1 Ecosystems: Matter Cycling

EVPP 111 Lecture

Spring 2004

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Energy Flow and Matter Cycling

- Energy flows through ecosystems
- Matter Cycles through ecosystems
  - types of cycles
  - types of reservoirs
  - major biogeochemical cycles

3 Energy flow vs. Matter Cycling

- energy flows through the earth system
- Matter cycles through the earth system

4 Matter cycles within ecosystems

- Organisms depend on the ability to recycle basic of “nutrients” of life
  - nutrients (matter)
    - any atom, molecule, or ion an organism needs to live, grow, or reproduce
      - some required in fairly large quantities
        - C, H, O, N, phosphorus, sulfur, calcium
      - some required in small or trace amounts
        - sodium, zinc, copper, iodine

5 Matter cycles within ecosystems

- nutrients
  - globally, only small portion of these substances is contained within organisms
    - most exist in nonliving reservoirs
      - atmosphere, water, rocks

6 Matter cycles within ecosystems

- Matter cycles
  - continually through both biotic and abiotic components of ecosystems
    - called biogeochemical cycles.
      - cyclic pathways involving biological, geological and chemical processes
      - driven directly or indirectly by incoming solar radiation and gravity
      - connect past, present, future forms of life

7 Matter cycles within ecosystems

- cycling of matter through ecosystems
  - begins with incorporation of substances into bodies of living organisms from non-living reservoirs
    - materials pass from organisms that first acquire them into bodies of

organisms that eat eat them
- until they complete the cycle and return to the nonliving world, through decomposition

8 Matter cycles within ecosystems
- there are many biogeochemical cycles
  - unified by involvement of four reservoirs of earth system through which matter cycles
    - lithosphere (rocks and soils)
    - atmosphere
    - hydrosphere(oceans, surface waters, groundwater, glaciers)
    - biosphere (living organisms)

9 Matter cycles within ecosystems
- matter in these reservoirs have different average times of storage or cycling
  - depending on two main determinants
    - chemical reactivity of the substance
    - whether it has a gaseous phase at some point in cycle

10 Matter cycles within ecosystems
- Generalized average times of storage or cycling based on reservoir
  - long
    - lithosphere (rocks and soils)
  - intermediate
    - hydrosphere(oceans, surface waters, groundwaters, glaciers)
    - biosphere (living organisms)
  - short
    - atmosphere

11 Matter cycles within ecosystems
- 3 main categories of biogeochemical cycles
  - Hydrologic
  - Gaseous
  - Sedimentary

12 Matter cycles within ecosystems
- hydrologic
  - hydrologic (water) cycle

13 Matter cycles within ecosystems
- Gaseous
  - involves exchanges among atmosphere, biosphere, soils and oceans
  - include
    - carbon Cycle
    - oxygen Cycle
    - nitrogen Cycle

14 Matter cycles within ecosystems
- Sedimentary
  - involves materials that move from land to oceans and back
  - include
    - phosphorous cycle
    - sulfur cycle

15 Matter cycles within ecosystems
- Main biogeochemical cycles
  - hydrologic cycle
    - hydrologic cycle
  - gaseous
    - carbon cycle
    - nitrogen cycle
  - sedimentary
    - phosphorous cycle

16 Matter cycles within ecosystems
- Main biogeochemical cycles
  - hydrologic cycle
    - hydrologic cycle
  - gaseous
    - carbon cycle
    - nitrogen cycle
  - sedimentary
    - phosphorous cycle

17 Biogeochemical cycles: hydrologic
- hydrologic cycle
  - most familiar of all biogeochemical cycles
    - all life depends on water
      - main constituent of bodies of most organisms
      - source of H^+, whose movements help generate ATP

18 Biogeochemical cycles: hydrologic
- hydrologic cycle
  - ~98% of all water on earth is free water
    - circulating between atmosphere and oceans
  - ~2% of all water on earth is captured in any form
    - frozen
    - held in soil
    - incorporated into bodies of organisms

19 Fig. 16.1

20 Biogeochemical cycles: hydrologic

- hydrologic cycle
  - function
    - collects, purifies, distributes earth's fixed supply of water

21 Biogeochemical cycles: hydrologic
- hydrologic cycle
  - main processes
    - evaporation
    - transpiration
    - condensation
    - precipitation
    - infiltration
    - percolation
    - runoff

22 Biogeochemical cycles: hydrologic
- hydrologic cycle - main processes
  - evaporation
    - conversion of liquid water (from surface waters and soils) to water vapor (in atmosphere)
    - source of water vapor in atmosphere
      - ~84% - evaporation from oceans
        - which cover 3/4th of earth's surface
    - driven by energy from sun

23 Biogeochemical cycles: hydrologic
- hydrologic cycle - main processes
  - evapotranspiration
    - evaporation from leaves of plants
      - of water extracted from the soil by roots and transported throughout the plant
    - driven by energy from sun

24 Biogeochemical cycles: hydrologic
- hydrologic cycle - main processes
  - condensation
    - conversion of water vapor into droplets of liquid water
    - necessary in order for precipitation to occur
    - changes in temperature
      - affect amount of moisture that can be "held" by an air mass

25 Biogeochemical cycles: hydrologic

- hydrologic cycle - main processes
  - precipitation
    - conversion of water vapor into droplets of liquid water
    - can take form of
      - rain, sleet, hail, snow
    - requires condensation nuclei
      - tiny particles on which droplets of water vapor can collect
      - sources include
        - volcanic ash, soil dust, smoke, sea salts, particulate matter from human activities (factories, vehicles, power plants, etc.)

26 Biogeochemical cycles: hydrologic
- hydrologic cycle - main processes
  - precipitation continued
    - fate
      - becomes locked in glaciers
      - impinges directly on oceans or other surface water bodies
      - infiltrates soil or porous rock
      - becomes surface runoff

27 Biogeochemical cycles: hydrologic
- hydrologic cycle - main processes
  - infiltration
    - movement of water into soil and porous rock
    - affected by
      - substrate type
      - vegetation cover
      - degree of saturation
      - topography

28 Biogeochemical cycles: hydrologic
- hydrologic cycle - main processes
  - percolation
    - downward flow of water through soil and permeable rock formations
      - to groundwater storage areas called aquifers
      - to oceans
    - dissolves and transports minerals and nutrients

29 Biogeochemical cycles: hydrologic
- hydrologic cycle - main processes
  - runoff

- down slope surface movement back to the sea to resume cycle
- replenishes surface waters such as lakes and streams
- causes soil erosion
  - movement of soil and weathered rock fragments from one place top another

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31 Biogeochemical cycles: hydrologic
- hydrologic cycle
  - human impacts
    - have increased over past century via
      - withdrawal
      - vegetation removal
      - modification of water quality

32 Biogeochemical cycles: hydrologic
- hydrologic cycle
  - human impacts
    - withdrawal of large quantities of freshwater from streams, lakes, underground sources
      - for
        - needs in heavily populated areas
        - irrigation
      - leads to
        - groundwater shortages
        - intrusion of ocean salt water into groundwater supplies

33 Biogeochemical cycles: hydrologic
- hydrologic cycle
  - human impacts
    - vegetation removal
      - for
        - agriculture, mining, roads, timber harvesting, building construction
      - leads to
        - increased runoff
        - reduced infiltration that recharges groundwater supplies
        - increased risk of flooding
        - accelerated soil erosion

34 Biogeochemical cycles: hydrologic
- hydrologic cycle
  - human impacts
    - modification of water quality
      - by adding
        - nutrients (such as phosphates and nitrates in fertilizers

- pollutants
- changing ecological processes that purify water naturally

35 Matter cycles within ecosystems
- Main biogeochemical cycles
  - hydrologic cycle
    - hydrologic cycle
  - gaseous
    - carbon cycle
    - nitrogen cycle
  - sedimentary
    - phosphorous cycle

36 Biogeochemical cycles: carbon
- carbon cycle
  - carbon
    - essential to life as we know it
    - building block of molecules of life

37 Biogeochemical cycles: carbon
- carbon cycle
  - based on carbon dioxide (gas)
    - constitutes ~0.04% by volume of troposphere
      - is key component of “nature’s thermostat”
        - if too much CO_2 is removed from atmosphere, it will cool
        - if too much CO_2 is added (or remains in) atmosphere, it will warm
      - dissolved in ocean

38 Biogeochemical cycles: carbon
- carbon cycle
  - can trace carbon cycle by considering how carbon enters and leaves each of the four main reservoirs

39 Biogeochemical cycles: carbon
- carbon cycle
  - lithosphere
    - largest reservoir for earth’ carbon
      - rocks such as limestone ($CaCO_3$) deposited as sediment on ocean floor and on continents

40 Biogeochemical cycles: carbon
- carbon cycle
  - lithosphere
    - enters
      - death, burial, compaction over geologic time

- becoming sediment, marine sediments, sedimentary rock, fossil fuels
- leaves
  - very slowly
    - weathering, uplifting over geologic time, volcanic activity
  - exception: combustion of fossil fuels

41 Biogeochemical cycles: carbon
- carbon cycle
  - biosphere
    - enters
      - photosynthesis, consumption
    - leaves
      - cellular respiration, death

42 Biogeochemical cycles: carbon
- carbon cycle
  - hydrosphere
    - oceans
      - are second largest reservoir of earth's carbon
      - play role in regulating amount of CO_2 in atmosphere
    - CO_2 is readily soluble in water
      - fate
        - some stays dissolved in sea water
        - some is removed by marine photosynthesizing producers
        - some reacts with sea water to form carbonate ions (CO_3^{2-}) and bicarbonate ions (HCO_3^-)

43 Biogeochemical cycles: carbon
- carbon cycle
  - hydrosphere
    - enters
      - weathering, leaching, runoff, diffusion, cellular respiration
    - leaves
      - photosynthesis, diffusion, incorporation into sediments

44 Biogeochemical cycles: carbon
- carbon cycle
  - atmosphere
    - enters
      - cellular respiration, combustion of wood, combustion of fossil fuels, volcanic action, diffusion from ocean
    - leaves
      - photosynthesis
      - diffusion from the ocean

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46 Biogeochemical cycles: carbon

- carbon cycle
  - flow of carbon in form of carbon dioxide from atmosphere to biosphere (photosynthesis) and back to atmosphere (respiration)
    - is approximately in balance

47 Biogeochemical cycles: carbon

- carbon cycle
  - human impacts
    - since industrial revolution and especially since mid-1950s, humans activities have been adding CO_2 to atmosphere in two ways
      - clearing trees and plants that remove CO_2 via photosynthesis
      - burning fossil fuels and wood

48 Biogeochemical cycles: carbon

- carbon cycle
  - human impacts
    - fossil fuels
      - over millions of years, buried deposits of dead organic matter become compressed between layers of sediment where they form carbon-containing fossil fuels such as coal and oil
      - carbon in fossil fuels is not released into atmosphere for recycling until
        - long-term geologic processes expose deposits to chemical and mechanical processes that can liberate carbon
        - fossil fuels are extracted and burned

49 Biogeochemical cycles: carbon

- carbon cycle
  - human impacts
    - fossil fuels
      - in past few hundred years, humans have extracted and burned fossil fuels that took millions of years to form
        - thus, removing carbon from its major reservoir far faster than it can be added to that reservoir
        - causing disruption in carbon cycle

50 Biogeochemical cycles: carbon

- carbon cycle
  - human impacts
    - fossil fuels
      - in past few hundred years, humans have extracted and burned fossil fuels that took millions of years to form, resulting in
        - removal of carbon from its major reservoir far faster than it can be added to that reservoir
        - addition of carbon to atmosphere far faster than it can be removed

51 Biogeochemical cycles: carbon

- carbon cycle
  - human impacts
    - consequence of increased atmospheric concentration of CO_2
      - enhances planet's natural greenhouse effect
        - producing "global warming"

52 Biogeochemical cycles: carbon
- carbon cycle
  - human impacts
    - consequences "global warming"
      - will be discussed in detail later in course
      - include
        - disruption of global food production
        - increase average sea level

53 Biogeochemical cycles: carbon

54 Matter cycles within ecosystems
- Main biogeochemical cycles
  - hydrologic cycle
    - hydrologic cycle
  - gaseous
    - carbon cycle
    - nitrogen cycle
  - sedimentary
    - phosphorous cycle

55 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - nitrogen gas (N_2)
    - constitutes ~78% of earth's atmosphere
    - cannot be absorbed or used directly by multicellular organisms
    - must be "fixed" or combined with hydrogen or oxygen to provide compounds these organisms can use
      - occurs via
        - atmospheric electrical discharges in form of lightning
        - activities of certain bacteria

56 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - several processes involved
    - fixation
    - nitrification
    - assimilation
    - ammonification
    - denitrification

57 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - nitrogen fixation
    - converts gaseous nitrogen (N_2) to ammonia (NH_3), a form that can be used by plants
      - $N_2 + 3H_2 \rightarrow 2NH_3$
    - carried out by specialized bacteria
      - cyanobacteria in soil and water
      - Rhizobium bacteria
        - living in small nodules on root systems of variety of plants (including legumes such as soybeans, alfalfa)

58 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - nitrification
    - two step process carried out by specialized aerobic bacteria
      - most of ammonia (NH_3) in soil is converted to nitrite ions (NO_2^-) which are toxic to plants
      - nitrite ions are then converted to nitrate (NO_3^-) which are easily taken up by plants

59 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - assimilation
    - plants
      - roots absorb inorganic ammonia (NH_3), ammonium ions (NH_4^+), and nitrate ions (NO_3^-)
      - use these ions to make nitrogen-containing organic molecules such as DNA, amino acids, proteins
    - animals
      - obtain their nitrogen by eating plants or plant-eating animals

60 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - ammonification
    - process of converting nitrogen-rich compounds of living organisms and their wastes back into
      - simpler nitrogen-containing inorganic compounds such as ammonia (NH_3)
      - water-soluble salts containing ammonium ions (NH_4^+)
    - carried out by variety of decomposer bacteria and fungi

61 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - denitrification
    - process of converting nitrogen compounds (ammonia, ammonium ions, nitrite ions, nitrate ions) back into nitrogen gas (N_2) which can be returned to atmosphere

- carried out by specialized bacteria
  - mostly anaerobic bacteria in water-logged soil, in bottom sediments of lakes, oceans, swamps, bogs

62 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - human impacts
    - interventions in nitrogen cycle over past 100 years include
      - adding adding nitric oxide to atmosphere
      - adding nitrous oxide to atmosphere
      - removing nitrogen from topsoil
      - adding nitrogen compounds to aquatic ecosystems

63 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - human impacts
    - adding adding nitric oxide (NO) to atmosphere when burning fuel
      - $N_2 + O_2 \rightarrow 2NO$
      - nitric oxide (NO) can combine with oxygen to form nitrogen dioxide (NO_2) which in turn can react with water vapor to nitric acid (HNO_3)
        - droplets of nitric acid dissolved in rain or snow are components of acid deposition

64 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - human impacts
    - adding nitrous oxide (N_2O) atmosphere
      - through action of
        - anaerobic bacteria on livestock wastes
        - commercial inorganic fertilizers applied to soil
      - which can reach stratosphere
        - enhance natural greenhouse effect
        - contribute to ozone depletion

65 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - human impacts
    - removing nitrogen from topsoil
      - via
        - harvest of nitrogen-rich crops
        - irrigation of crops (leaching)
        - burning or clearing forests or grasslands

66 Biogeochemical cycles: nitrogen
- nitrogen cycle
  - human impacts

- adding nitrogen compounds to aquatic ecosystems
  - via
    - agricultural runoff
    - discharge of municipal sewage
  - constitutes excess nutrients that
    - stimulate rapid growth of algae and aquatic plants
  - can lead to
    - depletion of water dissolved oxygen(via action of decomposers)
    - disruption of aquatic ecosystems

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68 Fig. 5.17

69 Matter cycles within ecosystems

- Main biogeochemical cycles
  - hydrologic cycle
    - hydrologic cycle
  - gaseous
    - carbon cycle
    - nitrogen cycle
  - sedimentary
    - phosphorous cycle

70 Biogeochemical cycles: phosphorus

- phosphorous cycle
  - phosphorous
    - plays a critical role in plant nutrition
    - is element most likely to be scarce enough to limit plant growth
    - exists in soil only in small amounts
      - when it weathers out of soil its transported to rivers and oceans and eventually accumulates in sediment
    - is found in atmosphere only as small particles of dust
      - at normal temperatures and pressures it is not in gas form

71 Biogeochemical cycles: phosphorus

- phosphorous cycle
  - phosphorous
    - is only naturally brought back up from sediments by the uplift of lands or by marine animals
      - which can be consumed by animals such as seabirds
        - which then deposit guano (feces) rich in phosphorous, and can be used as fertilizer

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73 Biogeochemical cycles: phosphorus
- phosphorous cycle
  - human impacts
    - interventions in nitrogen cycle over past 100 years include
      - mining
      - reducing available phosphate in tropical forests
      - adding phosphate to aquatic ecosystems

74 Biogeochemical cycles: phosphorus
- phosphorous cycle
  - human impacts
    - mining
      - large quantities of phosphate rock for use in
        - commercial inorganic fertilizers
        - detergents

75 Biogeochemical cycles: phosphorus
- phosphorous cycle
  - human impacts
    - reducing available phosphate in tropical forests
      - by removing trees
        - causes phosphorus in soil to be washed away

76 Biogeochemical cycles: phosphorus
- phosphorous cycle
  - human impacts
    - adding phosphate to aquatic ecosystems
      - via
        - runoff from animal wastes from livestock feedlots
        - runoff of commercial phosphate fertilizers from cropland
        - discharge of municipal sewage

77 The End.