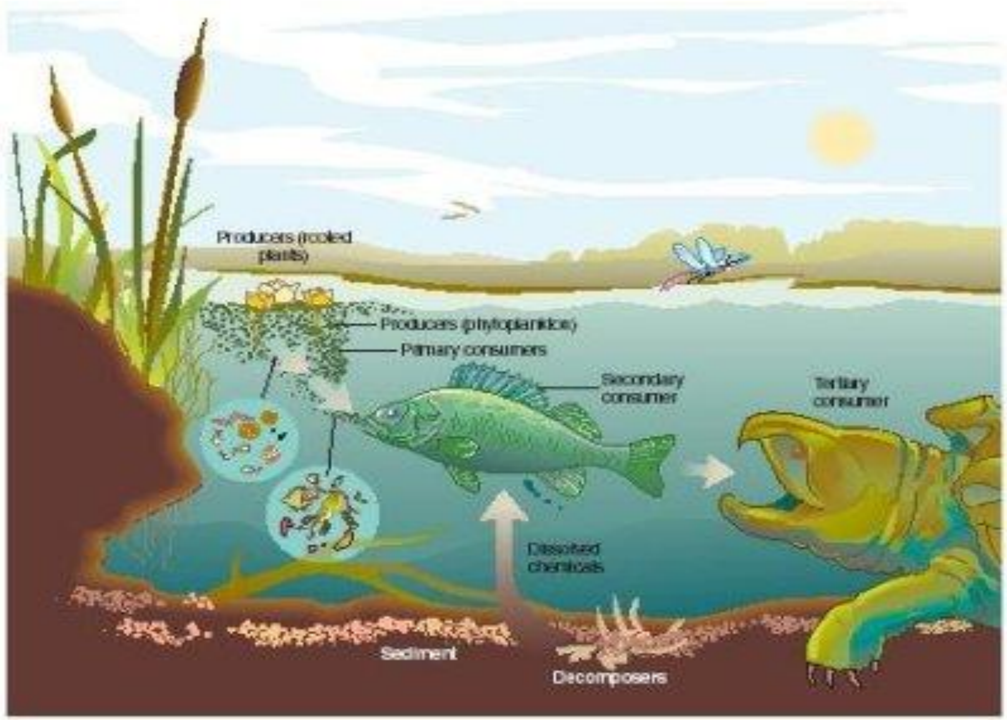
- Many different processes could be used to assess ecosystem integrity: ecosystem metabolism (respiration, primary and secondary production), litter decomposition, and nutrient cycling.

- The methodological approaches used to assess effects of contaminants on ecosystem metabolism are consequently different in aquatic and terrestrial ecosystems.

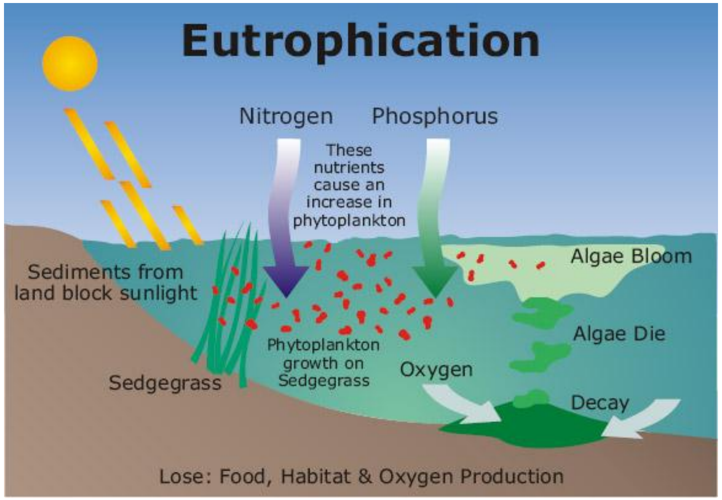
A) Aquatic Ecosystems

PRIMARY PRODUCTION

- Primary production in aquatic ecosystems is particularly sensitive to many anthropogenic stressors.
- The role of nutrients such as N and P are both regulators of ecosystem production as well as stressors when threshold levels are exceeded.

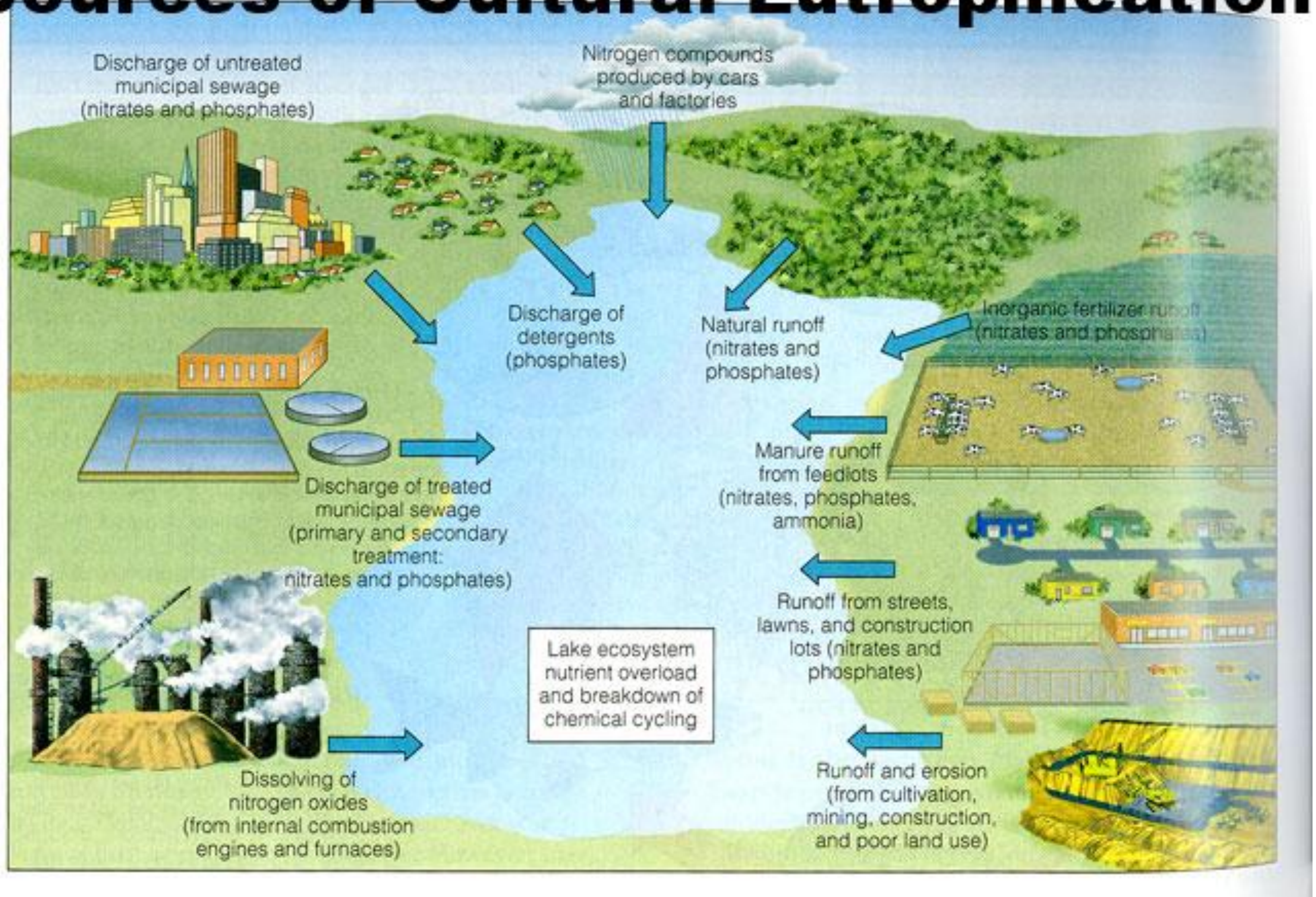


- These increased nutrient levels are often associated with toxic algal blooms, increased plant growth, oxygen depletion, fish kills, and major shifts in community composition. Land-based inputs of nutrients also increase eutrophication and have negative effects on primary production of macrophytes in coastal areas
- These effects resulted from reduced light supply associated with increased phytoplankton production.



- Availability of N and P can directly regulate primary production and biomass accrual in aquatic ecosystems (Biggs 2000). However, the direct effects of nutrients on primary production are complex and may be mediated by other factors such as hydrologic characteristics and abundance of grazers

Sources of Cultural Eutrophication



- Input of nutrients associated with agricultural, domestic, industrial, and atmospheric sources are widely regarded as major stressors of aquatic ecosystems (National Research Council 1992).

SECONDARY PRODUCTION

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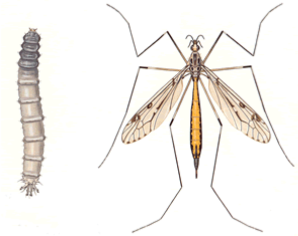
Production may either increase or decrease, depending on the nature of the stressor !

- Contaminants and other stressors may alter the amount and rate of energy flow to higher trophic levels.
- The utilization of available energy in an ecosystem is thus an important measure of ecological integrity.
- The most common functional response related to energetics measured in aquatic ecosystems is the abundance of different functional feeding groups (Rawer-Jost et al. 2000,Wallace et al. 1996).
- The utility of functional feeding groups as a metric in ecological assessments is based on the assumption that specialist feeders such as scrapers and shredders are more sensitive to contaminants than generalist feeders such as collector gatherers and filterers (Barbour et al. 1996).

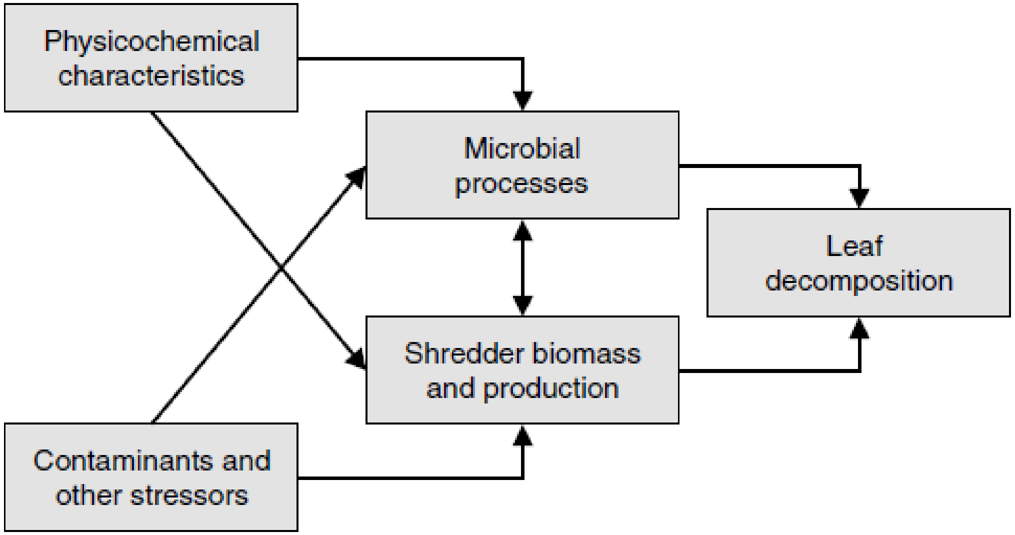
Blackflies: *Filter-collectors*.
Larval can filter out particles as fine bacteria.



Crane Flies : larva and adult stages
Large *shredders* of leaf litter.

DECOMPOSITION

- Breakdown rate coefficients (*k*), measured by regressing remaining mass of litter against time, are generally reduced in disturbed ecosystems.
- Effects of contaminants on litter decay may result either from alterations in microbial processes or reduced abundance of macroinvertebrate shredders

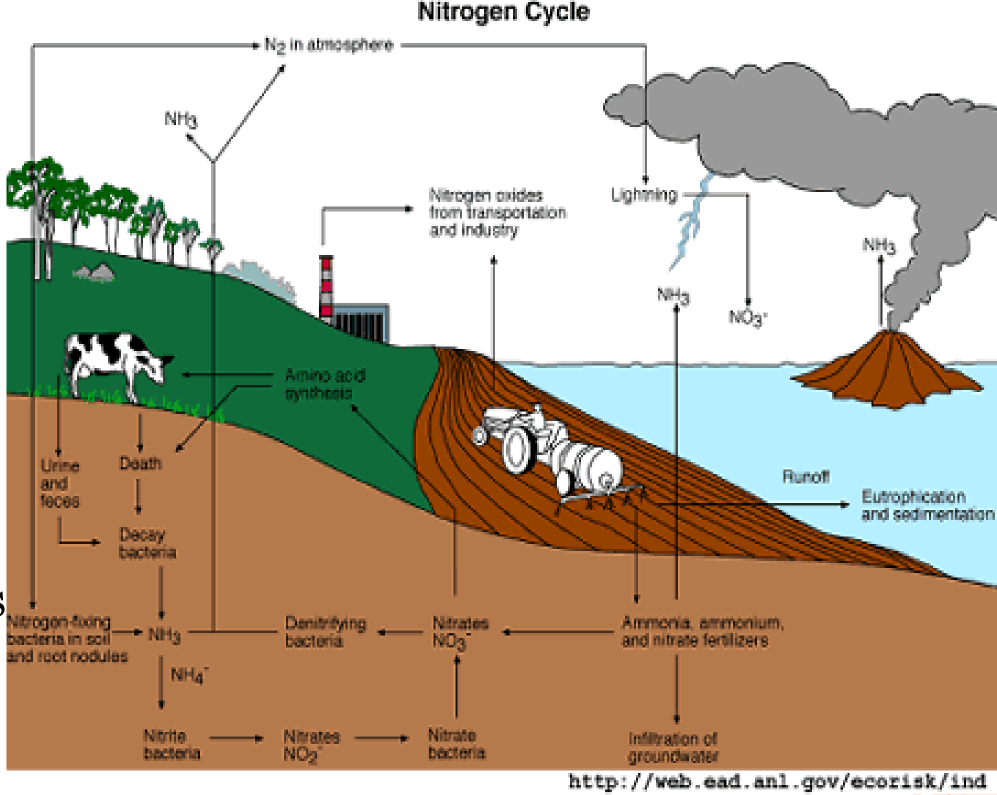


Conceptual model showing the effects of contaminants and physicochemical characteristics on microbial processes, shredder biomass, and leaf litter decomposition.

- Stream acidification by atmospheric deposition or other sources can have direct effects on litter decomposition

NUTRIENTS CYCLING

- The majority of studies investigating effects of contaminants on nutrient cycling in aquatic ecosystems have focused on nitrification, denitrification, and other processes associated with N flux .



- Most of this research has been conducted within the context of understanding effects of nutrient enrichment, especially N and P, on freshwater and estuarine ecosystems.
- Eutrophication, caused by the release of excess nutrients, is regarded as the major threat to freshwater and coastal ecosystems
- Because rates of nitrification and denitrification in aquatic ecosystems are dependent on concentrations of ammonium (NH4*)* and nitrate (NO3*)*, these processes are likely to increase in areas receiving anthropogenic inputs.

B) Terrestrial Ecosystems

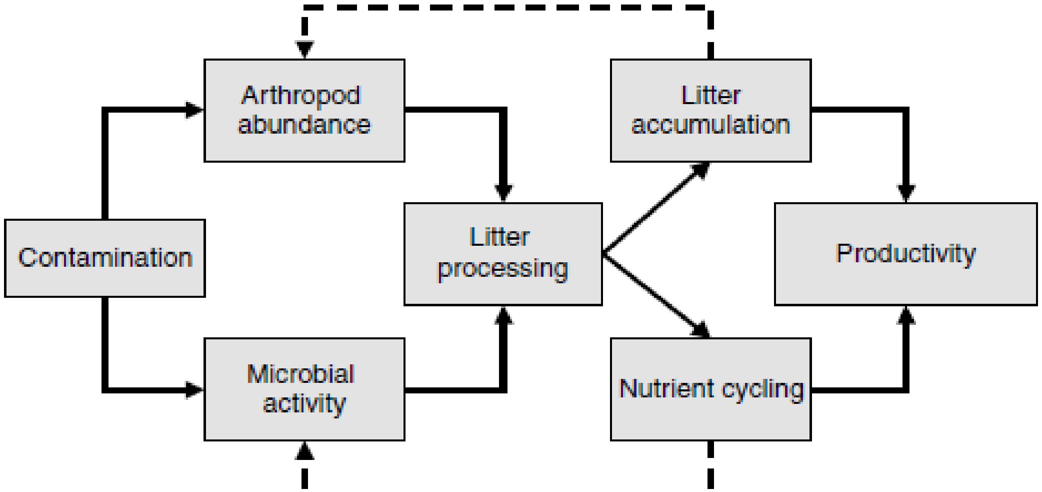
RESPIRATION AND SOIL MICROBIAL PROCESSES

- Effects of contaminants on microbial and soil ecosystem processes, especially soil respiration, have been examined in considerable detail
- Ecosystem processes in soils are significantly more sensitive to contaminants than the plant communities they support
- Dai et al. (2004) reported a strong inverse relationship between heavy metal concentrations in soils and respiration rates

- Shifts in community structure, such as an increase in biomass of fungal populations and a decrease in bacterial populations, can also result in changes in soil ecosystem function
- Biological factors such as acclimation or adaptation of soil microorganisms to contaminants may also explain some of the variation observed in these studies

LITTER DECOMPOSITION

- Litter decomposition is an important process in terrestrial ecosystems that is closely related to primary productivity, energy flow, and nutrient cycling.



Conceptual model showing the potential mechanisms of contaminant effects on leaf litter processing, nutrient cycling, and productivity. Dashed lines indicate potential feedback between certain processes.

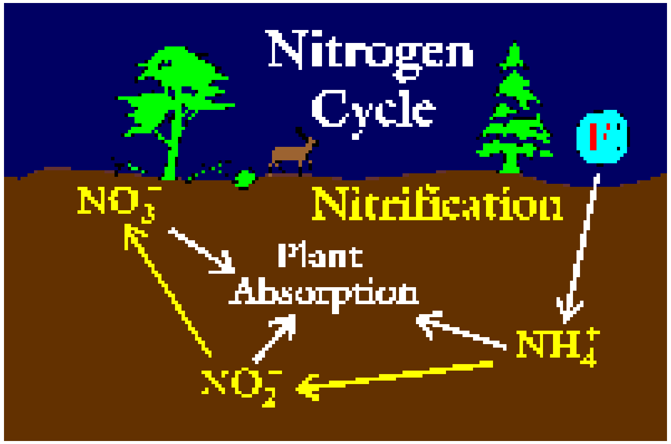
- The changes in nutrient supply can affect primary productivity and subsequent litter production.
- Microbial processes controlling decomposition are particularly sensitive to contaminants

- Because litter decomposition is relatively easy to measure and sensitive to a variety of stressors, it is a useful endpoint for ecological risk assessment in terrestrial ecosystems.
- Reduced litter decomposition can also affect nutrient cycling and growth of vegetation, thereby reducing soil organic content and increasing contaminant bioavailability (Derome and Nieminen 1998, Johnson and Hale 2004).
- Because contaminants may affect processing of detritus and accumulation of organic material in soils, the ability of an ecosystem to assimilate contaminants may be reduced because of lower organic content and subsequently greater contaminant bioavailability (Derome and Nieminen 1998).

- Approaches employed in terrestrial ecosystems to measure litter decomposition are similar to those in streams and involve measurement of weight loss of litter placed at reference and contaminated field sites.
- Because decomposition rates are generally lower in terrestrial systems, litter bags must be deployed for longer periods of time (e.g., 12–24 months) to obtain reliable decay coefficients (*k*).

NUTRIENT CYCLING

- The majority of studies investigating the influence of contaminants on nutrient dynamics in terrestrial ecosystems have focused on **nitrification**, which is defined as the conversion of ammonium to nitrite (NO2*)* and nitrate (NO3*)*.



- Nitrification is a critical component of the nitrogen cycle that ultimately determines the availability of soil N to plants and other organisms. The sensitivity of this two-step process to contaminants is dependent on the relative sensitivity of the two groups of bacteria responsible (*Nitrosomonas* and *Nitrobacter*).
- Because nitrification and microbial decomposition are sensitive to contaminants and influence the amount of organic materials in soils, contaminant bioavailability would likely be increased in ecosystems where these processes are inhibited.

CONCLUSION

- A holistic understanding of factors that regulate transport and transformation of nutrientsin ecosystems requires integration of aquatic and terrestrial processes
- An important distinction between terrestrial and aquatic ecosystems is that N often limits productivity in terrestrial ecosystems whereas P is frequently the primary limiting nutrient in aquatic ecosystems
- The potential for conductingsurveys of contaminant effects on ecosystem processes over a relatively large spatiotemporal scale is amajor strength of these comparative approaches.
- Because the ecosystem processes are strongly interrelated and influenced by natural biotic and abiotic , quantifying the direct effects of contaminants is challenging.

THANK YOU FOR YOUR ATTENTION !

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