Science and Environment

by Xia, Tingfeng

Wednesday 5th February, 2020

Preface

Earth' s natural system is undergoing considerable change. Although these changes are following a natural cyclical path, the past 200 years have seen an accelerated rate, scale and scope of change not witnessed before. To understand and assess the global impacts of these changes, ENV200 has been designed to examine them through a scientific lens. These impacts have global implications: atmospheric systems and climate change, the biosphere and conservation of biodiversity.

— Syllabus

Contents

1 Lecture 1 - Understanding Environmental Issues and Science

1.1 Learning Outcomes

- Describe several important environmental problems facing the world.

  > There are seven major problems discussed in this lecture, they are climate change, hunger, clean water, energy resources, air quality, biodiversity loss, and marine resources.

- List several examples of progress in environmental quality.

  > Plateau of population growth, decrease in life-threatening diseases, more access-able renewable energy source, more access-able education due to Internet, decrease in rate of deforestation, and better protected marine resources.

- Explain the idea of sustainability and some of its aims.

  > Sustainability is a search for long term ecological stability and human progress. Quote: "meeting the needs of the present without compromising the ability of future generations to meet their own needs"

1.2 Definition - Environmental Science

- Environmental science is the systematic study of our environment and out place in it, and
- Environmental science draws on many fields of knowledge to fully understand a problem and solve it.

1.3 Environmental and Political Problems

1.3.1 Climate Change

Human activities have greatly increased concentrations of carbon dioxide and other greenhouse gases over the last 200 years. Climate models indicate that by 2100, if current trends continue, global mean temperatures will probably warm between about 2 and 6 degrees Celsius.

1.3.2 Hunger

Over the past century, global food production has increased faster than human population growth, but hunger remains a chronic problem. At least 60 million people face acute food shortages due to weather, politics, or war.

1.3.3 Clean Water

- 1.1 billion people lack access to safe drinking water.
- Every year polluted water contributes to the death of more than 15 million people.
- 40 % of the population live in countries where water demands now exceed supplies.

1.3.4 Energy Resources

- Fossil fuels (oil, coal, and natural gas) presently provide around 80 percent of the energy used in industrialized countries.
- Supplies of these fuels are diminishing, and there are many problems associated with their acquisition and use.
- Investing in renewable energy and energy conservation measures could give us cleaner, less destructive options.

1.3.5 Air Quality

- Air quality has worsened dramatically in many areas, especially China and India.
- Nobel laureate Paul Crutzen estimates that at least 3 million people die each year from diseases triggered by air pollution.
- Word-wide, the UN estimates that more than 2 billion metric tons of air pollutants (*which doesn't include carbon dioxide, or wind-blown soil*) are released each year.

1.3.6 Biodiversity Loss

Habitat destruction, overexploitation, pollution, and introduction of exotic organisms are eliminating species at a rate comparable to the great extinction that marked the end of the age of dinosaurs.

1.3.7 Marine Resources

- More than a billion people depend on seafood for their main source of animal protein.
- According to the World Resources Institute (WRI), more than three-quarters of the 441 fish stocks for which information is available are severely depleted or in urgent need of better management.

1.4 Signs of Progress

1.4.1 Population

Population has stabilized in most industrialized countries where democracy has been established.

- Since 1960, the average number of children born per woman worldwide has decreased from 5.0 to 2.45.
- The UN Population Division predicts that the world population will stabilize at about 8.9 billion by the year 2050.

1.4.2 Health

The incidence of life-threatening infectious diseases like smallpox and polio have been reduced sharply in most countries during the past century, while life expectancies have nearly doubled.

1.4.3 Renewable Energy

Encouraging progress is being made in a transition to renewable energy sources.

- Growth in wind energy, solar, and biomass power and improvements in efficiency are beginning to reduce reliance on fossil fuels.
- The cost of solar power has plummeted (dropped, at high speed), and both solar and wind power are now far cheaper, easier, and faster to install than nuclear power or new coal plants.

1.4.4 Information and Education

- Literacy and access to education are expanding in most regions of the world.
- The Internet makes it easier to share environmental solutions.
- Expanding education for girls is driving declining birth rates worldwide.

1.4.5 Conservation of Forest and Nature Preserves

- Deforestation has slowed in Asia.
- A former leader in deforestation, Brazil, is now working to protect forests.
- 13.5% of the world's land area is now in protected areas.

1.4.6 Protection of Marine Resources

- Marine protected areas and better monitoring of provides for more sustainable management.
- Marine reserves have been established in California, Hawaii, New Zealand, Great Britain, and many other areas.

1.5 Definition - Sustainability

- *Sustainability* is a search for long term ecological stability and human progress.
- World Health Organization director Gro Harlem Brundtland has defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

1.6 Definition - Science

- Science is a process for producing knowledge based on observations. We develop or test theories (proposed explanations of how a process works) using these observations.
- Science also refers to the cumulative body of knowledge produced by many scientists.
- Science rests on the assumption that the world is knowable and that we can learn about it by careful observation and logical reasoning.

1.7 Orderly Procedure - Scientific Method

1. Make an observation and identify a question.
2. Propose a hypothesis
3. Test the hypothesis.
4. Gather data from the test.
5. Interpret the results. (Re-define and revise original hypothesis if it didn't work; Go back to step 2.)
6. Report for peer review.

1.8 Conclusions

- We face many persistent environmental problems, but we can also see many encouraging examples of progress.
- Resolving these multiple problems together is the challenge for sustainability.
- Science gives us an orderly, methodical approach to examining environmental problems.

2 Lecture 2 - Energy and Material Cycles

2.1 Energy

(Definition) Energy is the ability to do work, such as moving matter over a distance or causing a heat transfer between two objects at different temperatures. Energy can take many different forms, heat, light, electricity, and chemical energy are examples that we all experience.

(Definition) kinetic Energy is the energy contained in moving objects. Examples include a rock rolling down a hill, wind blowing through the trees, water flowing over a dam, or electrons speeding around the nucleus of an atom.

(Definition) Potential Energy is energy that are stored and is available to use. Examples include rick poised at the top of a hull and water stored behind a dam. ***Note:*** Chemical energy stored in the food or gasoline are also forms of potential energy that can be released to do useful work.

Basics of Energy

- Heat describes the energy that can be transferred between objects of different temperatures.
- The study of thermodynamics deals with how energy is transferred in natural processes.
- The first law of thermodynamics states that energy is conserved

- The second law of thermodynamics states that, with each successive energy transfer or transformation in a system, less energy is available to do the work. (Energy transfer/transformation incurs a cost.)
- Entropy tends to increase in all natural systems.

Life and Energy

- Nearly all life forms on earth relies on the sun for ultimate power source, either directly or indirectly.
- The energy is captured by green plates which are often called ***primary producers*** because they create carbohydrates and other compounds using just sunlight, air, and water.
- There are organisms that get energy in other ways, These organisms gain their energy from ***chemosynthesis***, a process which allows them to extract energy from inorganic chemical compounds such as hydrogen sulphide.

Plants' Energy: Sun

- Thermonuclear reactions from our sun emit powerful forms of radiation, including potentially deadly ultraviolet and nuclear radiation.
- Nearly all organisms on the earth's surface depend on solar radiation for life-sustaining energy, which is captured by green plants, algae, and some bacteria in a process called photosynthesis.
- **(Definition) photosynthesis** converts light energy into useful, chemical energy in the bonds that hold together organic molecules.

2.2 Populations, Communities, and Ecosystems

(Definition) Population consists of all the members of a species living in a given area at the same time.

(Definition) Community All of the populations of organism living and interacting in particular area make up a community.

(Definition) Ecosystem is composed of a biological community and its physical environment.

2.2.1 Food Chains, Food Webs, and Trophic Level Link Species

- In ecosystems, some consumers feed on a single species, but most consumers have multiple food sources.
- Similarly, some species are prey to a single kind of predator, but many species in an ecosystem are beset by several types of predators and parasites.
- In this way, individual food chains become interconnected to form a food web.

(Definition) Trophic Level

- A trophic level is an organism's feeding status in an ecosystem.
- Primary producers (or ***autotrophs***) feed themselves using only sunlight, water, carbon dioxide, and minerals.
- Other organisms in the ecosystem are consumers (***or heterotrophs***) of the chemical energy harnessed by the primary producers.
- Herbivores are consumer who are eaters.
- Carnivores are flesh eaters.
- Omnivores eat both plant and animal matter.

Recyclers: Parasites, Scavengers, and Decomposers

- Like omnivores, these recyclers feed on all trophic levels.
- Scavengers (e.g. jackals and vultures(秃)) clean up dead carcasses of larger animals.
- Detritivores, such as ants and beetles, consume litter, debris, and dung.
- Decomposer organisms, such as fungi and bacteria, complete the final breakdown and recycling of organic materials.

2.3 The Hydrologic Cycle

- The path of water through our environment is perhaps the most familiar bio-geo-chemical cycle.
- Most of the earth's water is stored in the oceans, but solar energy continually evaporates this water, and wind distribute water vapour around the globe.
- Water condenses over land surfaces, in the form of rain, snow, or fog, supporting terrestrial ecosystems,
- Organisms emit the moisture they have consumed through respiration and perspiration. Eventually this moisture reenters the atmosphere or enters lakes and streams which ultimately returns it to the ocean.

3 Lecture3 - Environmental Systems

3.1 Bio-Geo-Chemical Cycles

- Nutrients are cycled continuously among different components of the ecosphere in characteristic paths known as biogeochemical cycles.
- Generalized nutrient cycle model help represent the complexity of the earth's process.

- Under *natural conditions*, recycling rates between components achieve a balance over time in which inputs and outputs are equal.
- Human activities speed up transference between cycles components.
- Pollution problems result from human-induced accumulation in one or more components of a cycle.

3.1.1 The Carbon Cycle

- Carbon dioxide is the main reservoir for the carbon that is building block for all necessary fates, proteins, and carbohydrates that constitute life.
- Plates take up carbon dioxide directly from the atmosphere through the process of photosynthesis,
- Carbon is incorporated in biomass and passes along the food chain.
- Respiration by organism transforms some carbon in biomass back into carbon dioxide which enters atmosphere.
- Cellular respiration by decomposers helps to return carbon from dead organisms into the atmosphere as carbon dioxide (methane-CH_4 in anaerobic conditions)
- The cycling of carbon and the flow of energy through food chains are intimately related.
- Carbon can be stored in the lithosphere (岩石圈) for extended periods of time as organisms become buried before they decompose.
  - This is particularly true under relatively inefficient anaerobic decay conditions such as in peat bogs (泥炭沼泽).
  - Over millions of years, past forest, marine, and freshwater ecosystems have been transformed into fossil fuels through heat and compression.

3.1.2 The Nitrogen Cycle

- Nitrogen is a colourless, tasteless, odourless gas required by all organisms for life.
- 78% of earth's atmosphere is composed of N.
- The main way in which the atmospheric reservoir is lined to the biotic components of the food chain through ***nitrogen fixation***[1] and ***denitrification***[2]

[1] TL;DR: Nitrogen fixation is a process by which molecular nitrogen in the air is converted into ammonia or related nitrogenous compounds in soil.
[2] The loss or removal of nitrogen or nitrogen compounds

The Nitrogen Fixation Process

- ***Nitrogen Fixation*** occurs as bacteria transform atmospheric nitrogen into various forms that are available to plant.
- The most important nitrogen fixers are bacteria of the Rhizobium family that grow on root nodules of plants.
- These bacteria combine gaseous N_2 with H_2 to make ammonia (NH_3) and ammonium (NH_4^+).
- Other bacteria then combine ammonia with oxygen to form nitrites (NO_2^-).
- A third group of bacteria converts nitrites to nitrates, which green plants can absorb and use.
- Plant cells absorb nitrates, and use them to build amino acids and eventually proteins.

Mineralization is the process by which decomposing biomass is converted back to ammonia and ammonium salts by bacterial action returned to the soil.

3.2 The Phosphorus Cycle

- The phosphorus cycle takes millions of years,
- Minerals become available to organisms after they are released from rocks or salts.
- Primary Producers take in inorganic phosphorus, incorporate it into organic molecules, and then pass it on to consumers.
- In this way, phosphorus cycles through the ecosystem.
- (富营养化) Excess phosphates in bodies of water can stimulate explosive growth of algae, upsetting ecosystem stability.

3.3 The Sulphur Cycle

[3]

- The form of S in soils depends on the presence (aerobic) or absence (anaerobic) of oxygen (a reflection of the relationship of the particular site of transformation to the water table) and the presence of other elements such as iron.
- Human activities also release large quantities of sulphur, primarily through burning fossil fuels. These precesses can contribute to acid precipitation.
- The biogenic sulphur emissions of oceanic phytoplankton may play a role in global climate
- The phytoplankton release sulphur compounds into the atmosphere which can reflect sunlight, cooling the earth.
- This may be a feedback mechanism that keeps Earth's temperature within a suitable range for life.

[3] Counter-intuitively enough, S is actually a "cooling gas"

4 Lecture4 - Biomes and Biodiversity

Terrestrial Biomes (陆地生物群落)

- We call large biological communities *biomes*.
- If we know the range of temperature and precipitation in a particular place, we can generally predict what kind of biome is likely to occur there.
- An important characteristic of each biome is its biodiversity, or the number of variety of different biological species that live there.

Biomes vary with latitude

- many temperature controlled biomes occur in latitudinal bands,
- A band of boreal (北方的) forest crosses Canada and Siberia.
- Tropical forests occur near the equator.
- Expansive grasslands lie near - or just beyond - the tropics.
- Many biomes are even named for their latitudes: e.g. tropical forests, and arctic tundra.

Vertical Zonation

- Vertical zonation is the term applied to vegetation zones which are defined by altitude.
- Temperature and precipitation change with elevation as well as with latitude.
- In mountainous regions, temperatures are cooler and precipitation is usually greater at high elevations.
- Mountains are cooler and often wetter, then low elevations.

Examples

- **Tropical Rainforests:** Tropical rainforests occur where rainfall is abundant - more than 200cm a year - and temperatures are warm to hot year around.
- **Tropical Savanna and Grasslands:** They are dry most of the year, where there is too little rainfall to support forests, we find open grasslands, or grasslands with sparse tree cover, which we call savanna.
- **Desserts** occur where precipitation is uncommon and slight, usually with less than 30cm rain per year.
- **Temperature Grasslands** usually have rich soil. As in tropical latitudes, temperature (midlatitude) grasslands occur where there is enough rain to support abundant grass but not enough for forests.

- **Temperature Scrublands** have summer drought. Often, dry environments support drought-adapted shrubs and trees, as well as grass. These mixed environments can be highly variable. They can also be very rich biologically. Such condition could be described as mediterranean scrub, or as known in California, chaparral. Ever green shrubs with small, leathery leaves from dense thickets, or other small trees often cluster in sheltered valleys.
- **Temperature Forests** can be Evergreen or Deciduous. These forests are grouped by tree type, broad-leaved deciduous or evergreen coniferous.

Deciduous Forest (落叶林)

- Broad leaf forests occur throughout the world where rainfall is plentiful. In mid-latitudes, these forests are deciduous and lose their leaves in winter.
- The loss of green chlorophyll (叶绿素) pigments can produce brilliant colours in these forests in autumn.

Coniferous Forests (针叶林)

- Coniferous forests grow in a wide range of environmental conditions
- Often, they occur where moisture is limited: in cold climates, moisture is unavailable (frozen) in winter; hot climates may have seasonal drought sandy soils hold little moisture, and they are often occupied by conifers.
- Thin, waxy leaves (needle shaped) help these trees reduce moisture loss.

Temperature Forests (温带森林)

- The coniferous forests of the Pacific coast grow in extremely wet conditions. The wettest coastal forests are known as temperate rainforest, a cool, rainy forest often enshrouded in fog.

Boreal Forests (北方针叶林、泰卡林)

- Because conifers can survive winter cold, they tend to dominate the boreal forest.
- Dominant trees are pines, hemlocks (铁杉树), spruce (云杉), cedar (雪松), and fir (冷杉).
- Boreal forests are found in Siberia, Canada and western US.

Tundra

- Tundra is a treeless landscape where temperatures are below freezing most of the year.
- It occurs at high latitudes or on mountaintops, has a growing season of only two to three months.

4.1 Marine Ecosystems

- Most marine communities depend on photosynthetic organisms.
- Phytoplankton (浮游植物): tiny, free-float photosynthetic algae often support a marine food web rather than trees or grasses.
- In oceans, photosynthetic activity tends to be greatest near coastlines, where nitrogen, phosphorus, and other nutrients wash offshore and fertilize primary producers.

Deep-sea Thermal Vent Communities

- These communities are based on microbes (微生物) that capture sulphur compounds released from thermal vents on the ocean floor.

Tidal Shores (海礁) Corel reefs are among the best-known marine systems, because of their extraordinary biological productivity and their diverse and beautiful organisms.

Mangroves (红树林) Mangroves are a diverse group of salt-tolerant trees that grow along warm, calm marine coasts around the world.

Estuaries and Salt Marshes (盐碱滩) Estuaries are bays where rivers empty into the sea, mixing fresh water with salt water. Salt marshes, shallow wetlands flooded regularly or occasionally with seawater, occur on shallow coastlines, including estuaries.

Tidal Shores (潮池) Tidal pools are depressions in a rocky shoreline that are flooded at high tide, but retain some water at low tide.

4.2 Freshwater Ecosystem

- Freshwater environments are far less extensive than marine environments, but they are centres of biodiversity.
- Most terrestrial communities rely, to some extent, on freshwater environments.
- In desserts, isolated pools, streams, and even underground water systems support astonishing biodiversity as well as provide water to land animals.

Lakes have extensive open water

- Freshwater lakes, like marine environments, have distinct vertical zones.
- Near the surface is a sub-community of plankton, mainly microscopic plants, animals and protists.
- Fish move through the water column, sometimes near the surface and sometimes at depth.
- The bottom, or benthos, is occupied by a variety of snails, burrowing worms, fish, and other organisms.

5 Lecture 5 - Biomes and Biodiversity (II)

Three Biodiversity Defined Biodiversity refers to the variety of living things. There are three kinds of biodiversity that are essential to preserve ecological systems and functions

- *Genetic diversity* is a measure of the variety of versions of the same genes within individual species.
- *Species diversity* describes the number of different kinds of organisms within a community or ecosystem.
- *Ecological diversity* refers to the richness and complexity of a biological community.

Benefits of Biodiversity

- Provisioning services which involve the production of renewable resources (e.g. food, wood, fresh water)
- Regulating services which lessen environmental change (e.g. climate regulation, pest/disease control)
- Culture services represent human value and enjoyment (e.g. landscape aesthetics, cultural heritage, outdoor recreation, and spiritual significance.)

Urban Bio-diversity

- As of 2005, more people live in urban than in rural areas for the first time in Earth's history.
- Cities draw on their surrounding ecosystems for goods and service, and their products and emission can affect regional and even global ecosystems. Healthy ecosystems and biological diversity are necessary for our cities to function properly.

5.1 Threats to Bio-Diversity

- Extinction, the elimination of species, is a normal process of the natural world. However, human impacts have accelerated that rate recently.
- In geologic history, extinctions are common. Studies of the fossil record suggest that more than 99 percent of all species that ever existed are now extinct.
- Most of those species were gone long before humans came to the scene.
- Periodically, mass extinctions have wiped out vast numbers of species and even whole families.

Habitat Destruction is usually the main threat

- The most important extinction threat for most species - especially terrestrial ones - is habitat loss.
- Over the past 10000 years, humans have transformed billions of hectares of former forests and grasslands to croplands, cities, roads, and other uses.
- Sometimes we destroy habitat as a side effect of resource extraction, such as mining, dam-building, and indiscriminate fishing methods.

World Forests

- Forests, woodlands, pastures, and rangelands together occupy almost 60 percent of global land cover.
- Ecosystems Services provided: lumber, paper pulp, and grazing lands for livestock, regulating climate, controlling water runoff, providing wildlife habitat, purifying air and water, and supporting rainfall.
- Forest and grasslands also have scenic, cultural, and historic value.

Tropical Forests

- Tropical forests are among the riches and most diverse terrestrial systems.
- Although they now occupy less than 10% of the earth's surface, these forests are though to contain more than 2/3 of all higher plant biomass and least 1/2 of all the plant, animal, and microbial species in the world.
- The FAO estimates that about 10 million hectare, or about 0.6 percent, of existing tropical forests are cleared each year.