EVS1101 - Introduction to Environmental Sciences

Lecture 1 - Introduction

Planetary System
- 3rd planet from the sun
- water = life
- small terrestrial planets // huge ice or gaseous outer planets
- sun has over 99.8% of the solar system mass
- life developed on earth because of the liquid water covering

Water on Mars?
- polar caps have solid CO_2 and H_2O, some seasonal variation
- **dendritic drainage patterns** comparable to those on earth suggest water once flowed

Planet Earth
- 4.6 **billion** years old
- oldest rock ~4.55 billion years old found in northern Quebec

Life on Earth
- fossilized life forms reported in **3.4-3.5 billion** year old rocks; turns out they were minerals
- humans appeared **3.5-4.4 million years ago**
- modern humans have been around for **~200,000 years**
- if earth was 24h old, we would have appeared at 23h59

Earth Structure
- thickness varies; thick on continent and thin at bottom of the ocean
- **core is rich in Fe and Ni**
- mantle has a variable composition
  - Fe, Mg, Al, Si, and O
  - 2800 km thick
- **athstenosphere:** uppermost part of the mantle, temp and pressure make rock ductile
- **lithosphere:** crust and uppermost mantle, rigid outermost shell of the earth
- **crust:** rocky outer skin, composed of
  - 45% oxygen, 27% silica, 8% aluminium, 7% iron, calcium, etc.
  - **continental crust:** ~ 45km thick, mostly granite
  - **oceanic crust:** ~ km thick, mostly compost of basalt
  - oceanic crust is denser than continental crust

Dynamic Earth

- **subduction zone:** plates collide and one goes under (west coast)
- **expansion zone:** plates moving away from eachother (atlantic)
- **metamorphic rocks:** pre-existing rocks being heated/transformed
- Wisconsin glaciation: extended from the North Pole to Wisconsin
- earths surface is constantly changed and reworked via a range of processes operating over vastly different scales of space and time
    - **plate tectonics:** volcanoes, earthquakes, etc, move at 2-15 CM per year
    - **rock cycle:** igneous, metamorphic, sedimentary
    - **glaciations:** climate changes
    - **elemental cycling:** e.g. carbon, nitrogen, sulfure, etc.
    - **erosion and weathering**

Plate Tectonics

- earth's internal heat drives convection currents in mantle
    - **causes movement of overlying crust tectonic plates**
- earth's surface consists of about 15 main tectonic plates
    - move at **2-15cm per year**
    - different types of plate boundaries cost
        - formation of new crusts
        - earthquakes, volcanisms, and mountain building

Simplified Rock Cycle

- sedimentary basins host fossil fuels
- metamorphic rocks host precious elements (diamonds)

1. **igneous:** formed from **cooling molten rock**
2. **sedimentary:** formed by precipitation/cementation of particles compressed into new rock
3. **metamorphic:** heat and pressure **transform igneous or sedimentary rocks**

Carbon Cycling

- CO_2 (+4) is the inorganic carbon fixed by plants in photosynthesis (reduction)
- CH_2O (0) is the organic carbon that can be oxidized to CO_2
- the numbers are the oxidation numbers
- **photosynthesis is a redox reaction**

Sulfur Cycling

- sulfide (-2) and elemental sulfur(0) can be oxidized to sulfate (+6)
- sulfate can be reduced to sulfur and sulphide in low temp reactions by microorganisms
- **sulfate can make a very acidic environment**
- sulfide usually exists as a mineral

Iron Cycling

- Ferrous iron (Fe^{2+}) exists under reducing conditions
- Ferrous iron can be soluble and can react easily with sulfide, ex. **pyrite is iron disulfide**
- Ferric iron (Fe^{3+}) in oxidizing conditions, highly insoluble and will precipitate (pH 4-9)

Forms of Energy

- water vapour is a greenhouse gas
- **primary producers:** base of the food chain, mostly in the ocean
- solar energy is essential for the various ecosystems, especially for photosynthesis
- solar energy heats up the atmosphere and the oceans —> evaporation
- the energy received by the earth is returned as electromagnetic radiations, there is a balance

Defining the Environment

Environment Canada (1993):

“Everything that surrounds and affects or influences an organism or a group of organisms; it includes both living and nonliving components as well as both natural and human-built elements”

Environment

- **Lithosphere:** solid reservoir (rocks, soil, sediments, etc.)
- **Hydrosphere:** liquid recevoir (oceans, lakes, rivers, glaciers, etc.)
- **Atmosphere:** gas reservoir (air and other gasses)
- **Biosphere:** living reservoir (microorganisms, plants, animals, humans, etc.)
- surface biosphere vs. deep biosphere in the earths crust/oceans such as archaea
- **Ecosphere:** includes lithosphere, atmosphere, biosphere, hydrosphere

Pollutants

- **Point sources:** discrete, localized, and often readily measurable discharges of chemicals: oil spill from a truck on the highway, easily located/dealt with
- **Non point sources:** more difficult to measure because they often cover large areas or are a composite of numerous point sources: gas emissions from cars, fertilizer runoffs
- **Sink:** physical or chemical process removing a substance from a reservoir: ex precipitation of zinc in a lake, one day its there and one day its not. where did it go?

Environmental Issues

- ozone layer thinning due to chemicals
- how sustainable is gold? it will be gone within 20 years
- Do we replant as many trees as we cut?
- Which wildlife species and habitats are threatened? Is the climate changing?
- What is the status of the stratospheric ozone layer? Are we protecting enough natural areas
- Are air pollution and water pollution getting worse? How sustainable are Canada's renewable resources?
- Do we recycle enough?(383kg garbage/person in Canada and only 20% recycled)

Basic Chemistry

- atoms: electrons, protons, neutrons
- isotopes: atom of an elements possessing a variable number of neutrons
- ions: can gain or lose electrons
- molecules: groups of atoms which share or transfer electrons
- ion species: charged molecules
- carbon 14 dating for example in ice scores

Basic Chemistry - pH

- measure of acidity (concentration of H+)
- affects the solubility of many elements ex. Al, Fe, etc.
- ph = -log[H+]
    - **acidic = pH <7**
    - **neutral = pH 7**
    - **alkaline = pH > 7**
- pOH = -log[Oh-]
- **pH + pOH = 14**
- pH of Ottawa River is 8 because bicarbonate buffer due to Ottawa basin carbonate rocks
- geology will dictate pH value
- most lakes on the Precambrian shield (north of Ottawa) are slightly acidic because of the lack of buffering ability of the host rock, and the water is in eq. with the atmosphere which is rich in CO2, so it dissolves in the water and makes it acidic.
- heavy metals that precipitate can bioaccumulate and become concentrated in the biomass which can be lethal; for example lead.

pH of Natural Waters

- major sources of acidity in waters include:
    - carbonic acid (H2CO3); dissolution of CO2 and carbonate minerals
    - organic acids: breakdown of vegetation, soil pore waters in tropical climates (intense biological productivity) may be at pH<4
    - sulfuric acid: oxidation of sulfide minerals, FeS2, in particular in mining areas leading to **acid mine drainage (AMD)**

Acidic Waters - Crater Lakes

- created by volcanos
- Poás (Costa Rica) is the most acidic crater lake int he world (pH of 0)
- continous degassing of HCl, H2S, & SO2 from underlying magmas keep these waters acidic

Redox Chemistry

- oxidation/reduction: effect on solubility, transport
- important in element cycling (C, N, Fe, Mn, U, Cr, As, Se, etc)
- oxidation: loss of electrons: Fe2+ = Fe3+ + e-
- reduction: gain of electrons: Fe3+ + e- = Fe2+

Rules for Assigning Oxidation State

1. oxidation state of all elements in their free form is always zero
    - e.g. N2 (g); oxidation sate of N = 0
    - Fe metal, oxidation state of Fe = 0
2. oxidation state of H is usually 1+, and O is 2-
    - unless in free form of H2 or O2, where they are zero (rule 1)
3. oxidation state of a mono-atomic **ion** equals its charge
    - e.g. Na+ is 1+
4. the sum of the oxidation states of the atoms in a molecule is equal to the charge of that molecule

Assigning Oxidation State Examples

- Cl2 (g): Cl is in its pure form, so ox st. = 0
- NH4+ (aq): H= 1+; Total species charge +1 = (N) + (4x +1), so N = -3
- HCO3- (aq): H = 1+, O = -2; total species charge -1 = (1+) + (C) + (3x-2), so C = +4

Redox Reactions

- always coupled; reduction of one constituent accompanied by oxidation of another

$$\text{Reduced}_a + \text{Oxidized}_b \longrightarrow \text{Oxidized}_a + \text{Reduced}_b$$

- e.g. oxidation of Fe(II) by oxygen
- **4Fe2+ (aq) + O2 (g) + 4H+ (aq) = 4Fe+ (aq) + 2H20 (aq)**

Fe (2+) O (0) (4) Fe (3+) O (-2)

Terminology and Units

- anoxic conditions: absence of oxygen
- oxic conditions: presence of oxygen
- aerobic vs. anaerobic: use of O2 by microorganisms
- redox potential
  - pe = -log{e}
  - positive: low {e}, oxidizing
  - negative: high {e}, reducing

Concentration of Units

- Concentration: g/L, g/g. vol/vol, mole/L, ppm, ppb, etc.
- Prefixes:
  - **m = milli (10^-3),**
  - **μ= micro (10^-6) and**
  - **n = nano (10^-9)**

- **mg/L = 1 ppm**
- **μ/L = ppb**
- **n/L = ppt**

Converting Concentrations Examples

1. **Get Moles:**
   - nmole x 10^-3 = mole
   - umole x 10^-6 = mole
   - nmole x 10^-9 = mole

2. multiply by MW

3. result in grams, convert to PPM, PPB, PPT

- g x 10^3 = ppm
- g x 10^6 = ppb
- g x 10^9 = ppb

Resources

- Physical resources essential to sustain life are limited, with the exception of solar energy
- A sustainable economic system would operate without a net consumption of natural resources, i.e., the rates of resource use would equal or be smaller that the rates at which they are regenerated or re-cycled
- There are renewable and non-renewable resources

Non-Renewable Resources

- Non-renewable resources are present in finite quantity
- Extraction of resources: metals, fossil fuels, coal, etc. (development of new extraction tools)
- The recycling of resources is essential
- The use of alternative sources of energy (ex: use of biomass, solar panels, wind, etc.)

Easter Island

- Remote island in S. Pacific
  - 1772, European explorers reached island, finding barren landscape, <2000 people
  - But evidence of sophisticated earlier civilization of ~30,000
  - Resource over-exploitation
    - Trees felled (statues, canoes)
      - Top-soil erosion, lower freshwater (enhanced run-off), poorer crop yields
- without trees, the soil is subject to erosion. if the fertile soil erodes, you cannot produce crops

Renewable Resources

- Capable of being re-generated after harvesting, they could be used forever
- Ex: animals, plants, sols, water, solar energy
- A renewable source of energy can be degraded in the long term or contaminated or over-utilized (ex: Easter Island)

Resource Management

- Crops, animal stocks, forests can be harvested sustainability with proper practices
- Need to maintain a healthy environment
- Need to maintain a good genetic diversity
- Need to avoid over-exploitation
- Human factors can influence the size and productivity of natural resources

Mining & Mineral Processing

- many towns are only existent because of mineral deposits
- Non-renewable resources
  - Metals, salts, rocks (granite, marble, etc.)
- Ore extraction technique can improve our recovery and extend the resources
- Essential for the economy of Canada and the world
  - 32 billion to the Canadian economy (2009)
- The mining industry creates jobs and infrastructure (roads, power lines, etc.) (58 000 direct jobs (2008))
- Often associated with major environmental problems

Mining Activity in Canada

- Concentrated in northern Ontario, Quebec, southern SK/western MB

Mining Activities

- Canada is one of the world's largest mineral exporters
- Large producer of:
  - Pb, Zn, Ni, Cu, Au (occur as sulfides)
    - Sudbury, Timmins (ON); Flin Flon (MB), Noranda (QC)
- Chrysotile (asbestos)
  - Asbestos, QC
- Uranium
- Potash
- Diamonds

Uranium Mining

- World's leading producer
  - Northern SK (former mines in NWT & ON)

Potash Mining

- potash is a combination of potassium and chloride or sulfide salts
- Largest in world
  - Southern SK; western MB
  - Largely used in fertilizer

Diamond Mining

- Canada is now the 3rd largest diamond producer in the world
  - Northwest Territories: Diavik, Ekati, Snap Lake

Canada's Reserve

- Apparent lifetime
  - Total metal reserve / metals produced from mine per year
  - Snapshot
- Depends on market price (esp. Au)
- Does not account for newly discovered metal ores or improvements in extraction/processing

Metal	Apparent Life (y)
Ni	Thirteen
Cu	Twelve
Au	Nine
Zn	Nine
Ag	Six
Pb	Five

Recycling

- About 50% of the 15 million tons of iron and steel produced every year in Canada comes from recycled iron and steel scrap
- More than 90% of the lead consumed in Canada can be economically recycled
  - Secondary lead production represented approximately 60% of total Canadian refined lead production in 2008 (40% in 1995)
- Worldwide, lead production from recycled materials surpassed primary production for the first time in 1989

The Mining Processes

1. **Prospecting/Exploration**
   - if you sample water/sediment and it has an unusually high amount of copper; chances are there is a copper deposit in it. exploratory drilling will ensue, then the site will be mapped and valued and the decision to mine will be made.
2. **Mining/Milling**
   - first the rock is extracted in bulk, then crushed, then treated with water/chemicals. then a gravity gradient is created to separate the ore from the host rock. ex, silicate is lighter than the host rock therefore it will separated then it is concentrated. The waste rock/water combination, mining residues, known as mine tailings.
3. **Smelting/Processing**
   - Concentrated metal ore heated (roasting) or leached to extract metal
   - Many metal ores occur as sulfide minerals – heating produces SO_2 air pollution
4. **Post-Operational**
   - dealing with the mistakes of the old mines to prevent further contamination of the environment due to things like mine tailing into lakes
   - management of tailings, site rendition

Smelting: Pyrometallurgy

- We heat up the rock to transform from a metal sulfide to a metal oxide, the sulfur is oxidized
- if the SO_2 is not trapped, it will cause acid rain
- a strong reduced agent, coke, reduces the metal oxide transforming it to a pure metal
- the by product CO needs to be removed because it also will cause acid rain
  - Roasting
    - **$2M^{(+2)} S^{(2-)} (s) + 3O^{(0)}_2 = 2M^{(+2)} O^{(2-)} (s) + 2\ S^{(+4)}O^{(2-)}_2 (g)$ (high T)**
      where M is Ni, Zn, Pb, etc
  - Reduction
    - **$M^{(+2)} O^{(2-)}(s) + C^{(0)} (s) = M^0 (s) + C^{(2+)} O^{(2-)} (g)$ (high T)**
      where C is charcoal, coke

Hydrometallurgy

- used when pyrometallurgy is not cost effective
- they have been experimenting with bioactive leaching agents
  - Leaching:
    - **$2CuS(s) + 4H^+ (aq) + O_2 (g) = 2Cu^{2+} (aq) + 2S + 2H_2O$**
  - Reduction:
    - **$2Cu^{2+} (aq) + 2H_2O = 2Cu(s) + O_2 (g) + 4H^+ (aq)$**
- Metal (e.g. Cu) leached from ore (sulfide oxidized)
- Dissolved metal then reduced to metallic form and collected

Environmental Impacts: Land

- Exploration requires temporary access to large tracts of land, ecosystem impacts are typically localized and short- term. e.g. building roads, cutting down trees and ruining soil
- Milling and processing require much smaller tracts of land, but their impact in terms of tailings and waste rock disposal is much more significant and longer-term
- Existing and new mining facilities are now required to reclaim the land they disturb in accordance with government-approved reclamation plans
  - Of the total land areas disturbed by mining, about10% has been rehabilitated or re-vegetated to date
  - Mine tailings dumped into lakes in the past have caused lakes to disappear
- Methods to slow down the oxidation of pyrite
  - cover the pyrite with water, because the water prevents oxygen from diffusing into the tailing below
  - vegetation covers; non sensitive plants
  - add lyme to the tailing, it neutralizes the acidic activity from oxidizing pyrite or metals

Rehabilitation of Mining Impacted Land

- to grow anything on top of these non-fertile mine tailings you must put a layer of soil. only species non-sensitive to metal toxicity will thrive because the roots will extract water that is contaminated with the metals in the mine-tailings.

Environmental Impact: Air

- the particulate flying around in the air are toxic to animals and fish
- Smelters require high operating temperatures and emit various pollutants directly into the local atmosphere
  - particulate matter, nitrogen oxides, sulfur dioxide, metals, and organic compounds
- Such substances may redeposited locally or transported over long distances
  – Heavy metals are deposited within 30 – 50 km stack – Acid deposition of SO2, NOx
- Dry (as gases or particulates) and/or wet (rain, snow)
- Smelter facilities are located at FlinFlon & Thompson (MB), Sudbury & Timmins (ON), and Noranda (QC)
- the Mining sector have the biggest contribution towards SOx emissions

Acid Deposition

- Queenstown, Tasmania: became a tourist attraction
- Sudbury was once largest single source of SO2 emissions in N. America (1969)
  - Emission reductions allowed vegetation to return

Environmental Impacts: Water

- Pollutants from:
  - Mine dewatering
  - Liquid effluents from the milling process
  - Surface water drainage and seepage from waste storage areas and inactive mines (acid mine drainage)
- Mine wastes are treated and stored on site. Untreated liquid effluents are normally released to the natural aquatic environment only when they meet strict environmental requirements; however, spills sometimes occur
  - E.g. breaches in tailings dams

Impacts: Tailing Dam Breaches

- Spills caused by breaches in tailings dams
  - Omai gold mine (Guyana, 1995)
    - 3.2 million m3 of cyanide tailings into adjacent river
  - Los Frailes Pb-Zn mine (Aznalcollar, Spain, 1998)
    - 4.5 million m3 of metal-rich tailings into adjacent wildlife reserve
  - Baia Mare Au mine (Romania, 2000)
    - 0.1 million m3 of cyanide tailings into river Danube

Acid Mine Drainage

- The most serious problem facing the mining industry in Canada
- Exposure of metal sulfides (e.g. pyrite FeS_2) in mine tailings and waste rock may generate acid mine drainage
  - Acidic waters rich in dissolved metals
- Controlling acid mine drainage is extremely difficult
  - Major challenge for the mining industry
    - Especially for abandoned mines
- the acidic waters rich in dissolved metals; these metals exist as free ions so they are bio-available to living species
- acid mine draining is leaking of waters, it is rich in acidic metals

Example

- if you dig you will encounter the oxidized tailings, acidic pH, for the first couple of centimetres, and then below that you will find the original normal pH mine tailings

Timmins Mine

- they excavated the tailings, mixed them with lyme, lined the bottom with lyme. all of this expensive work in order to prevent more oxidation and acid mine draining

Acid Mine Drainage

(1) Oxidation of sulfide:

- **$FeS_2 + 3\frac{1}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$**

(2)Oxidation of iron:

- **$Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O$**

- Abiotic Fe^{2+} oxidation is very slow at low pH
- Acidophilic microorganisms can catalyze Fe^{2+} oxidation by several orders of magnitude
  - *Acidothiobacillus ferroxidans* is the most important of such bacteria
- NOTE: most mines in Ontario are silicate based; no buffer for the acid
- pyrite is fine when its below ground with no oxygen
- the problem is when we bring it out of the ground and treat it, finally exposing it to oxygen
- in the first oxidation equation, we oxidize the sulfur in pyrite; creating acidity
- acidophilic iron oxidizing bacteria; they colonize the site and oxidize ferrous iron and transform it into ferric iron. they are a catalyst to the second reaction

Acid Mine Drainage

(3) **$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3(s) + 3H^+$**

- The Fe^{3+} formed may precipitate

(4) **$FeS_2 + 14Fe^{3+} + 8\ H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$**

- OR become an oxidant of FeS_2
  - positive feedback system

- Equation 3; ferrous iron can precipitate and create the iron colour; also generating acidity
- or Equation 4:, ferrous iron in solution oxidizing pyrite forming soluble ferric iron; this generates 16 moles per protons which is very acidic. the available Fe^{2+} creates a loop because it will be oxidized by the acidophilic iron oxidizing bacteria
- this creates more soluble heavy metals

Contaminants Associated with AMD

- gold mining is associated with arsenic which is left in the tailings, in Nova Scotia these tailings grow arsenic tolerant pitcher plants who have bioaccumulated much arsenic
- gold mining used to involve mercury because it has a high affinity for gold and would concentrate the gold in the smelting process. this mercury was not recycled and was dumped back with the tailings providing exposure to humans
- in mercury, it bioaccumulates in the base of the food chain and eventually ends up in the big fish that we eat such as tuna. hair and nails test tell us about mercury exposure
- **Organic compounds**
  - Base metal milling commonly uses a flotation process, whereby chemicals are mixed with ore in water solutions to separate the desired mineral from the ore
  - Flotation reagents used in base metal concentrators may include kerosene, organic flotation agents, and sulfuric acid. Residual reagents can be found both in the effluents from a mill and in stored tailings
- **Cyanide**
  - Gold mines are the major users of cyanide, which is employed in the milling process
  - Cyanide and cyanide–metal compounds may be removed from gold mill effluent either by natural degradation or by a treatment process, prior to discharge
- **Heavy metals**
  - Effluents from metal mines can contain As, Cd, Cu, Fe, Pb, Ni, Zn at various concentrations. All of these can have harmful effects on downstream aquatic life, esp. fish
    - May also contain Hg (e.g. alluvial gold mining)

Case Study; Au in Amazon Basin

- bootleg mine where people dump mercury into sediments in order to capture the gold via heating it up
- mercury is very volatile, therefore they are inhaling the neurotoxin mercury vapour
- mad hatter: mercury was used to make factory hats, turning the wearers crazy
- Soaring gold price in late 1970s prompted gold rush in South America
- Alluvial sediments in Amazon basin panned for gold
- Use Hg for gold extraction (Hg adheres to Au, forming amalgam)
- Hg driven off by evaporation
  - Mad hatter
- Annual discharge of Hg to Amazon ecosystem estimated at 100 tonnes

Energy

- There are many energy sources in the world, but most of them are produced in industrialized countries
- Many sources of energy are non-renewable, such as hydrocarbons (fossil fuels)
- Dependence on fossil fuels

- **Energy Demand - Worldwide Outlook**
- Most energy consumption also occurs in industrialized countries
- World energy demand is growing (~1.6%/year)
  - Most growth will come from emerging economies (e.g. China, India) as population, economy grows

Energy Supply - Canada

- Important sector of Canadian economy
  - 7.2% GDP, 2% directly employed
- Net exporter of energy
- Dominated by fossil fuels
- Electricity generation
  - Hydro, nuclear & fossil

Energy Production

- Fossil fuel power plant
- Nuclear power plant with boiling water reactor

Hydrocarbons (Fossil Fuels)

- Coal
  - Organic matter deposited on land, buried, T&P ↑ with burial, form coal
- Oil (petroleum)
  - Analogous to coal formation, but marine environments
- Natural gas
  - **Thermogenic** (highT&P, with oil)
  - **Biogenic** (anaerobic microbial degradation of organic matter)
    - Shallow depths (e.g. landfill, swamps)

Coal

- problem will coal is that pyrite is usually associated, therefore the open pit mines fill up with water and begins to oxidized creating artificial acidic lakes
- Used since ancient times
  - E.g. Romans in Britain 200-300 A.D.
- Most abundant fossil fuel
  - China & USA top producers & consumers (60%)
- Subsurface mining (shafts)
- Near surface
  - Open pit
    - E.g. Alberta & BC
  - Strip mining
    - Prairies & NB

Natural Gas

- Methane (CH_4)
- Only recently become widely used
  - Energy, heating, cooking
  - cleaner burning
    - Lower CO_2 emission than coal or oil
- Canada is worlds 3rd largest producer (after Russia & US)
  - Offshore Atlantic Canada

Producers and Consumers

Production (% world production)	Consumption (% world consumption)
United States, 20.1	United States, 22.2
Russian Federation, 17.6	Russian Federation, 13.2
Canada, 5.4	Iran, 4.5
Iran, 4.4	Canada, 3.2
Norway, 3.5	China, 3.0

Oil (petroleum)

Oil brought to surface by:

1. Initial release of surround rock pressuring by tapping oil
2. Pumping
3. Water/gas injection (secondary extraction)

Worldwide Oil Reserves

- Middle East holds over half of worlds proven oil reserves
- Canada has substantial oil reserves, but only produces 4% of worlds oil

Producers and Consumers

Production (% of world production)	Consumption (% of world consumption)
Russian Federation, 12.9	United States, 21.7
Saudi Arabia, 12.0	China, 10.4
United States, 8.5	Japan, 5.1
Iran, 5.3	India, 3.8
China, 4.9	Russian Federation, 3.2
Canada, 4.1	Saudi Arabia, 3.1
Mexico, 3.9	Germany, 2.9
Venezuela, 3.3	South Korea, 2.7
United Arab emirates, 3.2	Brazil, 2.7
Iraq, 3.4	Canada, 2.5

Oil/Tar Sands

- Moist sand/clay rich in thick bitumen
- Massive deposits in Canada
  - Extracted by strip mining (too thick for conventional drilling)
  - 2 metric tons of tar sands for 1 barrel of crude oil
- Costly to extract
  - 2 worth energy obtained per 1 invested!
  - 5 for conventional oil
  - Only economical recently

Environmental Impacts of Fossil Fuel Use

- the oil ponds release the greenhouse gas methane
- Accidental spills (most visible form)
  - E.g. Exxon Valdez (1989), North Alaska
    - 10 million gallons –
  - 1991 Gulf War (1991)
    - 42 – 460 million gallons
- Tar/oils sands mining
  - Contaminate local ecosystems
  - Oil ponds (similar to tailings ponds)

Gulf of Mexico 2010

• 4 million barrels of crude oil spilled, cost around 12 billion to clean up

Kalamazoo River 2010

• Enbridge, 3.8 million litres in Kalamazoo river, USA

Accidental Spills: Contaminated Soils

- gas station underground reserves leaking into the ground, towns where people tap into the ground for drinking water will be exposed to carcinogenic hydrocarbons

Shale Gas

- the waters used for extraction become saline and end up leaking into the water ecosystem killing the wildlife
- waste water plants are not able to deal with salt water conditions, so the companies were forced to clean their own water
- extraction of Methane (CH_4) trapped in geological formations consisting of shale
- fracking is used for the extraction, i.e., high pressure injection of a mixture of water, sand, and chemicals to displace the methane
- Fracking is controversial
  - Moratorium in Quebec since 2012 on fracking
  - Not allowed in France
  - But recently approved in the UK (2012) and other countries

Environmental Problems

- Utilization of large quantities of fresh water
- Fracking waste water is hard to treat,it contains large quantities of salts and other chemicals
  - Possibility to inject the waste water in certain salt geological formations, but local
  - Distillation and re-use (over costly and rarely implemented)
- Potential risk of aquifer contamination
- Green house gas emission
  - Local seepage of methane during extraction
  - Utilization of large drills, trucks, etc.

Environmental Impacts on Fossil Fuel Use

- Air pollution problems from fossil fuel combustion
  - Particulate matter (soot)
  - Acid deposition
    - SO_2, (esp. coal), NO_x
  - Toxic pollutants
    - Benzene
    - Mercury, arsenic (esp. coal)
- CO_2 emission
  - Driver of climate change
  - Gasoline (CH_2) combustion (automobiles etc)
  - Complete combustion: $CH_2 + 3/2\ O_2 = CO_2 + H_2O$

Carbon Capture and Storage

- Carbon sequestration
- From point sources (e.g. power plants, oil extraction rigs)
- Three general options
    1. Geological storage
    2. Ocean storage
    3. Mineral storage

Geological Storage

- Geological storage: injection of CO2 into porous rock formations:
    - Sedimentary basins
    - Depleted oil reservoirs and non economic coal beds
    - CO2 also injected in oil reservoirs to improve petroleum recovery
    - There must be an impermeable cap rock above to prevent CO2 from escaping
    - Such facilities exist in Norway and Canada, but so far they have only removed 0.01% of the global annual anthropogenic CO2

Ocean Storage

- Ocean storage: injection of CO2 at depths greater than 1000 meters where it is isolated from the atmosphere
- CO2 would be dissolved in the oceans and be part of the global carbon budget
- However,it might cause a slight pH decrease oft he water
- No know pilot scale project so far
- Dissolved in water: carbonate, bicarbonate and carbonic acid
    - increase the pH. organisms cannot bioprecipitate their shell.

Mineral Carbonation

- Mineral carbonation: Creation of stable minerals,such as calcite and magnesite, by reacting CO2 with silicate minerals containing Ca and Mg (permanent sink)

$$\underset{\text{(forsterite)}}{Mg_2SiO_4} + 2CO_2 = 2\,\underset{\text{(magnesite)}}{MgCO_3} + \underset{\text{(quartz)}}{SiO_2}$$

$$\underset{\text{(anorthite)}}{CaAl_2Si_2O_8} + CO_2 + H_2O = \underset{\text{(calcite)}}{CaCO_3} + \underset{\text{(kaolinite)}}{Al_2Si_2O_5(OH)_4}$$

- It would require large industrial scale operations whereby silicates would have to be mined and crushed (ex situ)
- CO2 could also be injected in basaltic rocks to form new carbonates in situ (slow kinetics)
- Some pilot studies(Iceland)

Renewable Energy - Hydroelectricity

- It supplies ~60% of Canadian electricity – bulk of electricity in BC, MB, QC, NL
- It is renewable
- Cleaner than fossil fuels
- Either storage (reservoirs) or river uses
- Dams and reservoirs can seriously alter aquatic ecosystems
- Has Limitations
  - Dams and reservoirs can seriously alter aquatic ecosystems
  - Habitat destruction (e.g. Three Gorges, China), thermal pollution
    - Only so many naturally suitable lakes, or rivers amenable to damming
  - Increased public awareness of ecological impacts

Renewable Energy - Biomass

- Biomass energy
  - From Earth's plant life
- Wood, peat, manure etc
  - Biofuels (e.g. ethanol from corn)
- Carbon neutral??
  - Much better than fossil fuels but not neutral
- Some problems
  - Deforestation, soil erosion, Increased price of food staple
- When you plot the land, you create anoxic conditions. Flooding the land with water, you create anoxic conditions, and mercury will escape from the rock or soil below and enter the water column.
- Biomass: heat with wood, trees grow back, biofuels are gases that are produced from degradation of organic material (driven from bacteria)

Renewable Energy - Solar

- Solar energy
- Convert Suns energy to electricity using photovoltaic cells
  – Expensive to produce
- Costs diminish with take up
- not complete without CO_2 emissions

Renewable Energy - Wind

- Fastest growing energy sector worldwide
- No direct CO_2 emissions (or SO_2, NO_x, heavy metals etc)
- (Few) drawbacks
  - Only works at certain wind speeds – Erratic power a problem
  - Threat to bats
  - Unsightly (?)

Renewable Energy - Geothermal

- Commonly exploited in certain geological settings
  - Tectonic plate margins (magma close to surface)
    - Hydrothermal systems
- Iceland, New Zealand, Japan, western USA

Renewable Energy - Tidal

- Harness change in water level from tides
  - Sluice across tidal basin
    - Tide flows in, then trapped
    - Released at low tide, driving turbines
- Bay of Fundy
  - Greatest tidal difference in world
    - 16 m at head of bay!
  - One of only 3 tidal energy stations in world (Annapolis, NS)

Nuclear Energy - Fission

- Supplies~15%ofCanada's electricity (but ageing reactors)
  - 50% in ON
- Harnessing forces that hold atomic nucleus together
- 235U fuel rods bombarded with slow neutrons —> 235U breaks apart
  - Heat (steam for electricity generation)
  - Control rods slow chain reaction
- controllable
- CO_2 free
  - Attractive option to replace fossil fuels – But not without problems
- Waste management
  - Public acceptance for the disposal of nuclear fuel waste
- (Very small) possibility of accident with large consequences
- what do we do with waste uranium?

Nuclear Meltdown

- Lots of heat generated by nuclear fission – Cooling essential
- What happens if cooling halted?
- Meltdown
  - Metal around nuclear fuel rods melts, releasing radiation
  - E.g. Three Mile Island (1979, PA; near miss, partial meltdown)
- Chernobyl
  - 1986, Ukraine (then USSR)
  - Explosion releasing radioactive material (131I, 137Cs)
  - 31 people killed, 4000 cases of thyroid cancer

Fukishima Disaster

- March 11, 2011
- Tsunami inundated the Dai-ichi nuclear power plant
  - Emission of 137Cs (half- life of 30 years), 134C (2 year half-life), 131I and 133Xe)
- Soil, water and air contamination • No-go area of 20 km around plant

Soils

- Important natural resource
  - Supports diverse ecosystems
  - Agriculture
- Composed of minerals, organic matter, water & air
- Colour
  - brown black (rich in o.m.) white gray (poor in o.m.) orange (rich in Fe)
- Formed from
  - Weathering of underlying bedrock
  - Erosion
  - Deposition & decomposition of organic matter
- Soil is essential as a natural resource. Composed of inorganic materials, organic materials, minerals and water
- Characterize soil by colour.

Weathering

- The physical breakdown and chemical alteration of rocks and minerals at the Earths surface
- Three types:

1. **Physical (mechanical) weathering**
   - Physical disintegration of rock – No chemical change
2. **Chemical weathering**
   - Interaction with atmosphere/
   - hydrosphere etc changes chemical make up of the rock
3. **Biological weathering**
   - Living things break down
   - parent material by physical or chemical means

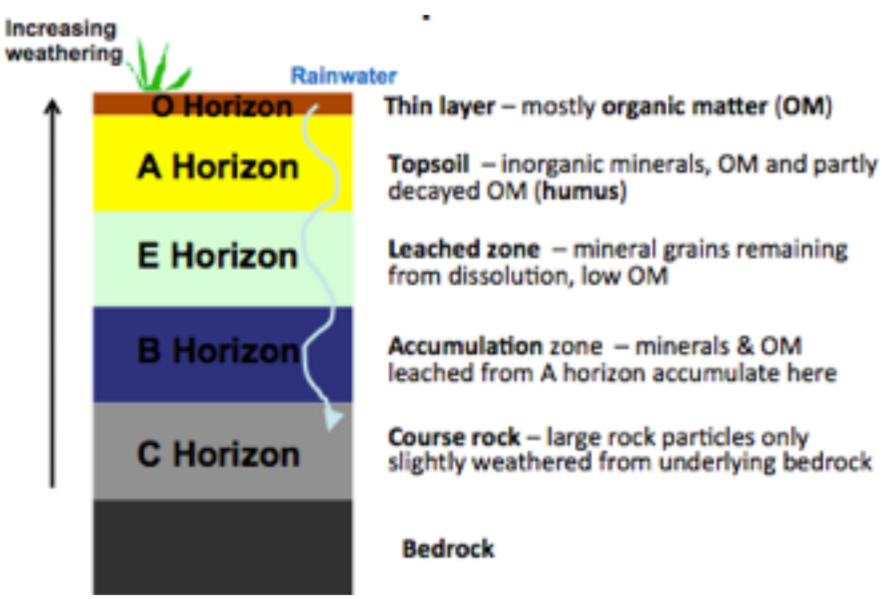
Chemical Weathering

- Primary agent of chemical weathering is water (and oxygen). rain slightly acidic
  - Also CO_2, SO_2, NO_x, organic matter
- Mineral dissolution:
  - $CaCO_3 + 2H^+ = Ca^{2+} + H_2O + CO_2$ (g) (calcite)
  - $2NaAlSi_3O_8 + 2H^+ + H_2O = Al_2Si_2O_5(OH)_4 + 4SiO_2 + 2Na^+$

    (Na-feldspar) (clay) (silica)

    (albite)

Soil profile



Real Soil Profile

- **Topsoil -** inorganic minerals, OM, and partly decayed OM (humus)
- **Leached Zone - mineral grains remaining from dissolution (e.g. quartz), low OM**
- **Accumulation Zone -** minerals (e.g. oxides of Fe and Al) and OM leached from A horizon accumulate here
- **Course Rock** - Large rock particles only slightly weathered from underlying bedrock

Soil Texture

- Depends on the Size of the particles;
  - Sand = 0.05 - 2mm diameter Silt = 0.002 - 0.05mm diamete Clay = less than 0.002mm diameter

Agriculture - a New Renewable Source

- Healthy crops: risk of infections, pathogens
  - Addition of pesticides, pesticides are a problem because they are so hard to degrade
- Good soil quality - Addition of nutrients, fertilizers
- Problems of over-exploitation, contamination and erosion

Physical Erosion

- The amount of organic matter in soil varies widely, from 1–10% in most agricultural soils to more than 90% in wetlands where peat is accumulated.
- Erosion of soil by wind and water is considered the most widespread soil degradation problem in Canada, especially in the Prairie provinces.
- Recent research suggests that losses of soil organic matter in Canada's un-eroded agricultural soils since initial cultivation are typically in the 15–30% range
- The amount of organic matter taken out of the soil in the form of crops is replenished by adding crop residues, manure and commercial fertilizers

Pesticides, Herbicides, and Insecticides - POP's

- Insecticides are used for insect control,primarily against Spruce Budworm and Hemlock Looper, and herbicides are used against competing vegetation
- Agriculture accounts for 80% of total sales,whereas domestic and industrial users account for the remaining 18%.
- From1982 to1993,the area of insecticide treatment fell from 3 million hectares to 256 000 ha, reflecting a decline in Spruce Budworm populations.Two-thirds of the area treated in 1993 involved the use of the biological insecticide BT (Bacillus thuringiensis).

Contaminants

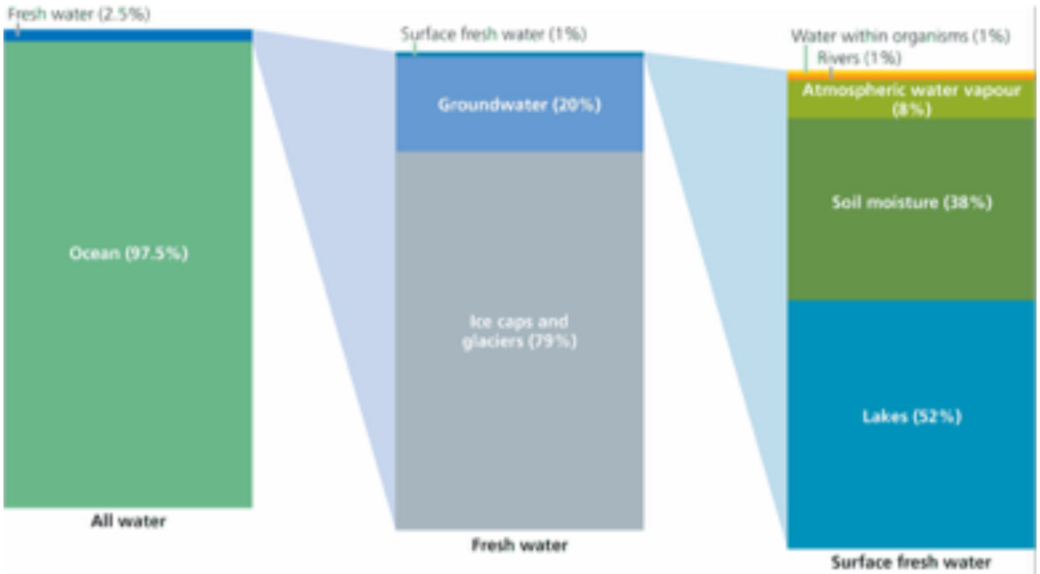
- Contamination of soil by heavy metals (e.g.,cadmium, lead, zinc) is a concern because metals are persistent and may affect plant, animal and human health
- Heavy metals enter agricultural soils primarily through atmospheric deposition and application of soil amendments such as fertilizers, animal manures, and sewage sludge, which is applied to agricultural land as a source of organic matter and nutrients

Earth - A Blue Planet

• “How inappropriate to call this planet Earth, when clearly it is Ocean.” - Arthur C. Clarke
• 70% of Earth’s surface is covered with water

Hydrologic Cycle

- 70% of the earth’s surface is covered with water
- 10% is covered with ice
  97.5 % of water is in the oceans 2.5 % is freshwater



Hydrologic Cycle

- Major Factors
  - Evaporation - water rises into the clouds leaving behind particles
  - Condensation - water accumulates in clouds
  - Precipitation - water falls from clouds back to land
  - Surface Runoff - water runs on ground collecting particles
  - Percolation - water seeps into the soil and eventually aquifer
  - Groundwater Recharge - water seeping into aquifer via percolation

Water as a Resource

- Water is a renewable resource essential to support life on Earth
- Surface waters (lakes, rivers, streams) can be used as a source of drinking water, for irrigation, for hydroelectricity and recreational activities
- Groundwaters are present in aquifers. Recharge is achieved through precipitation
- Water resources are related to the climate: low or high precipitation
- Surface and ground waters are threatened by pollution

Water Usage

- Regions of the world with the smallest water resources per capita are Asia, Africa and Europe, whereas America has the largest resources
- North America consumes the most water per capita, whereas under-developed countries consume the least
- In Canada, water is mainly used by the industries (including the power plants), whereas in the U.S., water is mainly used for irrigation
- Canadians use 5.4 billions m3/yr of water (surface and groundwaters)

Water Usage - Worldwide

- Regions of the world with the smallest water resources per capita are Asia, Africa and Europe, whereas Americas have the largest resources
- North America consumes the most water per capita, whereas under- developed countries consume the least
- Agriculture accounts for bulk of worldwide water usage (73%)

Water Usage - Canada

- In Canada, water is mainly used by the industries (including the power plants), whereas in the U.S., water is mainly used for irrigation
- Canadians use 5.4 billion m3/yr of water (surface and groundwaters)

Groundwater Supplies

- you can't tell if your tap water is contaminated
- Groundwaters are used for domesJc purposes in rural areas (wells)
  - Supplies 4% of Canadians
  - Pollution can be a problem:
    - Walkerton, ON (May 2000)
      - Farm animal waste washed into
      - vulnerable well
  - Groundwater supply contaminated with
    - E. coli 0157:H7
      - 7 died, 2300 made ill
      - Failures in adequate water testing —> Safe Drinking Water Act, ON (2002)

Water Conservation

- Canada 2nd worst developed nation for water consumption
- In the prairies, 58% of the water is used for agriculture
- Improved irrigation could reduce agricultural withdrawals by 20-30%
  Price agricultural water to encourage conservation
  - Use lined or covered canals to prevent evaporation
  - Irrigate at times when evaporation is minimal (night, early morning)
  - Use better irrigation systems: sprinklers, etc
  - Improve the quality of the soil: better infiltration
  - Plant crops that require little water

Water Reservoirs

Rainwater

- 83% of rainwater is generated by evaporation from the oceans
- Contains dissolved solids (Na, K, Ca, Cl, HCO_3, SO_4, etc.)
  - Total dissolved solids (TDS) = 7 mg/L
- Contains dust particles

Lakes

- water from forest beds flow into the lakes
  - have a lot of dissolved metals
- lakes have hidden and visible inlets
- Water composition is determined by the river water that flows into them
- Contain solids (from the watershed) and dissolved solids
- Water is mixed by the acJon of the wind
- Often stratified
  - Thermal stratification
    - Max density of water: 4˚C
    - Chemical stratification

Physical characteristics: Discharge (Q)

Q = AV (m^3/sec) — A: cross-sectional area (m^2) V: average velocity (m/sec)

__Lake Stratification__

- **epilimnion - highest level in stratified lake**
- **metalimnion - middle layer in stratified lake**
- **hypolimnion - bottom level of stratified lake**
- in the spring, dense water mixes around everywhere
- in the summer, the dense cold water is at the bottom
- in the fall, the water at the top becomes a bit denser and falls and mixes with the bottom cold water, homogenizing the water completely
- in winter there is also layering of the water, with dense at the bottom
- **thermokline -** the water density differential barrier, located in the metalimnion
- pink lake is stratified, anoxic conditions at the bottom create anoxic conditions;
  - this can lead to the once stable minerals at the bottom letting their elements being reduced e.g. iron; this dissolves the minerals and the iron goes into solution as ferrous iron; toxic.
- Monomictic or dimictic lakes turnover once or twice a year, respectively
- • Meromictic lakes do NOT turnover – Permanently stratified
  – E.g. Pink Lake, Gatineau Park
  – Lake Nyos, Cameroon

__Great Lakes and St. Lawrence River__

- 18% of the world's fresh surface water, together make up the largest freshwater lake system in the world. they are all connected and discharge via the St. Lawrence River.
- Combined drainage area of all the lakes is 766 000 km2
- Residence time (how long water stays in lake) range from 2.6
  years for Lake Erie to 191 years for Lake Superior.
- Water depth ranges from 19 m (Erie) to 147 m (Superior)
- Water flows out of Lake Ontario into the St. Lawrence River at a rate of about 6 850 m3/s, whereas it reaches 10 000 m3/s at the mouth of the Saguenay River

__Rivers__

- has a higher TDS because rivers get their water from more surface runoff
- **1 meter cubed = 1000L**
- seconds to day = divide seconds by 60, again by 60, then by 24
- Derived from rainwater that has either run off or run through its surrounding rocks
- TDS = 118 mg/L
- Suspended and dissolved material is transported downstream by gravity
- **Physical characteristics: Discharge (Q)**
  - **Q = AV (m3/sec) — A: cross-sectional area (m2) V: average velocity (m/sec)**

Hydrograph

- rivers discharges very little in winter
- most in spring
- vey little in summer
- more in fall

Contaminants

- Metals: Cu, Zn, Cd, Cr, Al, Hg, etc
- Organic compounds and organo-chlorinated compounds
- Fertilizers
- Sources: industrial effluents, mines, agriculture, surface runoff, etc.

Logging

- problem in quebec, the logging rivers used to float wood have some of the trees sunk to the bottom where they decompose and create acidic conditions

Agriculture

- for example in China the tomato fields with runoff tomato juice which is acidic can contaminate water

Drinking Water Guidelines in Canada

Toxic metals	Concentration (mg/L)
As	0.010 (modified in 2006)
Pb	0.010
Hg	0.001
Volatile Organic chemicals	**Concentration (mg/L)**
Benzene	0.005
CCl_4	0.002 (modified in 2010)
Microorganisms	
E. coli	none per 100 mL

Oceans

- contains dissolved and suspended solids
- TDS = 35 g/L (33-37 g/L) rich in Na and CL
- dissolved and suspeded solids are added to the oceans by action of rivers, rain, marine volcanoes, ice and underground water flow
- material is lost from the oceans by evaporation (sea mist) and precipitation (silica, carbonates, etc)

Chemical Precipitation

- **Evaporative process**
  - $Na^+ + Cl^- = NaCl$
  - $Ca^{2+} + SO_4^{2-} = CaSO_4$
- **Carbonate Precipitation**
  - $Ca^{2+} + 2HCO_3^- = CaCO_3 + CO_2 + H_2O$
  - $Mg^{2+} + 2HCO_3^- = MGCO_3 + H_2O + CO_2$
- **Silica Formation**
  - $H_4SiO_4 = SiO_2 + H_2O$

Pollutants: PAH

- PAH (polycylic aromatic hydrocarbons)
  - fused aromatic rings
  - by-production of incomplete fuel combustion (coal, oil, biomass)
  - carcinogen, mutagen, teratogen
  - lipophilic
- Hamilton harbour and Sydney Tar Ponds
  - PAH, heavy metals, tar, PCBs
- St Lawrence Beluga Wale

Persistent Organic Pollutants: PCB's etc.

- PCB (polychlorinated biphenyl) and other synthetic organochlorines commonly contaminate the sediments of harbours and major river system discharging to there sea
- virtually all the PCB's that have escaped into the environment are still there
  - **persistent organic pollutant**
  - lipophillic, carcinogenic
- PCBs are widespread in the Atlantic Costal Region
  - several hundreds of ppm in beluga wales
  - found in edible crab, filets of flounder, salmon, etc. 2ppm is Health Canada Limit
- Sydney Tar Ponds
  - waste from steel mill, 3.5 tonnes of PCBs

Heavy Metal Pollutants

- natural and anthropogenic sources
- anthropogenic sources:
  - offshore oil and gas development
  - industrial effluents
  - municipal wastewater discharges
  - urban runoff
  - mining facilities
  - ocean dumping

Minimata Mercury

- Hg: lipophilic and biomagnifies up the food chain
- Minimata
  - 1950's japan, inorganic Hh and methylmercury discharged into Minimata fishing bay by chemical company. taken up by shellfish/fish food chain all the way up to humans where it caused neurological disease

Spills

- ocean traffic and industrial operations along the coast (e.g. pulp and paper mills) are the sources of most spills
- in the arctic, the annual sea lift of duel and other supplies to remote communities and industries constitutes one of the largest sources of oil contamination
- elevated levels of hydrocarbon have been documented for specific arctic areas, and bioaccumulation in benthic fish species such as flounder has been documented

Pulp and Paper Mill Discharges

- buildup of wood fibre in the receiving waters
- depending on the production process, pulp and paper mills may also be major sources of toxic chemicals, including dioxins and furans
- these chemicals have been found in the fatty tissue and muscle of crab and other shellfish in the pacific region, with the result that some commercial and noncommercial fisheries were closed, begging in the late 1980s

Nutrients, Eutrophication, and Toxins

- runoff of agricultural fertilizers and animal wastes, aqua cultural operations (hatcheries and cage sites), municipal effluents, and industrial wastewater (e.g. from the food processing industry), are primary sources of elevated levels of nutrients such as nitrogen and phosphorus in the oceans
- **P is a limiting nutrient in freshwaters, N is limiting in oceans**
- eutrophic waters can contain large amounts of cyanobacteria and algae which can affect the taste
- some microorganisms can also produce toxins
- excessive algal growth can lead to anoxia
- anoxia creates a stress amongst aquatic species and can also be responsible for the formation of H2S, which is toxic
- water quality is degraded and fisheries are affected
- experimental lakes in ontario

Experimental Lake Area

- used for understanding eutrophication
- divide a lake in two, add phosphate to one side to mimic green lakes
  - one turned completely green like the lakes with algal blooms
  - phosphorus deemed key player in fresh water systems
    - phosphorus was coming from the soap from peoples laundry

Sources of Phosphorus

- laundry detergents have been a major source of phosphorus inf reshwaters
- between 1960 and 1970, most detergents contained 50-65% Na-tripolyphosphate, it was a surfactant (makes bubbles)
- between 1960-1970, 3 million Kg/yr of detergent were used
- surface waters (lakes and rivers) turned green
- present say detergents do not contain P
- lake erie turned green

Toxins

- certain species of phytoplancton produce toxins during excessive algal growth
- generally non-toxic for aquatic life, but some can be highly toxic once introduced to the trophic chain, especially for humans
- intoxication by mussels is one example

Municipal Waters

- denitrification necessary (second treatment)
- Alberta does a tertiary treatment
- Victoria only performs primary treatment
- municipal water is still one of the mains sources of marine contamination in Canada
- **municipal** wastewater (including storm sewers) are a source of organic and metal toxic substances
- inadequately treated municipal wastewater's contain bacteria, viruses, protozoans, which become concentrated in the filter-feeding organisms such as clams and oysters, making them unfit for human consumption

Groundwater

- small portion of freshwater is held in aquifers
- **Aquifer:** geological unit that allows the transport of water (porous, permeable: sand)
- **Aquiclude:** geological unit that does not allow the transport of water (impermeable)
- example of an aquiclude would be clay which packs tightly therefore little water movement
- water table is the surface of the lake, anything below is saturated with water
- anything above the water table is the vados zone; the pores in the solid is filled with gasses
- unconfined aquifer: water can return to the water table via percolation recharge
- confined aquifer is surrounded by water impermeable clay, water cannot recharge

Mass Balance Concept

- 3 possible outcomes for pollutant in a specific location in the environment
  - can remain at location
  - can be transported
  - can be eliminated or transformed
- **Changes in storage of mass**
  - mass-in = Q-in X concentration-in = g/D
  - mass-out = Q-out X concentration-out = g/D
- **mass-in > mass out = a process removing the solute from the solution; a sink**
  - for Cu it could be a precipitation
  - for SO_4 it could be becoming reduced by sulfate reducing bacteria in the anoxic sediments
- **mass in < mass out = a process is producing the solute into the solution; a source**
- input rate = output rate + decay rate + accumulation rate
  - steady state: input rate = output rate (no storage change)

<u>Source of Contamination</u>

- **non-point sources:**
  - fertilizers, pesticides, acid rain, atmospheric fallout, surface runoff, etc
- **point sources: waste disposal**
  - sewage sludges, landfills, livestock wastes, mine tailings, wells for liquid waste disposal, fly ash from coal fired power plants, etc.
- **point sources: leaks and spills**
  - manufacturing facilities, leaky tanks, and pipelines, wood preservation facilities, etc.

<u>Transport and Dispersion</u>

- soluble and particulate pollutants
- physical transport
  - advection: bulk movement of water or air
- flux density (J) = rate at which chemical is moved by unit area
- **J = CV , C = [x], V= fluid/ air velocity**

<u>Acidification</u>

- characterized by an increase in concentration of protons H+, pH = -log[H+]
- caused by acid rain and acid mine drainage (acid leachate rich in metals)
- acid rain is produced when SO_2 and Nox and their oxidation products are present int he atmosphere
- the main acidifying species are H_2SO_3, H_2SO_4, and HNO_3, and they are returned tot he eath by a process known as wet deposition (rain, snow)

<u>Acid Rain</u>

- normal unpolluted rain is slightly acidic and the pH is around 5.6 due to equilibrium between CO_2 and H20
  - CO_2 (g) and H_2O (l) = H_2CO_3 (aq)
  - H_2CO_3 (aq) = H^+ + HCO_3^- (aq)
- an extreme case of acidification in Canada is Dorset ontario, area submitted to intense acid precipitations; pH 4.1
- rain is classified as Acid rain when the pH is < 5.6
- susceptibility of certain water body to acid rain depends on its capacity to act as a buffer or to neutralize the effects of the acidity
  - depends on the composition of the underlying rocks and soils
  - carbonate rocks are good buffers, but granite rocks are not

Sources of SO_2 and NO_x

- volcanic eruptions natural source of SO_2
- soil gases/ lighting is natural source of NO_x

Dry Deposition

- dry deposition occurs between wet deposition periods
- vegetation, soils, and water absorb SO_2 and NO_x gases and particular material
- once incorporated those compounds are transformed in acidic species

Acidification in Canada

- the Canadian shield region of eastern Canada and parts of the Appalachians or Atlantic Maritime ecozone are vulnerable to acidification
  - thin soils and granitic bedrock: little natural buffering capacity
    - buffer - resists changes to pH upon addition of acid/base

Lake Acidity

- in the sudbury region, the majority of the monitored lakes showed an improvement in acidity
  - attributed to the substantial control of SO_2 emissions from sudbury's nickel smelters
- despite significant SO_2 controls in eastern Canada, the acidity of most lakes showed little change in remainder of ON & QC
- some lakes are recovering, pH is rising back up. bio-diversity is being re-introduced.

Trends in Lake Acidity

- SO_4 lake levels lower but lake still acidified
- NO_x emissions changed little
- ON, QC, and the atlantic region also affected by emissions in US

Bio-indicators of Acidity

- certain species of phytoplankton (diatoms) can be used as indicators
- diatoms can remain in sediments and be used by palaeontologists as indicators to reconstruct acidity patterns

Impacts of Lake Acidification

- change in algal species, but population density remain the same
- certain aquatic plants (macrophytes) can take over in acidic waters
- invertebrate benthic organisms decrease in number at low pH (mussels affected)
- fish like salmon and trout are highly sensitive

Reducing Acidity

- neutralized by addition of carbonates and lime
- neutralization at high pH promotes metal precipitation, good for water quality

Lecture 4 - Atmosphere

Composition

- Atmospheric composition has evolved since the beginning of the earth
- Primitive atmosphere was composed of N_2, H_2O and CO_2 with some NH_3 and CH_4.
- Atmosphere underwent a dramatic change with the appearance of photosynthetic organisms: production of O_2 and organic carbon
- Photosynthesis: $6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$

Great Oxygenation Event

- banded iron formations - present of iron oxides, meaning there was oxygen somewhere
- Appearance of photosynthetic organisms
- Cyanobacteria appeared maybe 3.5 billion years ago (definitely by 2.7 billion years ago)
- **Photoautotrophs**
  - Use sunlight to convert CO_2 & water into organic carbon for cell
  - Also produces O_2

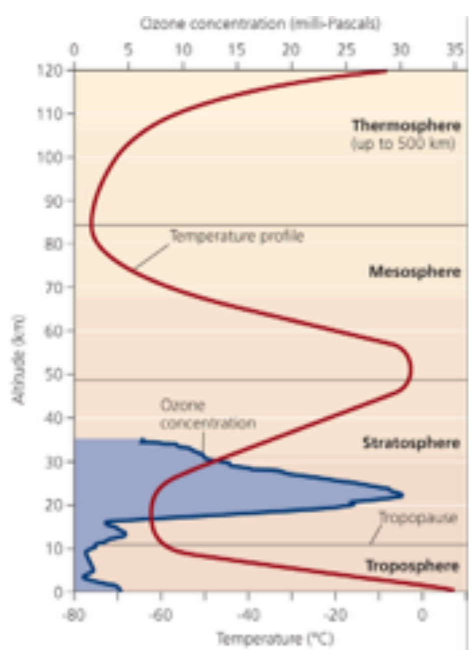
component	% (vol/vol)
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.035

Composition (Table 3.1)

- anthropogenic gasses are becoming trace compounds added to the overall composition
- The current earth's atmosphere is essentially composed of N_2 and O_2.
- O_2 is consumed during organic carbon degradation (respiration) and produced during photosynthesis

Layers

- Thermal boundaries between layers called pauses
- **Thermosphere:**
  - low density and pressure (< 10-5 atm.)
  - composed of atoms and ions
  - altitude > ~ 85 km
- **Mesosphere:**
  - ~ 50-85 km
  - absorption of solar radiation:
  - warming phenomenon
- **Stratosphere:**
  - 12-50 km
  - less solar radiation, temperature decreases with decreasing altitude
  - contains ozone (O_3)



Natural Formation of Ozone

- Ozone continuously created and destroyed in the stratosphere, by UV radiation
  - **Ozone production**
    - UV-C radiation splits O2 (photodissociation) :
      - $O_2 + h\nu > 2O$ ($\lambda < 240nm$)
    - Oxygen atom can then recombine with O2 to form ozone:
      - $O + O_2 + M > O_3 + M$ (M = thirdbody)

Natural Destruction of Ozone

- Ozone absorbs UV-B radiation, and is destroyed in the process (how it shields us)
  - **Ozone destruction**
    - UV-B radiation splits ozone (photodissociation):
      - $O_3 + h\nu > O_2 + O$ ($\lambda = 280–320nm$)
    - Oxygen atom produced can then split another ozone molecule :
      - $O + O_3 > 2O_2$

Imaging the Ozone Layer

- both poles have a vortex affect, bringing chemicals that would destroy ozone at a faster rate
- Ozone is measured in Dobson units (DU) in the stratosphere.
- Measure of thickness of the ozone layer if present at ground level
- 100DU=1 mm thick at ground level
- Presently,usually measured by satellites

Troposphere

- contains75-90%of the mass of the atmosphere and the majority of trace gases
- Can reach 8-17km
- within the troposphere,absorption of terrestrial radiation (by CO_2, H_2O and CH_4) causes warming near the surface. This is called the greenhouse effect
- without the green house effect,the mean temperature of the atmosphere at the surface of the earth would fall from the current 15 °C to -18 °C

Climate

- Weather is the physical condition of the atmosphere at a specific time and place. Weather is highly variable and unpredictable
- Climate is the long term view of weather patterns of a particular locality
- The earth is bathed in short-wave electromagnetic radiation from the sun.
- Earth receives 8.4 joules/cm2 minute as electromagnetic radiations

Solar Energy and Temperature

- Polar regions receive less solar energy than equatorial
- Sunlight spread over large surface area closer to poles
- Travels longer through atmosphere at poles

Atmospheric Circulation - Driven by Solar Energy

- Circulatory systems allow energy to move from equatorial regions to the poles
- Solar energy warms air, evaporates water, creates convection cells
  - Warm, moist air is less dense, so rises
  - As air rises, it expands, loses its moisture and cools
  - Cooling > Air descends, closing convection current

Incident Solar Radiation

- 30%of the incident solar energy is reflected back to the outer space
- 25% of the incident solar radiation is absorbed by gases, vapours and particulates in the atmosphere
- 45%of the incoming solar radiation passes through the atmosphere and is absorbed by the Earth's surface, plants, organisms, etc.
- The earth - atmosphere system not only absorbs radiation, but emits electromagnetic radiation: over a long period of time, the energy budget of the globe is seen in balance
- Solar radiation is absorbed by the green house gases, which include water vapour (H_2O), carbon dioxide (CO_2), nitrous oxides (NO_x), methane (CH_4), etc.. This is the natural greenhouse effect
- These gases re-emit energy at a longer wavelength: infrared
- Earth's surface temperature is determined by the equilibrium rates at which (a) solar energy is absorbed by the surface and (b) the absorbed energy is re-radiated in a longer wavelength form

Circulatory Systems

- Circulatory systems allow the energy to move from equatorial regions to the poles
- There are prevailing winds known as trade winds (tropical airflows that blow from the northeast in the northern hemisphere and from the southeast in the southern hemisphere), westerlies (mid-latitude winds) and polar easterlies

Climate and Oceans

- Climate is also influenced by oceans
- Water has high heat capacity
  Can absorb a lot of heat from the atmosphere and
- move this heat around the globe
- Oceanic conveyor belt or thermohaline circulation plays an important role in regulating climates
  - Cold water more dense than warm water
  - Water density increase with salinity
  - Both these properties drive global ocean circulation patterns

Thermohaline Circulation

- Driven by sinking of water in north Atlantic (North Atlantic Deep Water)
  - Cold water (made saltier by formation of sea ice) sinks
  - Cold , deep water resurfaces as it warms passing through the Pacific & Indian ocean
  - Returns to north Atlantic

Effects of Winds

- dilution of salinity in ocean because glacier melting, slowing down warm currents
- Winds blowing across the North Atlantic transfer a significant degree of warmth to the surrounding countries. The annual amount of heat absorbed from the conveyor belt is almost one-third as a much as that received from the sun in this location. North America is 6 °C warmer because of this effect.
- The Atlantic conveyor belt has decreased by 30% since 1957 because of glacier melting and lower salinity: decrease in T of 1-2 ° C in Europe in the next 20 years
- Winds blowing across the oceans create surface currents. The rotation of the earth influences the path of the currents.

Winds

- south of the equator, movement is essentially anti-clockwise
- movement is clockwise in the north hemisphere
- Air circulates in the atmosphere under 3 forces:
  - pressure gradient force
  - frictional force
  - Coriolis force : force that operates to the right over a surface that is rotating anti-clockwise and to the left, over a clockwise rotating surface
- the pressure gradient is the principal driving force producing horizontal airflow

Climates

- **tropical:** no discernible winter/summer seasonal change in temperature
  - (latitudes of 30° N and 30° S)
- **Mid-latitude:** (30-60° N, 30-55° S)
- **Polar:** the average temperature of the warmest month does not exceed 10° C
  - (latitudes > 60° N, and 55° S)
  - in polar regions, much of the ground is permanently frozen: permafrost

El Nino

- is a disruption of the ocean-atmosphere system in the Tropical Pacific having important consequences for weather and climate around the globe
- It occurs every 2 to 7 years. Recent events were in 1982-1983, 1986-1987, 1991-1993, 1994-1995, 1997-1998 (strong event), 2002 (weak event), 2004-2005 (weak event), 2006-2007, 2010
- this phenomenon is thought to be triggered when the steady westward blowing winds over the Pacific ocean weaken and reverse direction
- it allows a large mass of warm water (that is normally located near Australia) to move eastward along the equator, near the coast of south America

El Nino January 1998

- some of the waters near the equator were 4 or 5 degrees warmer than they should be

Impacts of El Nino

- if the fish leave, fishermen are affected which affects the economy of dependent countries
- It affects evaporation patterns and can cause floods, droughts, etc.
- It also affects fish populations by changing their migration patterns (change of T°, decrease of primary production caused by limited nutrients)
- El Nino is also blamed for coral bleaching (higher T° and lower salinity)
- 1982-1983, severe droughts in Australia, Indonesia, India and South Africa. In Australia alone, 2 billion dollar loss in crops
- 1997-1998, heavy rains in California, snow in Mexico, field fires in the Prairies, unusual warm winter in Canada. 34 billions in damage worldwide, 24 000 people died.
- Temperature of the water off the coast of BC was 2 to 3 °C above average in 1997-1998 z

La Nina

- Characterized by unusually cold ocean temperatures in the eastern equatorial Pacific, as compared to El Niño, which is characterized by unusually warm ocean temperatures in the Equatorial Pacific.
- Usually follows El Nino episodes
- Responsible for cooler temperatures in the Northeastern parts of US and Canada
- El Nina episodes in 1987,1995 and 1999 and 2008

Greenhouse Gases

- water vapour is the most common greenhouse gas
- Green house gases include
  - CO2, water vapour, nitrous oxide (N2O), methane (CH4) etc
- Solar radiation re- emitted by Earth’s surface at longer wavelength [infrared (heat)]
- Green house gases absorb some of this and re-radiate it back to the Earth’s surface
- This is the natural greenhouse effect (without it, surface would be 33 °C cooler)

Natural Greenhouse Effect

- we are putting anthropogenic into the atmosphere CO2
- The magnitude of green house warming depends on the quantities of the various greenhouse gases in the atmosphere and their relative efficiencies as absorbers and emitters of radiation.
- Water vapour is the most abundant
- Contributes about 21°C of warming to the natural greenhouse effect
- **CO2**
  - Less abundant than water vapour, but much more efficient absorber of radiation
  - Accounts for another 7°C of natural warming
- **Ozone, methane, and nitrous oxide**
  - Much less abundant
  - Responsible for the remaining 5°C

Greenhouse gas	Relative heat-trapping ability
CO_2	1
CH_4	21
N_2O	310

Anthropogenic Contribution to Greenhouse Effect

- Since industrial revolution, concentrations of greenhouse gases have increased substantially from 280 ppm to 393 ppm in 2012
- We could reach 400ppm in 2015-2016
- 60% of this increase has occurred since 1958, mirroring the rapid growth of a postwar global economy powered by fossil fuels

Other Greenhouse Gases

- Methane (CH_4) concentration have more than doubled
  - Tapping fossil fuel deposits
  - Livestock emissions
  - Enhanced fermentation in soils, sediments, wetlands etc
    - Landfills, rice production
- Nitrous oxide (N_2O) levels have also increased markedly
  - Auto emissions
  - Chemical manufacturing
  - Nitrogen fertilizers
- Also, synthetic greenhouse gases have been added to atmosphere
  - HFC, CFC (high heat trapping ability)

CO_2 Budget

- ~40% of CO_2 from fossil fuel combustion is present in atmosphere
- Remaining60% absorbed by forests &oceans
- Forests
  - Deforestation may lead to increased levels of CO_2 since it is not assimilated by the plants
    - Before widespread deforestation, the global terrestrial vegetation stored 900 billion tons of organic carbon (50% in tropical forests)
    - Now, only 560 billion tons of carbon are stored.
- Oceans
  - Immobilize large quantities of CO_2 (by precipitating $CaCO_3$), but their retention capacity is limited

Ocean Acidification

- Predicted pH decrease of 170% in year 2100 compared to year 1850 if CO_2 levels continue to increase at the same rate
- This could lead to the disappearance of 30% of the ocean species

Feedback Cycles in Climate Systems

- Feed back cycles/loops
  - Output from cycle is fed back into cycle
    - **Positive feedback** = self-reinforcing
    - **Negative feedback** = self-limiting
  - Climate system is filled with such examples of positive and negative feedback

Positive Feedback Cycles

- higher temperatures > melting of permafrost > release of methane into atmosphere > .. higher temperatures..
- higher temperatures > more evaporation > more water into atmosphere > higher temperatures…

Negative Feedback Cycles

- higher temperatures > more evaporation > more clouds to reflect sunlight > lower temperatures
- elevated CO_2 > more plant growth / phytoplankton growth > absorb atmospheric CO_2 > lower temperatures

CO_2 and Climate

- One of the most important indicators of climate change is the temperature of the surface atmosphere
- Thermometer temperature data go back to1880
- Air-temperature data can be biased by the fact that air T° can vary between cities and rural areas, that it can be affected by cooling effects caused by volcanic eruptions
- Recent analyses suggest a definite warming trend since the mid-19th century in some parts of the world.

Earth Surface Temperatures from Past

- We know from thermometer measurements that global temps have risen in past 130 years
- is this anomalous (and so worrying) or just a fluctuation when viewed over longer timescales?
- We need temperature data further back in time
  - Use proxies (surrogates) for temperatures
    - Human records (e.g. extent of sea ice)
    - Natural records (e.g. tree rings, coral reefs, pollen grains in sediments, ice cores)

Global Surface Temperatures over past 2000y.

- using ice cores, melt the ice and date it and trap the air that is in the bubbles in the ice to tell us what kind of gas is in the ice giving us the concentration of CO_2 in the air.
- we can also measure the isotopic concentration; the fractionation between heavy isotopes and light isotopes is dependent on temperature so we can estimate the temperature of the air when the ice originally formed

Ice Cores: A Window to Distant Climates

- Air bubbles trapped as snow falls and is compressed into ice at the poles
  - Melt ice to recover air bubbles and analyze its CO_2 concentration
- Measure isotopic composition of H & O in ice to determine past temperature
  - Warmer temperatures: higher levels of heavier isotopes (^2H, ^{18}O)
- Collect deep ice cores to recover information on past atmosphere (ice core in Antarctica: 800000 yrs

What about the Sun?

- Changes in Earth's orbit and its rotational axis alter the amount of solar energy its surface receives (Milankovitch) over periods of 20 000 – 100 000 years: trigger glaciations and interglacial periods
- Couldn't changes in the Sun's activity have influenced global surface temperature?
- Observed temp. increase can only be reproduced if we factor in greenhouse gases

Impacts of Warming

- At present rate of CO_2 increase in atmosphere, global surface temperatures predicted to rise by 1.1 to 6.4 °C during 21st century. Interestingly, the latest IPCC report (2013) showed that surface temperatures did not increase that much, despite increased CO_2 emissions. Where is CO_2 going? Scientists believe most of the CO_2 is absorbed by the oceans
- Most climate scientists say a rise of more than 2°C would lead to serious climate changes

Some Global Physical Impacts

- CO_2 absorption by oceans will make them more acidic
  - Already declined by 0.1 pH units (+ increase of 0.14-0.35 by the end of the century)
  - Impact organisms that form $CaCO_3$ shells, many of which are primary producers
- Increased intensity of Atlantic hurricanes
- Glaciers, ice sheets etc. will continue to melt
- Sea levels rise
  - Rose 17 cm in past century
  - Predicted to rise by 18-59 cm by 2100

Glacier Retreat

- Glacier melting and retreat observed throughout the world
  - E.g. Athabasca glacier
    - Shrinking 15 m per year
    - Lost half its volume in past 125 years

Sea Ice Minimum (2012)

- Arctic warming faster than elsewhere(twice the global average) (yellow line is the sea ice extent in 2007
- Arctic predicted to be free of sea ice by 2030–2040 •
- North west passage will be exploited commercially

Seal Levels Rise in Canada

- melting of glaciers, ice sheets, and thermal expansions
- seal levels will cause costal erosion and retreat
  - prince Edward island will be gone

Ecological Effects

- Some 20 – 30% of species face extinction if temperature rises > 2.2°C (50% probability)
  - Species ranges shift towards poles
- A change of T° would affect the seasonal precipitation patterns (warmer climates, less precipitation)
  - Droughts in tropical parts of world
- Warmer waters can cause the bleaching of corals and the migration of fish populations (less upwelling of nutrients by cold water)
- Ocean acidification
  - Impair ability of coral and other $CaCO_3$ shell forming organisms to grow

Ecological Impacts

- Polar bears
  - Hunt on pack sea ice, which is fast disappearing with climate change
- Amazon rainforest
  - Huge carbon sink (absorbs 2 billion tonnes CO_2 per year)
  - Drought in 2005 changed Amazon rainforest from a carbon sink to source
    Released 3 billion tonnes CO_2 !
- Sign of things to come?

- **Societal Effects**
- Crop yields in temperate zones may increase,BUT droughts in tropics will limit crop productivity which will lead to hunger/famine
- Sea level rise displace people from coasts
  - Warming Arctic disrupts aboriginal way of life
- Melting mountain glaciers reduce water supplies to millions of people
- Human health will suffer

Talking CO2 Emissions

- Vast majority from fossil fuel combustion
- Emissions per capita are directly related to the level of industrialization
- Canada and the U.S. are the largest producers of CO2 per capita
- Kyoto protocol to reduce CO2 emissions

Kyoto Protocol

- Canada was one of the first countries to sign the agreement on April 1998. It expired in 2013.
- Our initial goal was to reduce green house gas emissions by 6% below 1990 levels by 2008-2012
  - However, our emissions keep increasing (by 2006 they were 21% higher than emissions in 1990!)
  - The latest target was a 17% reduction by 2020 based on 2005 emissions (607 Mt) (Environment Canada 2012)
  - Works out as about 3% reduction based on 1990 emissions
- On Dec. 12th 2011, Canada pulled out of the Kyoto protocol
- Most industrialized countries have signed the protocol but the US were not part of it
- Did it really work?

Copenhagen Conference

- December 2009
- Meant to take over from Kyoto protocol
- No legally binding agreement made
- Stumbling blocks
  - Technological & financial assistance to developing countries to address climate change
  - Worry of China/India in limiting their economic growth
- CO2 reduction pledges

Nation	Observed emission change (1990-2006)
Russia	-32%
Germany	-17.2%
United Kingdom	-14.3%
France	-0.8%
Italy	+12.1%
Japan	+6.5%
United States	+15.8%
Canada	+29.1%

Cancun 2010 - UN Conference

- To commit to a maximum temperature rise of CO_2 above pre-Industrial levels, and to consider lowering that maximum to 1.5 degrees in the near future.
- To make fully operational by 2012 a technology mechanism to boost the innovation, development and spread of new climate-friendly technologies
- To establish a Green Climate Fund to provide financing to projects, programs, policies and other activities in developing countries via thematic funding windows

Duran 2011 - UN Conference

- 194 nations agreed to start negotiations on a new accord that would put all participating countries under the same binding commitments to control greenhouse gases

Doha 2012 - UN Conference

- They worked on these cond. phase of the Kyoto protocol for 2013-2020
- They set up plans to address future “loss and damage” in developing countries that may arise as a result of climate change - ranging from a rise in sea levels to severe weather events.
- Experts say that the planned emission reductions will not prevent the planet from warming up above 2 degrees

Warsaw 2013 - UN Conference

- Agreement between 190 countries to prepare their emission targets for the summit in Paris in 2015 (designed to replace the Kyoto protocol)
- The reduction of CO_2 emissions is planned for 2020
- Disagreement between the industrialized countries and the emerging ones on the emission targets of the emerging countries. Rich countries are arguing that countries like China and India will produce more emissions in 2020 than all rich countries combined.

Some Steps to Lower CO_2 Emissions

- Improve efficiency of vehicles (fuel economy) and reduce their use (better public transport)
- Replace coal power plants with nuclear and wind/solar power
    - Improve efficiency of coal power plants
- Capture CO_2 from power plants
- Stop deforestation and re-establish tree plantations

What if it Doesn't Work?

- Climate geoengineering
  - "options that would involve large-scale engineering of our environment in order to combat or counteract the effects of changes in atmospheric chemistry" Nat. Acad. Sci.
  - CO_2 sequestration
    - Carbon capture & storage
    - Ocean iron fertilization
  - Solar radiation management
    - Stratospheric sulfur aerosols
    - White roofs (enhance albedo)

Geoengineering - CO_2 Sequestration

- Carbon capture & storage methods
  - See earlier lecture on energy resources
- Ocean iron fertilization
  - Iron often limiting nutrient in open ocean
  - Add iron : stimulate phytoplankton: sequester CO_2
- Spraying sulfate aerosols in the atmosphere
  - Political aspects to consider

Sulfate Aerosols

- Aerosols would reflect back the solar energy into space: cooling effect

Stratospheric Ozone

- Ozone(O_3)primarily occurs as a "layer" in the stratosphere, at 20 – 30 km altitude
- Smaller amounts in the troposphere present as a pollutant (not naturally produced)
- Stratospheric ozone layer acts as a "shield" against potentially harmful UV radiation from sun

Falling Stratospheric Ozone Levels

- Between 1980 and 1994, the concentration of stratospheric ozone declined by about 5–6% over southern Canada and by 7–8% over the north
  - Our UV shield weakening
- Part of a global phenomenon that includes the seasonal formation of "ozone holes" over Antarctica

Stratospheric Ozone Loss

- 40% loss over the Arctic in one year (NASA) due to unusual long winter
- Stratospheric ozone loss linked to several widely used chlorine and bromine compounds
- Chlorofluorocarbons(CFCs) most abundant of these anthropogenic chemicals
- Other significant ozone-depleting compounds include:
  - Halons
  - Carbon tetrachloride (CCl_4)
  - Methyl chloroform (CH_3CCl_3)
  - Methyl bromide (CH_3Br)

Chlorofluorocarbons

- Stable,nontoxic,nonflammable, highly versatile chemicals first developed in the 1890's
  - Used over the past several decades as spray propellants, refrigerants, foam-blowing agents, solvents, and cleaning fluids
- Because of their chemical stability, CFCs can survive in the atmosphere for several decades to a few centuries
- They diffuse gradually from the troposphere into the stratosphere (they rise, where the kill o3)

CFCs vs. Ozone in the Stratosphere

- CFC's in stratosphere subjected to intense solar radiation (UV-C)
  - Molecule breaks down (photo dissociates), releasing a Cl atom
  - Cl atom breaks up ozone molecule:
    - $Cl+O_3 > ClO+O_2$
- ClO formed reacts with oxygen atom , regenerating free Cl atom:
  - $ClO+O > O_2 +Cl$
- In this way, a single atom of Cl can destroy hundreds of thousands of ozone molecules before finally forming a more stable combination with another substance

Chlorine Bearing Agents

- CFC-11andCFC-12 together account for about half of the ozone- depleting chlorine entering the stratosphere
- Other important chlorinated ozone depleting chemicals include
- Hydrochlorofluorocarbons (HCFCs)
- Carbon tetrachloride (CCl_4)
- Methylchloroform

Bromine Bearing Chemicals

- Halons
  - Fire extinguishers
- Methylbromide
  - Agricultural fumigant
  - Unlike other ozone depleting chemicals, methyl bromide has a relatively short lifetime
  - Bromine is, however, highly effective in removing ozone and methyl bromide is therefore considered to be a significant contributor to ozone depletion

Methyl Bromide

- In addition to anthropogenic input, CH_3Br also has natural sources
  Marine bacteria can produce it
- Highly toxic
  Gas used in fumigation
- High potential for depleting ozone
- Banned in Canada(2001)andUSA(2005)

Protecting the Ozone Layer

- Global production of ozone depleting substances has decreased since the signature of the Montreal Protocol in 1987
- Other agreements have been reached since,further decreasing the emission of ozone depleting chemicals
- If emissions are maintained at the present levels, stratospheric ozone should replenish itself to pre- industrial levels by 2050 (chlorine atoms can persist for decades in the stratosphere)

Importance of Montreal Protocol

- if we didn't have the Montreal Protocol, there would be very little UV protection by 2060

Nitrous Oxide; Unregulated Ozone Depleter

- Nitrous oxide (N_2O) is not regulated by the Montreal Protocol
  - Significant ozone-depleting potential
- “Limiting future N_2O emissions would enhance the recovery of the ozone layer from its depleted state and would also reduce the anthropogenic forcing of the climate system, representing a win-win for both ozone and climate”

Troposphoric Ozone

- Ozone in the lower atmosphere is an important pollutant
  - Ground-level ozone – Respiratory irritant
- It is not naturally produced
  - It is a photochemical pollutant
  - i.e. it is synthesized in the atmosphere by photochemical reactions involving a precursor

Production of Ground Level Ozone

- The main precursors is NOx
  - Originate from the combustion of fossil fuels (automobiles)

Ground-level ozone production

- NO_2 photodissociates:

$$NO_2 + h\nu \rightarrow NO + O \qquad (\lambda < 400\ nm)$$

- Oxygen atom combines with O_2 to form ozone:

$$O + O_2 + M \rightarrow O_3 + M \qquad (M = \text{third body})$$

Smog

- Historically, smog was a problem from burning of coal (i.e,coal rich in sulfur), and smoke from vehicle exhausts
- Great smog of London,UK(1952)
  - Thick fog from temperature inversion (cold air trapped beneath layer of warmer air)
  - Mixed with chimney smoke, particulates and SO2 from coal burning
  - Respiratory problems
  - 4000 immediate deaths (8000 more following months) – 1956 clean air act (UK)

Smog in China

- Concentrations PM2.5 > 1000 mg/m3
- Concentrations ~ 300 mg/m3 are considered hazardous by WHO
- Daily exposure ~ 20 mg/m3

Photochemical Smog

- Volatile organic compounds (VOCs)
  - Fossil fuel combustion (e.g. power plants, vehicles)
- Together, ground-level ozone and a number of other pollutants make up what is known as photochemical smog
  - It affects people with respiratory problems
- Because ozone formation depends on strong sunlight and is accelerated by heat, ozone concentrations tend to peak during the day and the summer
- In1990,Canada decided to reduce its ozone and VOC emissions by 10% to 15 % (1985 levels) Similar reductions in USA

Ground Level Ozone

- Ozone levels average around 100ppb in the southern States, while they vary between 40-60 ppb in the rest of the US and Canada
  - Limits for 8 h exposure: Canada 65 ppb (later in 2010); USA 75 ppb (under revision)
- The most affected area in Canada is the Windsor- Quebec corridor, where ozone concentrations can reach 110-160 ppb, sometimes 190 ppb
- Ozone levels can reach 500ppb in L.A. and remain above 100 ppb for weeks

Particulate Air Pollution

- Anthropogenic airborne particulates that are less than 10 µm in diameter (PM 10) are primarily a consequence of industrial processes and motor vehicle use
- Human-induced particulate pollution occurs primarily in larger cities, where industries, motor vehicles, heating plants, and residential furnaces provide many emission sources.
- In BC, YT, QC & Atlantic provinces, wood smoke from the burning of logging or sawmill waste and from the use of wood for home heating is a common source of pollution

Particulate Air Pollution Worldwide

- WHO Air Standard Quality is 100mg/m3; Canadian cities well below that
- cities like Beijing and Mexico city are way above that.

Icelandic Volcano

- iron released into the air fertilized the ocean and caused algal bloom

Automobile Emissions of Pb

- Between 1923 and 1975, gasoline contained Pb. It was used to increase the mechanical efficiency
- Pb emissions (as particulates) started to decrease in 1975 due to an increased use of catalytic converters to reduce emissions by cars
- Pb emissions accumulated in terrestrial and aquatic ecosystems (in lakes, soils, plants and animals)

Lecture 5 - Evolution, Biodiversity, and Population Ecology

Polar Plight

- hexabromocyclododecane - flame retardant being found in Antarctic. this means:
    1. **long range transport** - toxic compounds that are bi-products of industrial activities transported across the world due to their chemical and physical properties.
    2. **legacy contamination** - toxins that were deposited in the past that are no longer transmission but remain a concern.
- there is no longer any pristine environments on planet earth, everything is now contaminated even the most remote places.

Anoxic Atmosphere

- in the absence of oxygen, life developed in unicellular form because multi-celluar life requires a lot of energy, which oxygen eventually provided
- oxygen was a poison at first wiping a lot of the biodiversity out, but it eventually provided a lot of energy because of its oxidative properties when harnesses right.

Evolutionary events

- nutrients in the hot water such as hydrogen and methane contain energy in the form of electrons
- as time went on, RNA developed and then further complexified and eventually was able to self-replicate and catalyze simple reactions
- DNA developed, became more stable ensuring the genetic info was less susceptible to destruction, later surrounding itself with lipids: LUCA.

Life Forms

- archaea, bacteria, and eukaryotes.

Microfossil

- proof of these old archaea: fossils having the rocks around them dated with isotopic fractionation; give us a date of the rocks.
- **Stromatolites:** geological formations, fossils, which are an assemblage of filamentous microbes fossilized that we are able to date.

Elements of cellular Structure

- Eukaryotic vs. Prokaryotic Cells
  - **Eukaryotes**
    - DNA enclosed in a membrane-bound nucleus
    - Cells are generally larger and more complex
    - Contain organelles
  - **Prokaryotes**
    - No membrane-enclosed organelles, no nucleus
    - Generally smaller than eukaryotic cells

Striking Gold in Costa Rican Cloud Forest

- Golden toads were discovered in 1964, in Monteverde, Chile
- The mountainous cloud forest has a perfect climate for amphibians
- endemic in the region, thrived because of the big leafed plant water pools
- Unfortunately, they became extinct within 25 years due to global warming's drying effect on the forest

Evolution: Source of Earths Biodiversity

- Biological evolution = genetic change in populations of organisms across generations
- May be random or directed by natural selection
- Natural Selection = the process by which traits that enhance survival and reproduction are passed on more frequently to future generations than those that do not

Understanding Evolution is Vital

- It alters the genetic makeup of a population
- It is important for understanding antibiotic and pesticide resistance, agricultural issues, production, medicines, etc.
- Organisms adapt to their environment and change over time
  - such as bacteria and antibiotic resistance, changing the protein slightly
    - very first antibiotics are produced by fungi and other bacteria for competitiveness

Natural Selection Shapes Organisms

- In 1858, Darwin and Wallace both proposed natural selection as the mechanism of evolution
  - Organisms face a constant struggle to survive and reproduce
  - Organisms tend to produce more offspring than can survive
  - Individuals of a species vary due to genes and the environment
  - Some individuals are better suited to their environment and will pass on their genes; if you have genes that will allow you to thrive in the environment you will survive and have offspring that transfer the mutation to the next generation

Genetic Variation

- **Adaptive Trait (Adaptation)** = a trait that promotes reproductive success
- Mutations = accidental changes in DNA that may be passed on to the next generation
  - Non-lethal mutations provide the genetic variation on which natural selection acts
- Sexual reproduction also leads to variation (process of recombination of chromosomes)

Natural Selection Acts on Genetic Variation

- **Directional selection** = drives a feature in one direction
- **Stabilizing selection** = produces intermediate traits, preserving the status quo
- **Disruptive selection** = traits diverge in two or more directions
- If the environment changes, a trait may no longer be adaptive

Evidence of Natural Selection

- It is evident in every adaptation of every organism
- Evident in bacteria and fruit flies in laboratories
- Selective breeding of animals and artificial selection
- **Divergent Evolution:** one species evolves in many different directions
- **Convergent Evolution:** different species evolve towards one common form

Lactose Tolerance

- 10000 years ago no humans could digest lactose
- migration from the middle east because of agriculture towards the west and colder Europe, people kept animals for meat and cheese
- eating cheese which has less lactose, a mutation raised allowing them to digest some lactose
- now because of some evolutionary trait most oft he world is able to digest it.

<u>Evolution Generates Biodiversity</u>

- Biological Diversity = An area's sum total of all organisms
  - The diversity of species
  - Their genes
  - Their populations
  - Their communities
- Species = a population or group of populations whose members share characteristics and can freely breed with one another and produce fertile offspring
- Population = a group of individuals of a species that live in the same area

<u>Speciation Produces New Types of Organisms</u>

- The process of generating new species
  - A single species can generate multiple species
- Allopatric speciation=species formation due to physical separation of populations
  - Can be separated by glaciers, rivers, mountains
  - The main mode of species creation

<u>Populations can be Separated Many Ways</u>

- Sympatric speciation = species form from populations that become reproductively isolated within the same area
  - Feed in different areas, mate in different seasons
  - Hybridization between two species
  - Mutations

<u>Diversification Results from Speciation Events</u>

- Speciation generates complex patterns of diversity
- **Phylogenetic trees (Cladograms)**
  - Scientists can trace when certain traits evolved
  - Show relationships between species

<u>Extinction</u>

- Species generally evolve from simple to complex and small to big, but the opposite can occur, and some even disappear
- Extinction = the disappearance of a species from Earth
  - **Occurs when a species cannot adapt quickly enough to a changing environment**
  - Speciation and extinction affect species numbers
- Extinction is irreversible: once a species is lost, it is lost forever
- Humans profoundly affect rates of extinction;

Species Vulnerable to Extinction

- Extinction occurs when the environment changes too rapidly for natural selection to keep up
- Endemic species = a species only exists in a certain, specialized area. These species:
  - Are very susceptible to extinction
  - Usually have small populations
- Many other factors also cause extinction
  - Severe weather
  - New species
  - Specialized species

Earth Mass Extinctions

- **Background extinction rate** = extinction usually occurs one species at a time
- **Mass extinction events** = five events in Earth's history that killed off massive numbers of species at once
  - 50-95% of all species went extinct at one time
- Humans are causing the sixth mass extinction event
  - Resource depletion
  - Population growth
  - Development

Ecology is Studied at Several Levels

- Ecology and evolution are tightly intertwined
- Biosphere = the total living things on Earth and the areas they inhabit
- Ecosystem = communities and the nonliving material and forces they interact with
- Community = interacting species that live in the same area

Levels of Organization

- Population ecology = investigates the quantitative dynamics of how individuals within a species interact
- Community ecology = focuses on interactions among species
- Ecosystem ecology = studies living and nonliving components of systems to reveal patterns
  - e.g. Nutrient and energy flows

Organism Ecology: Habitat

- where the animal lives
- **Habitat =** the environment in which an organism lives – Includes living and nonliving elements
  - Scale-dependent: from square meters to miles
- **Habitat use** = each organism thrives in certain habitats, but not in others
- **Habitat selection** = the process by which organisms actively select habitats in which to live
  - Availability and quality of habitat are crucial to an organism's well-being
- Human developments conflict with this process

Organismal Ecology: Niche

- what the animal does
- **Niche =** an organism's use of resources and its functional role in a community
- Habitat use, food selection, role in energy and nutrient flow
  - Interactions with other individuals
- **Specialists** = species with narrow niches and very specific requirements
- Extremely good at what they do, but vulnerable to change
- **Generalists** = species with broad niches that can use a wide array of habitats and resources
  - Able to live in many different places

Population Characteristics

- All populations show characteristics that help scientists predict their future dynamics
- **Population size** = the number of individual organisms present at a given time
  - Numbers can increase, decrease, cycle, or remain the same
    - ex. the passenger pigeon; from darkening skies to extinction
- **Population density** = the number of individuals within a population per unit area
  - High densities make it easier to find mates, but increase competition, and vulnerability to predation
  - Low densities make it harder to find mates, but individuals enjoy plentiful resources and space
- **Population distribution (dispersion)** = spatial arrangement of organisms within an area
  - **Random** – haphazardly located individuals, with no pattern
  - **Uniform** – individuals are evenly spaced due to territoriality
  - **Clumped** – arranged according to availability of resources
    - Most common in nature
- Sex ratio = proportion of males to females
  - In monogamous species, a 50/50 sex ratio maximizes population growth
- **Age Structure** = the relative numbers of organisms of each age within a population
  - Age structure diagrams (pyramids) = show the age structure of populations

Birth and Death Rates
• Crude birth/death rates= rates per 1000 individuals
• Survivorship curves = the likelihood of death varies with age
   – Type I: More deaths at older ages
   – Type II: Equal number of deaths at all ages
   – Type III: More deaths at young ages

Populations Grow, Shrink, Stabilize
- **Natality** = births within the population
- **Mortality** = deaths within the population
- **Immigration** =arrival of individuals from outside the population
- **Emigration** = departure of individuals from the population
- Growth rate formula =
  - (Crude birth rate + immigration rate) - (Crude death rate + emigration rate) = Growth rate

Unregulated Populations
- Steady growth rates cause **exponential** population growth
  - Something increases by a fixed percent
  - Graphed as a J-shaped curve
- Exponential growth cannot be sustained indefinitely
  - It occurs in nature with a small population and ideal conditions

Limiting Factors Restrain Growth
- Limiting factors = physical, chemical and biological characteristics that restrain population growth: **Water, space, food, predators, and disease**
- **Environmental resistance** = All limiting factors taken together

Carrying Capacity
- Carrying capacity=the maximum population size of a species that its environment can sustain
  - An S-shaped logistic growth curve
  - Limiting factors slow and stop exponential growth
- Carrying capacity changes
- Humans have raised their carrying capacity, decreasing the carrying capacity of others

Perfect Logistic Curves not Often Found
• not usually found in nature, sometimes found in bacteria.

Influence of Factors Dependent on Population Density

- Density-dependent factors = limiting factors whose influence is affected by population density
  - Increased risk of predation and competition for mates occurs with increased density
- Density-independent factors = limiting factors whose influence isn't affected by population den
  - Events such as floods, fires, and landslides

Biotic Potential Variation in Species

- **Biotic potential** = the ability of an organism to produce offspring
- **K-selected species** = animals with long gestation periods and few offspring
  - Have a low biotic potential
  - Stabilize at or near carrying capacity – Good competitors
- **r-selected species** =animals which reproduce quickly
  - Have a high biotic potential
  - Little parental care

K-selected vs. R-selected Species

Table 3.3 Typical Characteristics of r-Selected and K-Selected Species

r-selected species	K-selected species
Small size	Large size
Fast development	Slow development
Short-lived	Long-lived
Reproduction early in life	Reproduction later in life
Many small offspring	Few large offspring
Fast population growth rate	Slow population growth rate
No parental care	Parental care
Weak competitive ability	Strong competitive ability
Variable population size, often well below carrying capacity	Constant population size, close to carrying capacity
Variable and unpredictable mortality	More constant and predictable mortality

Conclusion

- Organisms of the Monteverde cloud forest have helped illuminate the fundamentals of evolution and population ecology.
- Natural selection, speciation, and extinction help determine Earth's biodiversity.
- Understanding how ecological processes work at the the population level is crucial to protecting biodiversity.

Lecture 6 - Species Interaction and Community Ecology

Black and White and Spread All Over

- "The zebra mussel has altered aqua0c ecosystems beyond recognition." – Michael Bardwaj, Canadian Geographic
- In 1988 European ships discharged water into Lake St. Clair, Canada
- Within 2 years, the mussels invaded all 5 Great Lakes
- Populations grew exponentially – No natural predators, competitors, or parasites
  - although it recruited new predators
- Hundreds of millions of dollars of damage to property

Competition (Resources Limited)

- **Competition** = relationship where multiple organisms seek the same limited resources:
- Food, Water, Space, Shelter, Mates, Sunlight (for primary producers who give us the chemical boundaries of life)
  - **Intra specific competition** = among members of the same species
    - High population density = increased competition
  - **Inter specific competition** = among members of two or more species
    - Can lead to either competitive exclusion or to species coexistence

Niche: An Individual's Ecological Role

- **fundamental niche:** what you theoretically could access
- **realized niche:** what you actually access considering other factors such as competition.

Resource Partitioning

- Resource partitioning = species divide shared resources by specializing in different ways
  - Ex: one species is active at night, another in the daytime
  - Ex: one species eats small seeds, another eats large seeds

Effects of Resource Partitioning

- Character displacement = competing species evolve physical characteristics that reflect their reliance on the portion of the resource they use'
  - Ex: birds that eat larger seeds evolve larger bills
  - Ex: birds that eat smaller seeds evolve smaller bills
- Competition is reduced when two species become more different

Exploitative Interactions

- Predation = process by which individuals of one species (predators) capture, kill, and consume individuals of another species (prey)
- Parasitism = a relationship in which one organism (parasite) depends on another (host) for nourishment or other benefit
- Herbivory = exploitation in which animals feed on the tissues of plants

Food Web

- the **phytoplankton (algae and cyanobacteria)** are eaten by the **zooplankton**, then the zooplankton is eaten by the fish
- the zebra muscle introduced; it eats the algae and the zooplankton, the fish starves
  - because the zebra muscle eats by filtering the water, it increases sunlight proliferation so the sunlight now enters deeper in the water. also, the cyanobacteria has no predators
    - **this is the removal of competition and predation**
    - these two facts allow it to thrive and take over the lake, algal blooms grow

Algal Bloom

- once the algal bloom multiplies so much that the competition caused the water column to be over exploited the population begins to die.
- once the algal bloom dies, all of the organisms die and sink to the bottom as organic matter (carbon) as food for heterotropths - **autochtonous production/carbon** from primary prod.
- the **heterotrophic aerobic microbial community** will consume all of the organic matter as well as all the oxygen. the oxygen concentration in the lake will decrease until the water becomes anoxic because oxygen consumption > oxygen production

How the Ecosystem becomes Anoxic

- algal bloom of cyanobacteria is a huge biomass
- dies and becomes reservoir of organic matter
- it is being oxidized (burned) into CO_2 because microbes are harvesting energy, this costs oxygen. oxygen becomes the limiting reagent. system becomes hypoxic first, then becomes anoxic.

Consequences

1. fish die amongst other aerobic organisms
2. anaerobic organisms will take over; they literally stink
   - create H_2S, toxic and corrosive
   - also create fermentation products; toxicity & horrible smell (caderin, putrescin)
   - botulism
3. loss of recreational use, loss of drinking use, will give you rashes

Predators Kill and Consume Prey

- Structures food webs (example of zebra mussels in the great lakes)
  - Loss of 70% of zooplankton
  - Increase abundance of cyanobacteria
  - Mussels become preys for ducks, crayfish, sturgeons, eels, carp.

Effects of Predation on Populations

- Drives population dynamics and causes cycles in population sizes
  - e.g. hare and lynx cycling up and down

Avoiding Predation: Natural Selection

- Natural selection leads to evolution
- Predators: evolve adaptations that make them better hunters:
  - Live longer, healthier lives
  - Take better care of offspring
- Prey: evolve elaborate defences against being eaten

Organisms Develop Defences Against being Eaten

- cryptic colouration, warning colouration, mimicry, camouflage
- e.g. leaf insects that behave like and look like leaves
- e.g. pepper moths;
  - during industrial revolution white trees became black, white moths no longer blended into to black trees and were eaten more, moths mutated to gain more melanin and became black to blend in with black trees and thrived.

Parasites

- Some species live within the host
  - Disease, tapeworms
- Others are free- living, and have infrequent contact with their hosts
  - Ticks, sea lampreys
- Cordyceps fungus; serves as a control for population levels in forest insects

Coevolution

- Coevolution = hosts and parasites become locked in a duel of escalating adaptations
  - Has been called an "evolutionary arms race"
  - Each evolves new responses to the other
  - It may not be beneficial to the parasite to kill its host

Herbivores Exploit Plants

- May not kill the plant, but affects its growth and survival
- Defences:
  - Chemicals: toxic or distasteful parts
  - Physical: thorns, spines, or irritating hairs
  - Other animals: protect the plant

Mutualists Help Eachother

- Two or more species benefit from their interactions
- **Symbiosis** = mutualism in which the organisms live in close physical contact
  - Microbes within digestive tracts
  - Plants and fungi
- **Pollination**
  - bees, bats, birds and others transfer pollen from one flower to another, fertilizing its eggs
- **Human Microbio**
  - the array of bacteria in you and on you that interact and protect you

Enterotypes

- type of microbes you have inside your gut which could help identify you

Birth Microbes

- natural birth will pick up microbes that help digest milk, the first thing humans use for food
- c-sections will cause babies to take more time developing microbes for proper digestion.

Pollination

- in exchange for plant nectar, animals pollinate plants which allow them to reproduce

Relationships with No Effect on One Member

- **Amensalism** = a relationship in which one organism is harmed while the other is unaffected
  - Difficult to confirm, because usually one organism benefits from harming another
  - **Allelopathy** = certain plants release harmful chemicals – Or, is this competition?
- **Commensalism** = a relationship in which one organism benefits, while the other remains unaffected
  - **Facilitation =** plants that create shade and leaf litter allow seedlings to grow

Ecological Communities

- **Community =** an assemblage of species living in the same place at the same time
  - Members interact with each other
  - Interactions determine the structure, function, and species composition of the community
- **Community ecologists =** people interested in how:
  - Species coexist and relate to one another
  - Communities change, and why patterns exist

Energy Passes among Trophic Levels

- **Trophic levels** = rank in the feeding hierarchy
  - Producers
  - Consumers
  - Detritivores and Decomposers

Producers : The First Trophic Level

- **Autotrophs** = photosynthesis captures solar energy for photosynthesis to produce sugars.
- example of primary producers creating the chemical boundaries of life
  - use inorganic matter to create organic matter
  - CO_2 —> CH_2O
    - electrons in the cycle come from water
      - once water has lost all its electrons, we are left with Oxygen; hence the oxygen prod.
  - Green Plants
  - Cyanobacteria
  - Algae
- **Chemosynthetic bacteria** use the geothermal energy in hot springs or deep-sea vents to produce their food

Consumers: Organisms Consuming Producers

- **Primary consumers** = second trophic level
  - Organisms that consume producers
  - Herbivores consume plants; in lakes and fresh water we have daphnia “water cow”
  - Deer, grasshoppers
- **Secondary consumers** = third trophic level
  - Organisms that prey on primary consumers
  - Carnivores consume animals Wolves, rodents

Auto/Heterotrophs

- if you use organic carbon you are a heterotroph
- if you use inorganic carbon you are an autotroph

Consumers Occur at Higher Trophic Levels

- **Tertiary Consumers** = fourth trophic level
  - Predators at the highest trophic level
  - Consume secondary consumers
  - Are also carnivores
  - Hawks, owls
- **Omnivores** = consumers that eat both plants and animals

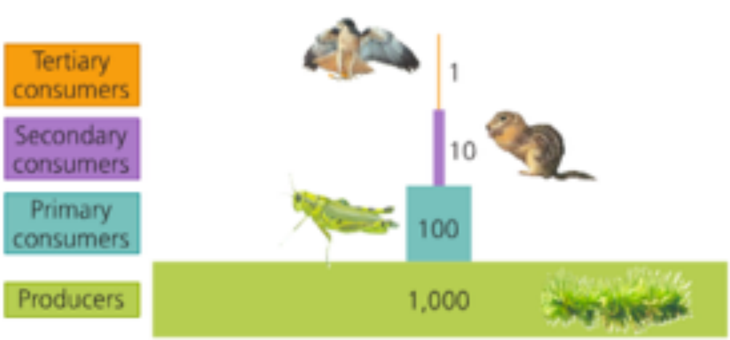
Detritivores and Decomposers

- Organisms that consume non living organic matter to produce inorganic matter
  - Enrich soils and/or recycle nutrients found in dead organisms, release C, O, N, P building blocks back to the primary producers
- **Detritivores =** scavenge waste products or dead bodies – Millipedes
- **Decomposers =** breakdown leaf litter and other non-living material
  - Fungi, bacteria
  - Enhance topsoil and recycle nutrients

Energy, Biomass, And Numbers Decrease at Higher Trophic Levels

- Most energy organisms use is lost as waste heat through respiration, the moment you eat something the energy is being used to live and if something eats you it will never get all of the energy that you had just harvested;
  - Less and less energy is available in each successive trophic level
  - Each level contains only 10% of the energy of the trophic level below it
- A human vegetarian's ecological footprint is smaller than a meat-eater's footprint

Pyramids of Energy, Biomass, and Numbers



Food Webs show feeding Relationships and Energy Flow

- **Food chain =** the relationship of how energy is transferred up the trophic levels
- **Food web =** a visual map of feeding relationships and energy flow
  - Count trophic levels and identify members of food webs

Keystone Species

- A species that has as a strong and far reaching impact on the community
  - Consequences of eliminating wolves in North America => increase in population of large herbivores => dramatic consequences on vegetation
  - Top-down effect; it will go down the trophic level and alter the primary producers
- e.g. the sea otter. it feeds on the sea urchin which is a primary consumer. it feeds on kelp, which is a primary producer. if it grows unrestricted and controlled it will overgraze the kelp, collapsing the entire food web because now there is no primary producer.
- e.g. the sea otter disappearing because the orcas were feeding on them. not normal. why?
  - because the things they ate on, sea lions were gone. why were see lions gone? because fish were gone. why were fish gone?
    - over fishing
    - absence of zooplankton
    - etc.

Trophic Cascade

- wolves re-introduced because herbivores were running wild and killing off too many primary producers
- once the wolf population increases, the elk population declines
- thus, browsing (number of events where elks graze) declines
- then, height of trees such as aspen, cotton, willow increase
- then, because trees were longer beavers became abundant
- also, because there was less browsing there was more grass
- more grass, more bison arrived

Ecosystem Engineers

- exist at different scales, micro and macro
- physically modify the environment
  - beavers
  - prairie dogs
  - fungus

Communities Respond to Disturbances

- Communities experience many types of disturbance
  - Removal of keystone species, spread of invasive species, natural disturbances
  - Human impacts cause major changes
- **Resistance =** community of organisms resists change and remains stable despite the disturbance
- **Resilience =** a community changes in response to a disturbance, but later returns to its original state

Succession Follows Severe Disturbance

- **Succession** = the predictable series of changes in a community following a disturbance
- **Primary succession** = disturbance eliminates all vegetation and/or soil life
- **Secondary succession** = a disturbance dramatically alters, but does not destroy, all local organisms

Primary Succession

- Glaciers, drying lakes, volcanic lava
- **Pioneer species =** the first species to arrive in a primary succession area (ex, lichens)
  - Contribute to soil formation
  - lichens change the rock physically by anchoring to the rock and creating fissures, also chemically by releasing chemicals that will change the rocks and break them.

Secondary Succession

- the remaining organisms form building blocks for the next population species
  - fires, hurricanes, logging etc.
- **Climax community** = the community resulting from successful succession
  - Remains stable until another disturbance restarts succession

Invasive Species Pose Threats to Community Stability

- **Invasive species** = non-native(exotic) organisms that spread widely and become dominant in a community
  - Growth-limiting factors (predators, disease, etc.) are removed or absent
  - They have major ecological effects (emerald ash borer)
  - Chestnut blight, from Asia, wiped out American chestnut trees
- Some species help people (i.e., European honey bee)

Biological Invaders

- arrows up/down to show increase/decrease
- zebra muscle invasion leads to increased light penetration, aquatic plants increase
- food webs go from planktonic to benthic
  - primary producers suspended above substate to primary producers on substate

Asian Carp Problem

- silver carp, bighead carp, grass carp, black carp
- planktonivores and herbivores to clean up ditches of invasive plants
- spread north from the southern US, Canada trying to block the spread
- hunting = mass deaths = huge organic mass = heterotropth degradation = …

Invasive Species, Avian Botulism and Deaths

- botulinum obligate anaerobe, go into dormant spore stage in oxygens presence for long time
- spores germinate in proper conditions, where they become extremely potent
- massive bird kills
- link between production of this toxin and eutrophication
  - zebra muscles are creating eutrophication conditions are allowing toxins to thrive
  - zebra muscles filter the water and uptake the toxins
  - round gobie fish eat the muscles, become sick
  - birds eat the fish and die of botulism

Controlling Invasive Species

- Techniques to control invasive species
  - Remove manually
  - Toxic chemicals
  - Drying them out
  - Depriving of oxygen
  - Stressing them
    - Heat, sound, electricity, carbon dioxide, ultraviolet light
- Prevention, rather than control, is the best policy.

Altered Communities Restored

- **Ecological restoration** = returning an area to unchanged conditions
  - Informed by restoration ecology = the science of restoring an area to the condition that existed before humans changed it
  - It is difficult, time-consuming, expensive
  - **Best to protect natural systems from degradation in the first place**

Widely Separated Regions Share Similarities

- Biome = major regional complex of similar communities recognized by
  - plant type
  - vegetation structure

Factors Shaping Aquatic Biomes

Aquatic biomes	Terrestrial biomes
Water temperature	Temperature
Salinity	Precipitation
Nutrients	
Currents	
depths	

Earths Biomes

- **Biome** = major regional complex of similar communities, recognized by dominated plant typ and vegetation structure
- **Ecoregion** = a particular representative of a biome; an example of it
- **Climatographs**
  - shows an area's mean monthly **temperature and precipitation**
  - Similar biomes occupy similar latitudes

Altitudes Create Patterns Analogous to Latitude

- Vegetative communities change along mountain slopes
- a hiker experiences several biomes

Aquatic and Costal Systems show Biome-like Patterns

- Areas equivalent to biomes exist in the oceans
  - Coastlines, continental shelves, open ocean, deep sea, coral reefs, kelp forests
- Aquatic systems are shaped by
  - Water temperature, salinity, and dissolved nutrients
  - Wave action, currents, depth
  - Substrate type, and animal and plant life

Conclusion

- We can visualize natural communities at a broad geographical scale (biomes) and at more local scales
- Species interactions:
  - Predation, parasitism, competition, mutualism
  - Represented by trophic levels and food webs
- Humans alter communities (e.g. invasive species)
- Ecological restoration attempts to undo negative changes

Lecture 7 - Ecosystem Ecology and Biogeochemistry

Complex Systems and Subsystems: Watershed

- largest water system in NA, any processes taking place in the drainage and watershed of the St. Lawrence will affect the Great Lakes system

Systems Show Defining Properties

- **System** = a network of relationships among parts of elements or components that interact with and influence one another
  - Exchange of energy, matter, or information
  - Receives inputs of energy, matter, or information; processes these inputs; and produces outputs
  - hard to understand and predict
- **Feedback loop** = a system's output serves as input to that same system

Negative Feedback Loop

- Negative feedback loop = output that results from a system moving in one direction acts as input that moves the system in the other direction => leads to dynamic equilibrium. (limit changes in a system). maintains pseudo-equilibrium.
- increase prey> increase predators > decrease prey> decrease predators.. increase prey…>

Positive Feedback Loop

- Positive feedback loop = instead of stabilizing a system, it drives it further toward one extreme or another. (increase changes in a system)
  - e.g. Erosion of river banks
  - e.g. cool climate, sunlight reflects off snow > climate warming = less snow, less reflection > dark surfaces exposed, more sunlight absorbed, gets hotter, more snow melts.

Case Study

- pollution coming from industry runoff. for example releasing toxic metals
- fish die, organic matter input into the system
- heterotrophs start consuming the oxygen available along with organic matter
- ecosystem will experience anoxia, leading into more die offs
- this will lead to more organic matter, leading to more anoxic conditions
  - more likely to occur in summer because
    - lower flow means less oxygen transfer with environment, less dilution, etc
    - warm temperature; metabolism speeds up

Systems: Defining Properties

- Dynamic equilibrium = system processes move in opposing directions at equivalent rates, balancing their effects
- Homeostasis = a system maintains constant or stable internal conditions
- Emergent properties = system characteristics not evident in the components alone
  - e.g. the tree as a habitat, as a CO_2 sink, as a primary producer are components of a tree.
    – "The whole is more than the sum of the parts"

A Systems Approach

- Environmental entities are complex systems that interact with each other
  - For example, river systems consist of hundreds of smaller tributary subsystems
- To solve environmental problems, all appropriate systems must be considered

Systems are Perceived in Various Ways

- Categorizing environmental systems helps make Earth's dazzling complexity comprehensible
- For example,the earth consists of structural spheres
  - **Lithosphere** = rock and sediment
  - **Atmosphere** = the air
  - **Hydrosphere** = liquid, solid or vapour water
  - **Biosphere** = all the planet's living organisms and the abiotic portions of the environment
- Boundaries overlap,so the systems interact

Ecosystems

- Ecosystem = all organisms and non living entities that occur and interact in a particular area at the same time
  - Includes abiotic and biotic components
  - Energy flows and matter cycles among these components
- Biological entities are highly intertwined with chemical and physical entities
  - Interactions and feedback loops

Ecosystems: Interactive Living and Non-Living Entities

- Energy entering the system is processed and transformed
- Matter is recycled within ecosystem, resulting in outputs such as heat, water flow, and waste products

Figure 5.8

- transferring matter from ecosystem levels
  - light energy > chemical energy stored in bonds of organic matter by primary producers using CO_2 which is an inorganic molecule.
  - primary consumers break down these bonds to harness the energy
  - part of the light energy is lost at each trophic level is used for sustenance, some lost as heat

Energy is Converted to Biomass

- **Primary production =** conversion of solar energy to chemical energy by autotrophs
- **Gross primary production(GPP) =** assimilation of energy by autotrophs
- **Net primary production (NPP) =** energy remaining after respiration, and is used to generate biomass
  - Available for heterotrophs
  - **Secondary production =** biomass generated by heterotrophs
  - **Productivity =** rate at which ecosystems generate biomass
    - Variation in net primary productivity among ecosystems and biomes results in geographic patterns of variation across the globe
      - most of the production on land occurs in tropical forests, high heat & high light.
      - most of the production in water occurs in Northern Water because there is less stratification and the water mixes, nutrients are brought back up where light is present and this stimulates primary production.

Net Primary Productivity

- High net primary productivity = ecosystems whose plants rapidly convert solar energy to biomass

Nutrients Can Limit Productivity

- **Nutrients =** elements and compounds required for survival that are consumed by organisms
- **Macronutrients =** nutrients required in relative large amounts (Nitrogen, carbon, phosphorus)
- **Micronutrients =** nutrients needed in smaller amounts
- adding high amounts of nutrients to a lake system will cause eutrophication.

Nutrient Runoff Devastating Aquatic Systems

- **Nutrient (biogeochemical) cycle =** the movement of nutrients through ecosystems
  - Atmosphere, hydrosphere, lithosphere, and biosphere
- **Pools (reservoirs) =** where nutrients reside for varying amounts of time
- **Flux =** movement of nutrients among pools, which change over time and are influenced by human activities
- **Sources =** pools that release more nutrients than they accept
- **Sinks =** accept more nutrients than they release

Hydrological Cycle

- Water is essential for biochemical reactions and is involved in nearly every environmental system
- Oceans are the main reservoir
- **Evaporation** = water moves from aquatic and land systems to air
- **Transpiration** = release of water vapuor by plants
- **Precipitation** = condensation of water vapuor as rain or snow

Groundwater

- **Aquifers =** underground reservoirs of sponge-like regions of rock and soil that hold groundwater
  - **Groundwater =** water found underground beneath layers of soil
  - **Water table =** the upper limit of groundwater held in an aquifer
  - Water may be ancient (thousands of years old)
- Groundwater becomes exposed to the air where the water table reaches the surface

Human Impacts on Hydrological Cycle

- Damming rivers increases evaporation and infiltration
- Altering the surface and vegetation increases runoff and erosion
- Spreading water on agricultural fields depletes rivers, lakes and streams
- Removing forests and vegetation reduces transpiration and lowers water tables
- Emitting pollutants changes the nature of precipitation
- The most threatening impact is overdrawing groundwater for drinking, irrigation, and industrial use
- Lake mono: bird sanctuary under threat if it connects to land
- most stressed regions of water is the Equator Tropic, California is struggling

Waterborne Diseases

- water transmits enteric viruses such as cholera
- vibrio cholera is naturally present in the environment
- cholera is a new disease after industrialization

The Carbon Cycle Illust.

- most important reservoir for carbon is the sedimentary rock, organic matter accumulates and concentrates into fossil fuels.
- second most important is the inorganic material in lakes
- human activities tend to move carbon from deep in the earth to the surface, we are using fossil fuels so fast we are re-emitting the carbon very fast
- **carbon pump:** organic matter sinking from euphoric zone, being consumed by bacteria and other heterotrophic matter, released as CO2 and it returns to top of the ocean and air.

The Carbon Cycle

- Carbon is found in carbohydrates, fats, proteins, bones
- Photosynthesis moves carbon from the air to organisms
- Respiration returns carbon to the air and oceans
- Decomposition returns carbon to the sediment, the largest reservoir of carbon
- The world's oceans are the second largest reservoir of carbon

Humans Affect the Carbon Cycle

- Burning fossil fuels moves carbon from the ground to the air
- Cutting forests and burning fields moves carbon from organisms to the air
- Today's atmospheric carbon dioxide reservoir is the largest in the past 650,000 years
  - The driving force behind climate change
- The missing carbon sink: 1-2 billion metric tons of carbon are unaccounted for
- It may be the plants or soils of northern temperate and boreal forests

Methanogenasis

- only occurs in the absence of oxygen
- process where dissolved organic matter (DOM) is converted to methane

The Nitrogen Cycle

- Nitrogen is 78% of our atmosphere but N2 gas is inert (not a usable form)
- **Nitrogen fixation =** Nitrogen gas is fixed (made into ammonia) by nitrogen-fixing bacteria
  - this produces a usable form (ammonium ions)

Nitrification and De-nitrification

- **Nitrification** = bacteria that convert ammonium ions first into nitrite ions then into nitrate ions
  - Plants can take up these ions
  - Animals obtain nitrogen by eating plants or other animals
- **Denitrifying bacteria =** convert nitrates in soil or water to gaseous nitrogen, releasing it back into the atmosphere. only occurs when oxygen is absent

Humans Affect The Nitrogen Cycle

- **Haber-Bosch process** = synthetic production of fertilizers by combining nitrogen and hydrogen to synthesize ammonia
  - Humans are fixing as much nitrogen as nature does
- Increased emissions of nitrogen-containing greenhouse gases
- Calcium and potassium in soil washed out by fertilizers
- Acidified water and soils
- Increased transfer from rivers to oceans
- Reduced biodiversity of plants adapted to low-nitrogen soils
- Changed estuaries and coastal ecosystems and fisheries

Eutrophication

- The process of nutrient over-enrichment, blooms of algae, increased production of organic matter, and ecosystem degradation
  1. Nitrogen input
  2. phytoplankton flourish at the surface
  3. dead phytoplankton and their waste drift to the bottom, providing more food to decomposers
  4. decomposer population grows and consumes more oxygen
  5. insufficient oxygen suffocates fish and shrimp at the bottom, hypoxia (dead zone) occurs

The Phosphorus Cycle

- involves no organisms

Phosphorus Cycle involves many Lithosphere and Ocean

- Phosphorus is a key component of cell membranes, DNA, RNA, ATP and ADP
- Geology:
  - Most phosphorus is within rocks and is released by weathering
  - With naturally low environmental concentrations, phosphorus is a limiting factor for plant growth
- Food webs: Plants take up phosphorus when it is dissolved in water

We Affect The Phosphorus Cycle

- Mining rocks for fertilizer moves phosphorus from the soil to water systems
- Wastewater discharge also releases phosphorus
- Runoff containing phosphorus causes eutrophication of aquatic systems
- Household detergents may contain phosphorus, when these spill into the lakes the lakes now contain more phosphorus (nutrients) than it did previously

Key Points - Midterm 1

Origins of Life: purely contextual, no direct questions

Natural Selection: can occur at different time scales, different processes, selective advantages

Carrying Capacity: biotic potential vs. environmental pressure preventing growth

K-Selected / R-Selected: differences in gestation periods/lengths

Interactions: mutualism, etc.

Food Web: level interactions and functions; what do they do?

Keystone Species: some species are more important than others

Invasive Species: e.g. zebra muscle

Feedback Loops: negative feedback loops = stability, positive = depredation

Energy: why we talk about it, the source, how it is converted/stored

Role of Nutrients: eutrophication

CO_2, Methane: greenhouse gas

Nitrogen Cycle:

Demographic Transition

Human Population at 7.2 Billion

- It would take 30 years, counting once each second, to reach 1 billion
- Populations continue to rise in most countries - Particularly in developing nations
- Although the rate of growth is slowing, we are still increasing in absolute numbers

Growing Fast as Ever

- It took all of human history to reach 1 billion
- In 1930, 130 years later, we reached 2 billion, and added the most recent billion in 12 years

Rates of Growth Vary With Region

- At 2.1% annual growth rate, the population would double in 33 years (currently 1.2%)
- If China's rate had continued at 2.8%, it would have had 2 billion people in 2004.

Perspectives on Human Pop. Changing

- Population growth results from technology, sanitation, food
  - Death rates drop, but not birth rates
- Some people say growth is no problem
  - New resources will replace depleted ones
  - But, some resources (i.e., biodiversity) are irreplaceably
- Quality of life will suffer with unchecked growth
  - Less food, space, wealth per person
- 1700s – more children meant better support in old age and more labour for factory work
- 1766: **Thomas Malthus** – growing population is eventually checked by limits on births or increases in deaths; malthusian nightmare; **pop. growth exponential, resources arithmetic**
- **1968: Paul Ehrlich** – population is growing too fast and must be controlled

Is Population Growth a Problem

- **Sheldon Richman** (cornucopian thinker) – humans find potential stuff and human intelligence turns it into resources
  - "The concept of carrying capacity does not apply to human world"
- Humankind will always be able to save itself with a "technological fix"
- Yet not all resources can be replaced or reinvented once they are depleted (e.g. extinct species, land)

Governments Fearing Falling Populations

- Policymakers believe growth increases economic, political, military strength
  - They offer incentives for more children
  - 60% of European nations think their birth rates are too low
  - In non-European nations, only 8% feel their birth rates are too low
- Nowadays, population growth is much more strongly correlated with poverty than with wealth

Raising the Carrying Capacity: The Cornucopian View

- before 100000 years ago we would have to spend most of our time struggling for food
- agriculture created a means to produce more food than necessary for yourself, this gave people more time. this led to diversification of society.
- industrial revolution led to the increasing efficiency of agriculture
- medical revolution leads to the increasing life spans and decreasing death rates
- we are in between industrial and medical

Population Growth Affects the Environment

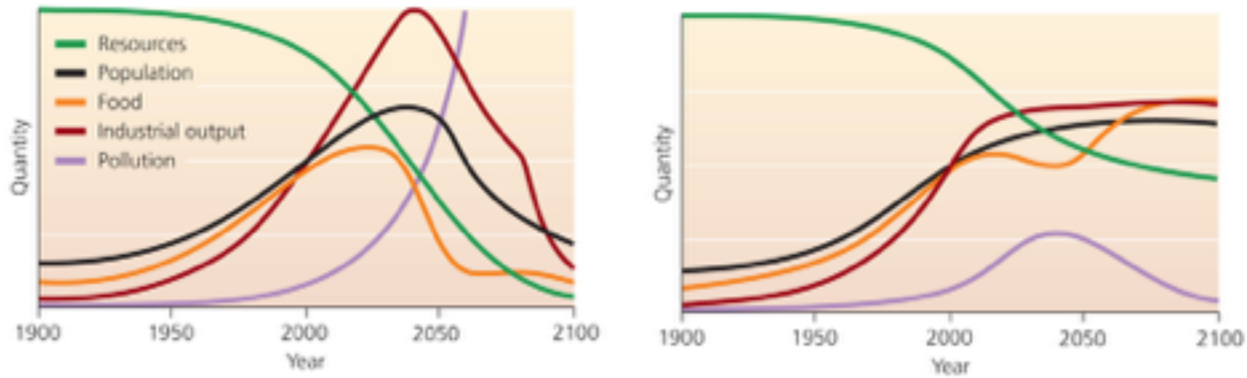
- The IPAT model: **I = P x A x T x S**
- Our total impact (I) on the environment results from the interaction of **population (P)**, **affluence (A)** and **technology (T)**, with an added **sensitivity (S)** factor
  - Population = individuals need space and resources
  - Affluence = greater per capita resource use
  - Technology = increased exploitation of resources
  - Sensitivity = how sensitive an area is to human pressure

What Have we learned from Rapa Nui

- island was covered in trees, society became experts at gathering resources from sea
- major decline in tree populations
  - they relied on them for food, agriculture, and shelter
  - also a bird habitat
  - when they used them all up for moai, they lost other capabilities
  - this increased erosion, arable lands a degraded

Computer Simulations Predicting Future

- Status quo leads to
  - Sudden food & population decrease
  - Pollution increase
- Sustainability leads to
  - Food & population stabilize
  - Pollution decrease



(a) Projection based on status quo policies

(b) Projection based on policies for sustainability

FIGURE 6.5

Demography: Study of Human Pop.

- Demographers study
  - Population size
  - Density and distribution
  - Age structure
  - Sex ratio
  - Birth, death, immigration, and emigration rates
- Population size - only one factor and does not tell the whole story
- A population's environmental impact depends on its density, distribution, and composition, as well as affluence, technology, and level of consumption

Population Size and Density

- Population size is only one factor
- Highest population density is in temperate, subtropical, and tropical climates

Population Distribution

- Humans are unevenly distributed around the globe -
  - Unpopulated areas tend to be environmentally sensitive (high S value in the IPAT equation)

Age Structure Affects Future Population Dynamics

- Having many individuals in young age groups results in high reproduction and rapid population growth

Population Growth Depends on Various Factors

- Whether a population grows, shrinks, or remains stable depends on:
  - Rates of birth, death, and migration
  - Birth and immigration add individuals
  - Death and emigration remove individuals
- Technological advances led to dramatic decline in human death rates
  - Widening the gap between birth rates and death rates resulting in population expansion
- Even though growth rate declines, absolute increase of people continues.

Total Fertility Rate Influences Population Growth

- Total fertility rate (TFR) = average number of children born per female member of a population during her lifetime
- Replacement fertility = the TFR that keeps the size of a population stable

Factors Affecting Total Fertility Rate

- Increasing urbanization decreases TFR
  - Children go to school, and increase costs
- With social security, elderly parents need fewer children to support them
- Greater education allows women to enter the labor force, with less emphasis on child rearing

Demographic Transitions

- Demographic transition = a model of economic and cultural change to explain the declining death and birth rates in industrializing nations
- high birth and death rates change to low birth and death rates
- As mortality decreases, there is less need for large families
  - Parents invest in quality of life

The demographic transition's four stages

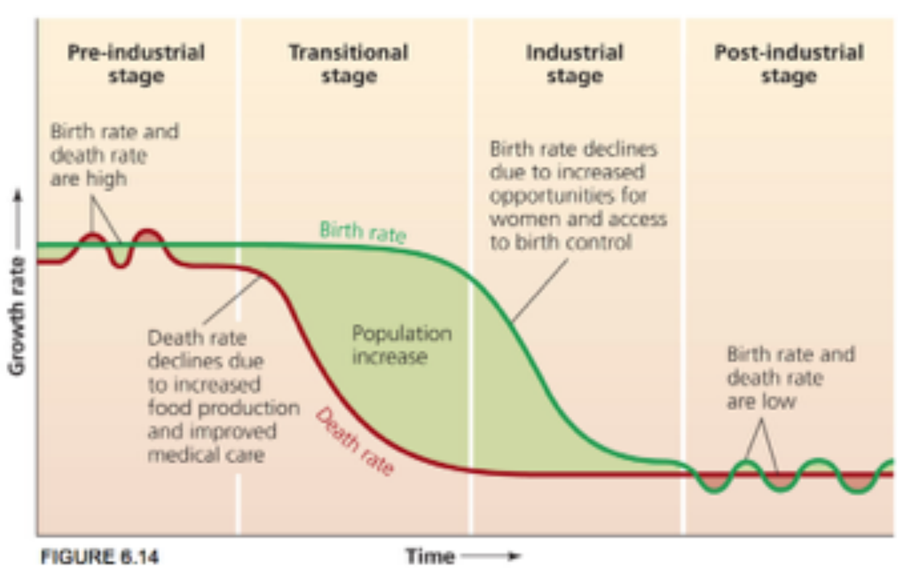


FIGURE 6.14

Is the Demographic Transition Universal?

- It has occurred in Europe, U.S., Canada, Japan, and other nations over the past 200-300 yea.
- But, it may or may not apply to all developing nations
- The transition could fail in cultures that
  - Place greater value on childbirth
  - Grant women fewer freedoms
- For people to attain the material standard of living of North Americans, we would need the natural resources of four and a half more Earths

Population of Women Affects Pop. Rates

- 2007: 54% of married women worldwide reported using modern contraception to plan / prevent pregnancy
- Social empowerment of women reduces unintended pregnancy
- Increasing female literacy is strongly associated with reduced birth rates

Poverty Is Strongly Correlated with Population Growth

- Poorer societies have higher growth rates than wealthier societies
  - Consistent with the demographic transition theory
  - They have higher fertility and growth rates, with lower contraceptive use
- 99% of the next billion people added will be born in poor, less developed regions that are least able to support them
- Poverty often results in environmental degradation (e.g. soil degradation, hunting of large mammals)

Consumption from Affluence Creates Environmental Impacts

- Affluent societies have enormous resource consumption and waste production
- People use resources from other areas, as well as from their own
- Individuals' ecological footprints are huge
- The addition of 1 Canadian to the world has as much environmental impact as 6 Chinese, or 12 Indians or Ethiopians, or 40 Somalians.
- Humanity's global ecological footprint surpassed Earth's capacity to support us in 1987

Wealth Gap Contributes to Pop. Growth and Conflict

- The richest 20% use 86% of the world's resources
- Leaves 14% of the resources for 80% of the world's people to share
- More than 1⁄2 of the world's population lives with less than $2 per day

Conclusion

How will the population stop rising? - demographic transitions

- governmental intervention
- disease
- social conflict

Lecture 9 - Soil and Agriculture

Soil as a System

- Soil consists of mineral matter, organic matter, air, and water
  - Dead and living microorganisms, and decaying material
  - Bacteria, algae, earthworms, insects, mammals, amphibians, and reptiles

Soil Formation is Slow and Complex

- Parent material = the base geologic material of soil
  - Lava, volcanic ash, rock, dunes
  - Bedrock = the continuous mass of solid rock comprising the Earth's crust
- **Weathering** = the physical, chemical, biological processes that break down rocks to form soil
  - **Physical (mechanical)** = wind and rain, no chemical changes in the parent material
  - **Chemical** = substances chemically interact with parent material
  - **Biological** = organisms break down parent material

Other Processes Affecting Soil

- **Erosion** = the dislodging and movement of soil by wind or water
  - Occurs when vegetation is absent
- Biological activity includes deposition, decomposition,and accumulation of organic matter
  - **Humus =** a dark, spongy, crumbly mass of material formed by **partial decomposition**
    - very complex system of strange molecules, abundant in oxygen; overall these humic substances bear an overall negative charge. important because nutrients are charged positively, therefore humus is good at holding onto nutrients.
    - bacteria cannot digest the humus' **lignin polymer** because it is too large, so some release **lignin modifying enzymes**, this turns it into **lignin monomers.**
      - because the reaction isn't specific, there are some random re-arrangements in the lignin polymer changing the structure &creates the complex haphazard molecule of humus.

<u>Soil Profile Consists of Horizons</u>

- **Horizon =** each layer of soil
- **Soil profile = t**he cross-section of soil as a whole
- **Topsoil =** inorganic and organic material most nutritive for plants
- **Leaching =** dissolved particles move down through horizons

- O Horizon - litter
- A Horizon - rich in nutrients
- E Horizon - poor because of leaching (Elluviation)
- B Horizon - very rich in nutrients/minerals (Illuviation

<u>Soil Classification</u>

- Soils are classified into 10 orders based on the processes thought to form them and their properties
- Properties of soil:
  - Color
  - Texture
  - Structure
  - pH

<u>Soil Colour</u>

- **Soil colour =** indicates its composition and fertility
  - Black or dark brown = rich in organic matter
    - also long lasting nutrients because of humic substances
  - Pale grey or white = indicates leaching

<u>Soil Texture Classification</u>

- Soil texture = the size of particles
  - Clay (smallest), silt, sand (largest)
- Loam = soil with an even mixture of the three
  - Influences how easy it is to cultivate and let air and water travel through the soil
- Silty soils with medium-size pores, or loamy soils with mixtures of pore sizes are best for plant growth and crop agriculture

<u>Soil Structure and pH</u>

- Soil structure = a measure of soil's "clumpiness"; facilitates bioactivity
  - Large clumps can discourage plant roots
  - Repeated tilling compacts soil
  - **Plowpan =** a hard layer resulting from repeated plowing that resists water infiltration and root penetration
- **Soil pH =** influences a soil's ability to support plant growth
  - Soils that are too acidic or basic can kill plants

<u>Soil Clump</u>

- mixture of sand, silt, and clay that are held together by organic matter and microbes, host bacteria, and contain water and air.

<u>Cation Exchange is Vital for Plant Growth</u>

- **Cation exchange =** process that allows plants to gain nutrients
  - Negatively charged soils hold cations of calcium, magnesium, and potassium
- **Cation exchange capacity =** a soil's ability to hold cations, preventing them from leaching, thereby increasing their availability to plants
  - A useful measure of soil fertility
  - Greatest in fine soils
- Cationic Bridges hold together the clay and humic substances
- the negative charge not only holds nutrients, but it can also hold toxic metals
- Retention upon pH decreases **$Al^{3+} > H^+ > Ca^{2+} > Mg^{2+} > K^+ = NH_4^+ > Na^+$**
- Nitrates (among all negative molecules) are not able to remain in the soil

<u>Soil: The Foundation for Feeding a Growing Population</u>

- Land devoted to agriculture covers 38% of Earth's land surface
- Agriculture = practice of raising crops and livestock for human use and consumption
- Cropland = land used to raise plants for human use
- Rangeland or pasture = land used for grazing livestock
- Soil = a complex plant-supporting system consisting of disintegrated rock, organic matter, water, gases, nutrients, and microorganism

<u>Population and Consumption Degrades Soil</u>

- Feeding the world's rising human population requires changing our diet or increasing agricultural production
- We must find ways to improve the efficiency of food production
- Mismanaged agriculture turns grasslands into deserts, removes forests, diminishes biodiversity, and pollutes soil, air, and water

Soil Degradation

- population dense regions have the highest rates of degraded soil
- Soil degradation results from deforestation, agriculture and overgrazing
- Over the past 50 years, soil degradation has reduced global grain production by 13%

Agriculture Invented Independently by Separate Cultures

- fertile crest where is now middle east
- the andes as well as mesoamerica

Green Revolution

- Green revolution = the use of new technology, crop varieties and farming practices introduced to developing countries
- Increased yields
- Created new problems and worsened old ones

Soil Degradation: Problems and Solutions

Problems

- erosion
- desertification

Solutions

- Soil conservation
- Restoring plant cover
- Preventing salinization
- Better fertilization practices
- Better grazing practices

Regional Differences in Soil Traits can Affect Agriculture

- Rain forests have high primary productivity, but the nutrients are in plants, not the soil
- Swidden agriculture = cultivation of a plot for a few years and then letting it regrow into forest
- Temperate grasslands have lower rainfall and less nutrient leaching

Erosion can Degrade Ecosystems and Agriculture

- Deposition = the arrival of eroded material at its new location
- Flowing water deposits sediment in river valleys and deltas
  - Floodplains are excellent for farming
- Erosion occurs faster than new soil is formed
- Erosion increases through: overcultivating fields, overgrazing rangelands, and clearing forested areas

Soil Erodes By Several Methods

- Wind (aeolian) erosion
- Water erosion (splash, sheet, rill, gully)
  - Rill erosion moves the most topsoil, followed by sheet and splash erosion
- Predicting losses by erosion:
  - Universal Soil Loss Equation (USLE)
  - Wind Erosion Prediction Equation

Soil Erosion is a Global Problem

- Humans are the primary cause of erosion
- 19 billion hectares of croplands worldwide suffer from erosion
- Kazakhstan lost tends of millions of hectares to wind erosion
- Soil degradation over the next 40 years in Africa could reduce crop yields by half
- The on-farm cost of agricultural land degradation in Canada is $670 million per year

Desertification Reduces Productivity of Arid Lands

- Desertification
  - A loss of more than 10% productivity from erosion, soil compaction, forest removal, overgrazing, salinization, climate change, depletion of water sources
    - A type of land degradation
    - Affects 1/3 of the planet's land area
    - Most prone areas are arid and semiarid lands
      - 40% of earth surface can be classified as drylands
      - Mostly through wind and water erosion

The Dust Bowl

- Native prairie grasses originally held erosion-prone soils in place
- 1879-1929: Widespread cultivation of wheat, and grazing of many thousands of cattle
  - Grass removal
  - Breaking down of soil structure
- Great Depression brought a cycle of poverty and overly intensive agricultural practices
- Dust storms (black blizzards) travelled up to 2000 km
- Lung irritation, dust pneumonia, grasshopper infestations

Farmers Protect Soil

- Crop rotation
- Contour farming
- Intercropping and agroforestry
- Terracing
- Shelterbelts
- Reduced tillage

Plant Cover Reduces Erosion

- Eroding banks along creeks and roadsides are stabilized by planting plants to anchor soil
- China has the world's largest tree-planting program (monoculture)
  - Slows erosion
  - Forests are not ecologically functional

Irrigation: Boost Productivity, Long Term Problems

- **Irrigation** = Artificially providing water to support agriculture
- **Waterlogging** = over- irrigated soils which suffocates roots
- **Salinization** = the buildup of salts in surface soil layers
- Salinization inhibits production of 20% of all irrigated cropland, costing more than $11 billion/ year

Salinization is Easier to Prevent than to Correct

- Choose crops appropriate for the area (e.g., barley)
- Irrigate with low-salt water
- Irrigate efficiently
  - Drip irrigation targets water directly to plants

Fertilizers Boost Yield but can be Over Applied

- Fertilizer = substances that contain essential nutrients
- Inorganic fertilizers = mined or synthetically manufactured mineral supplements
- Organic fertilizers = the remains or wastes of organisms
  - manure, crop residues, fresh vegetation
  - Compost = produced when decomposers break down organic matter
  - Not perfect
  - Problem with nitrate and methemoglobinemia

Conclusion

- Programs in Canada and worldwide have been successful in reducing topsoil erosion
- These programs require:
  - Research, education, funding, and commitment from farmers and governments
- To avoid a food crisis caused by population growth, we need
  - Better technology
  - Wider adoption of soil conservation techniques

Lecture 10 - Mercury

Exposure

- mostly through diet, through the fish food chain
  - predatory fish such as tuna or shark, trout, pikes
- mad hatters first proof of neurotoxicity, the factory workers were using mercury to soften hats
- the eventually started to deteriorate mentally

Naturally Occurring

- present everywhere; geosphere, biospheres, atmosphere
- almost half of the mercury emissions come from artisan gold mining
  - mercury amalgamates with gold because of its high affinity
  - to separate, you heat up the amalgamation to 500C, exposing miners to high levels of mercury and contributing to atmospheric mercury
    - mercury is still the highest priority contaminant; there isn't a single area in NA that isn't contaminated with mercury; you cannot eat the fish in those lakes
    - **You can drink the water from the lake, but you cannot eat the fish**

Bioaccumulation Properties

- mercury was used as a pesticides, became embedded into the wheat contaminating people
- bioaccumulates into a cell,
- mercury then bioamplifies
  - at each trophic level the amount of mercury increases, by huge factors - billions
  - lower you eat in the food web the less mercury you will be ingesting
- **methyl mercury - (CH3)Hg**, as opposed to mercury **Hg(II)**, can freely diffuse through lipid membranes because the methyl group causes it to be lipophillic.
- bioaccumulates at every tropic level, more mercury gets in than gets out

Hydro

- flood resevoirs, all trees and animals are submerged. OM starts to becoming mineralized & used by the bacteria, this may lead to anoxic conditions in the body of water.
- leads to methyl mercury production because methanogensis and hydrogen sulfate production occur in these anoxic conditions
- methyl mercury can stay rising in concentration for at least 20 years

How Mercury Affects Humans

- fat layer surrounds the brain, therefore elemental mercury cannot enter
- methyl mercury on the other hand can indeed cross the lipid layer around the brain
- gets into the brain and becomes de-methlyated
- mercury is known as a soft metal, it binds to soft ligans or chemical partners