Concepts of Biology

Introduction

Evolution and Life on Earth; Energy and Matter; and Biological Information and Interactions

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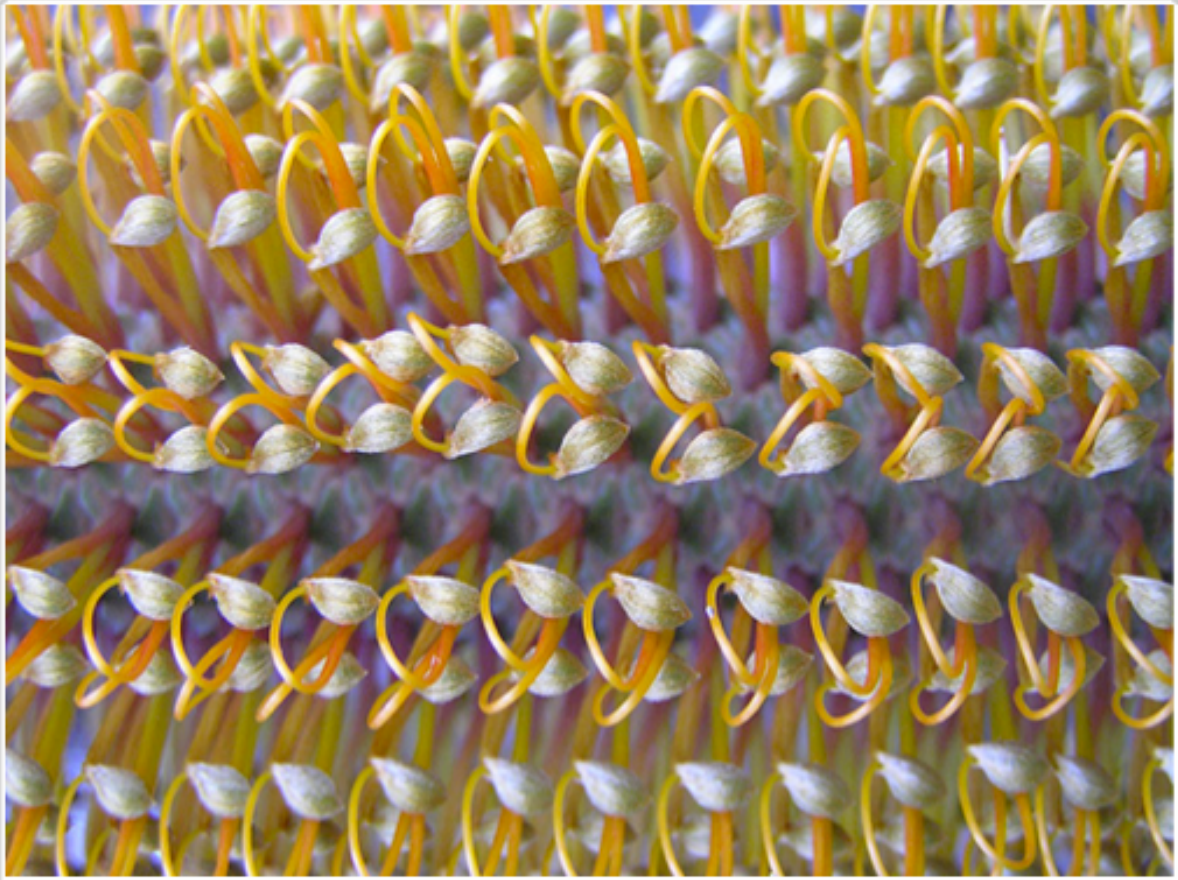
Evolution and Life on Earth



Blooms on a *Banksia*.
These flowerbuds are arranged in pairs and orderly rows on a Banksia shrub, native to Australia's moist woodlands. Centuries ago, patterns like these inspired naturalists to seek explanations about their origin. Today, forces of evolution are the primary explanations for the shapes and behaviors of organisms that develop and change over millions of years.

Evolution and Life on Earth

- **Topics Covered in this Module**
  - Life on Earth
  - Evolution: The Core Theme in Biology
- **Major Objectives of this Module**
  - Identify evolution as the core theme and unifying concept in biology.
  - Distinguish between the biological and common meanings of the word "evolution."
  - Explain how evolution has led to both the unity and diversity of life forms.
  - Explain biological classification in terms of evolutionary history.

Life on Earth

- Cuttlefish: its color is sensitive to the changes of environment
- How does this organism adapt to its environment in such a specific way?
- Fungus lives on the wings of a certain species of beetle?
- The answer is simply…….

Figure 1: A cuttlefish.
This cuttlefish senses its surroundings through its W-shaped eye. The eye sends information to the brain, which quickly relays messages to particular pigment cells in the skin. The muscles pull on the pigment cells, causing them to expand, and the cuttlefish instantly resembles what its eye sees. In this case, the cuttlefish displays tan and brown stripes on its back, perhaps to resemble the sandy seafloor.

EVOLUTION

Life on Earth

- Biological evolution: the enormous diversity of life, and also the its unity
- How can one process explain both the unity and the diversity of something as complex as biological life?
- Concept of diversity, e.g. in a summer day, a person may interact with different kind of species.
- But how does this diversity resemble unity? Or what does the unity of life mean?

Life on Earth

- Living things are diverse, but every living thing shares certain characteristics
- For example, every organism is composed of one or more cells
- Every organism also requires energy, has metabolism, grows, responds to stimuli, adapts, and reproduces
- All cells in all organisms contain DNA, a cell membrane, and ribosomes
- FOR NOW: consider DNA → the molecule that contains the universal code of life

Life on Earth

- DNA is packed into cells → enclosed (in eukaryotes) or not (in prokaryotes)
- Nucleus → membrane-enclosed subcompartment of the cell
- DNA in every cell → the same building blocks, shapes, acts in the same way, twisted in the same direction
- DNA is a greater unifier for all of life

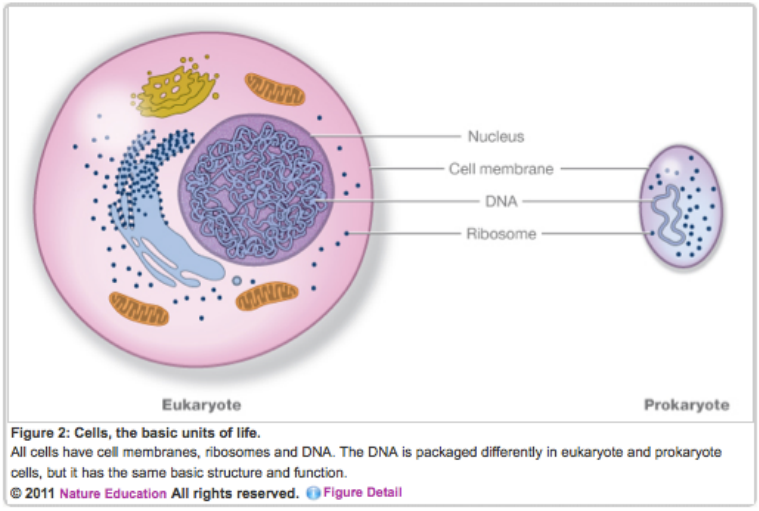


Figure 2: Cells, the basic units of life.
All cells have cell membranes, ribosomes and DNA. The DNA is packaged differently in eukaryote and prokaryote cells, but it has the same basic structure and function.

Life on Earth

- What does DNA have to do with evolution?
  - In every life, DNA → blueprint for life
  - DNA → relatively stable inside individual organism
- However, mistakes in DNA replication may change the code inside the DNA → MUTATION
- Another DNA changes happen when genes RESHUFFLE or RECOMBINE during the process of cell division (or reproduction)
- These changes lead to the genetic variation upon which evolution operates

Life on Earth

- Biological evolution → a process that results in heritable changes in a population over time
- This occurs by passing of modified DNA from generation to generation
- Then, what do astronomers mean when they say galaxies evolve? How is this different from the biological meaning of the word evolution?

Ancient people began to classify life

- Biological evolution based on DNA was not available until the 20th century
- But scientists have long pondered the concepts of evolution and the origins of diversity
- 30,000-year-old cave paintings in France → the distinct mammals

Figure 3: Recognition of diversity.
Ancient people painted caves with realistic-looking animals, indicating a degree of conceptual thought required for the ability to classify.

Ancient people began to classify life

- Classification → sorting out things into categories
- The science of classification → TAXONOMY (Greek *taxis* (arrangement), and *nomia* (method))
- The Father of classic taxonomy: Aristotle (384-322 B.C.E.) → classified animals and plants → "Ladder of Life" (*Scale Naturae*) →

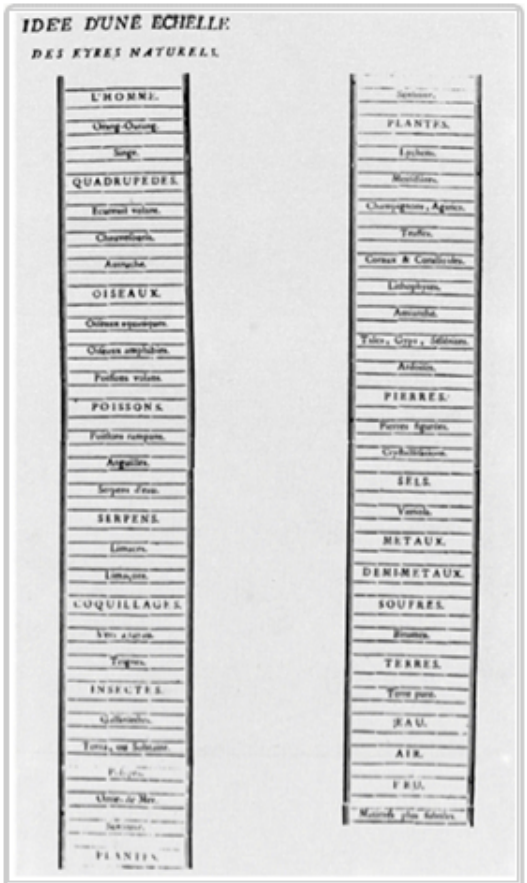


Figure 4: ***Scala Naturae.***
Derived from Aristotle's Ladder of Life, this French version of a *Scala Naturae* places humans at the top (L'Homme means man), followed by quadrupeds, birds, fish, serpents, molluscs (shelled creatures), insects, and plants. Nonbiological substances—rocks, metals and minerals—are added at the bottom in the image on the right.
Photo via Wikimedia Commons.

Ancient people began to classify life

- Classification of organisms based on the hierarchies of the similar gross morphological characteristics → Carl Linnaeus (1701-1778)
- Unified name that can be used in any language
- Language used: Latin → dead language, no

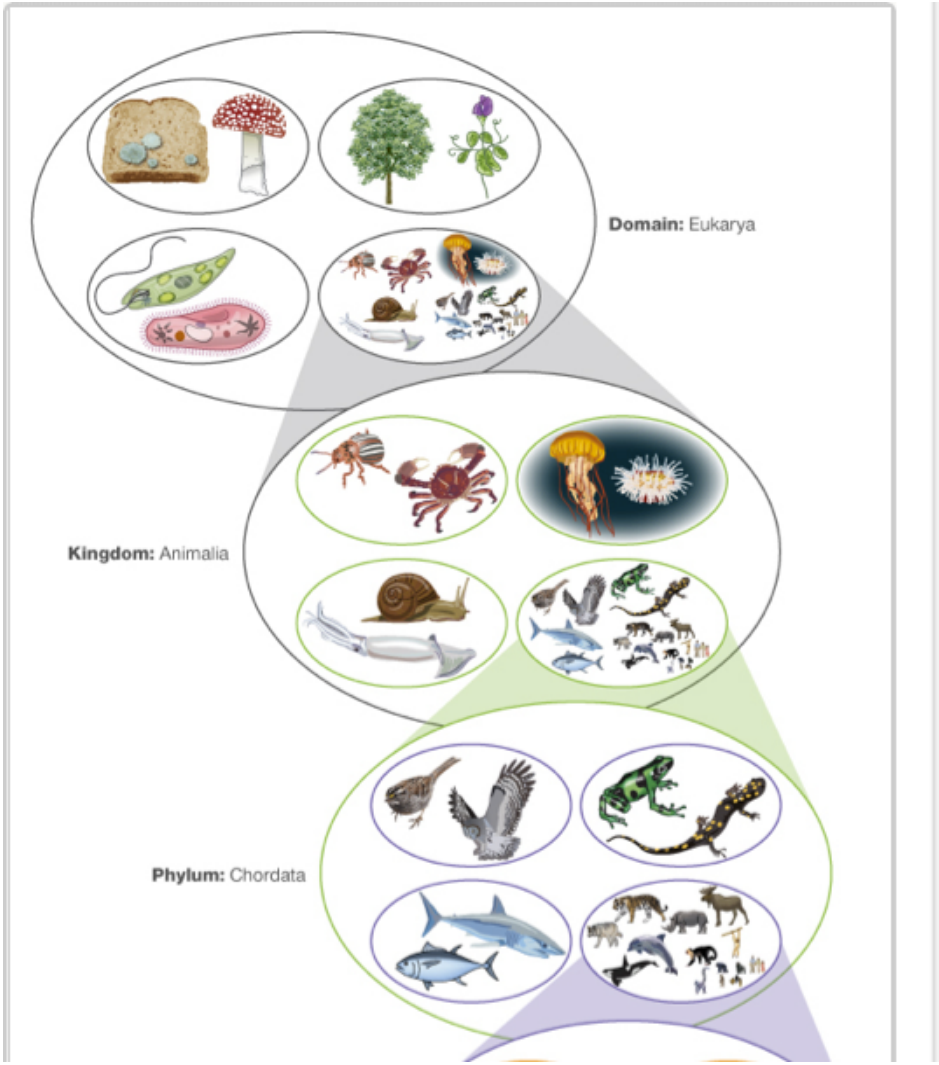
(Linnaeus)
Kingdoms
|
Classes
|
Orders
|
Genera
|
Species

New
Domain
|
Kingdoms
|
Phyla
|
Classes
|
Orders
|
Families
|
Genera
|
Species

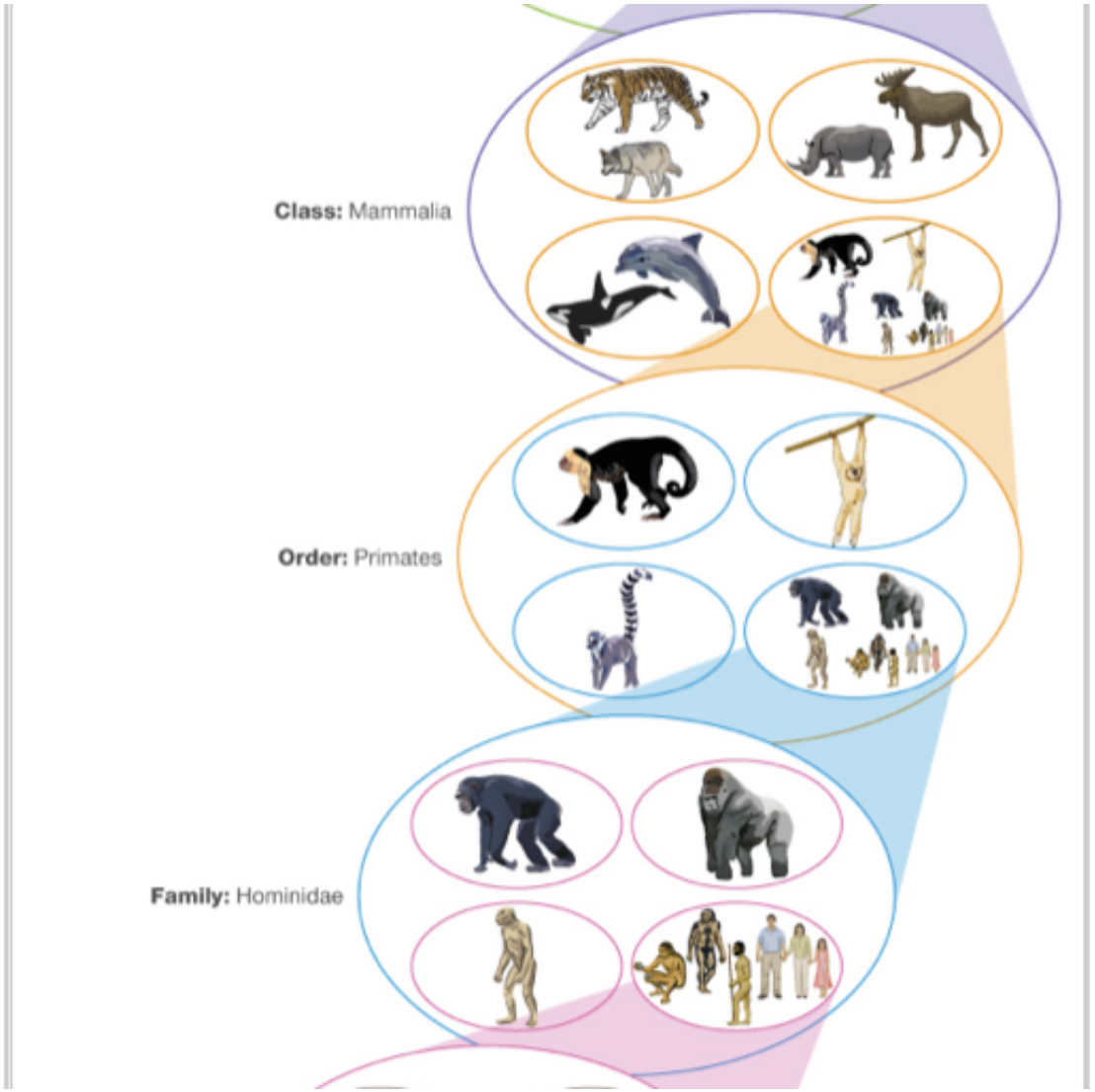
Linnaeus' binomial nomenclatur

- Binomial nomenclature (two-word names)- used to assign each organism with two part name e.g. *Homo sapience*
- Universal
- Latin-based
  - First word represents genus of organism e.g. *Homo*
  - Second word is specific epithet of a species within the genus e.g. *sapience*
  - Always italicized as a *Genus species* (*Homo sapiens*)
  - Genus may be abbreviated e.g. *Escherichia coli* as *E. coli*

The hierarchy of biological classification applied to humans



The hierarchy of biological classification applied to humans



The hierarchy of biological classification applied to humans

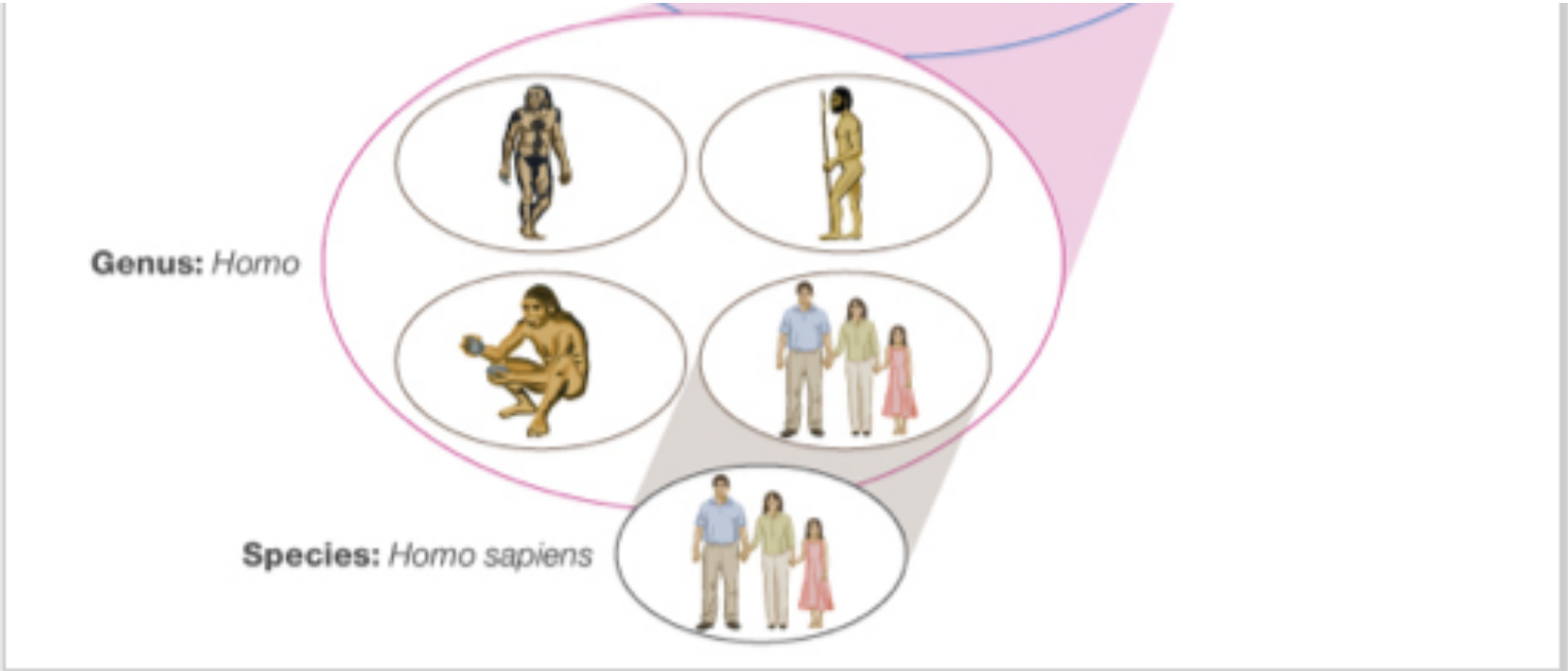


Figure 5: The hierarchy of biological classification applied to humans.
Biological classification is a hierarchy in which small groups are nested into larger ones. Species are designated using both their genus and species names (both italicized). The first letter of the species name is not capitalized. Humans' genus, *Homo*, contains other extinct species such as *Homo neanderthalensis* (upper left), *Homo habilis* (lower left) and *Homo erectus* (upper right). Classifications above the genus level are always capitalized but not italicized. In the largest grouping (the Eukarya domain), humans are grouped with all other animals, plants, fungi, and a large number of unicellular organisms.

 Figure Detail

The theory of evolution by natural selection is the cornerstone of the modern scientific understanding of life

- Ancient Greek, Arabs, Chinese, and Indians wrote about the changing nature of life on Earth
- Erasmus Darwin (1731-1802) Jean Baptiste Lamarck (1744-1829) Charles Darwin (1809-1882), Alfred Russel Wallace (1823-1913)
- Darwin & Wallace → published at the

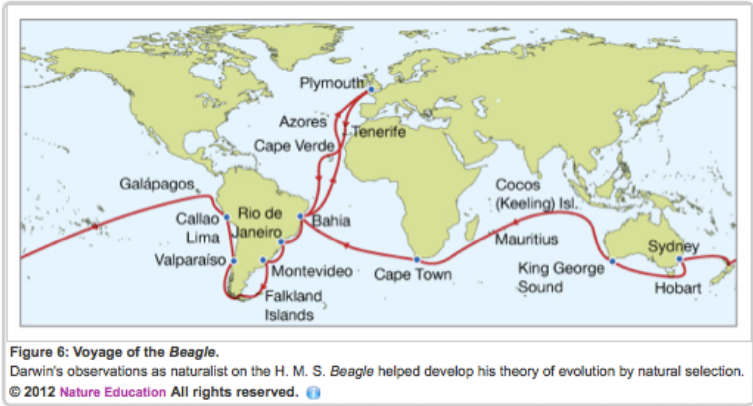


Figure 6: Voyage of the *Beagle*.
Darwin's observations as naturalist on the H. M. S. *Beagle* helped develop his theory of evolution by natural selection.

The theory of evolution by natural selection is the cornerstone of the modern scientific understanding of life

- What is species? And how did species arise? Whether and how species change over time.
- Darwin → different individuals in population in different islands → variation (color & beak size) passed to offspring through reproduction
- Not all offspring survive to reproduce, compete for limited resources →

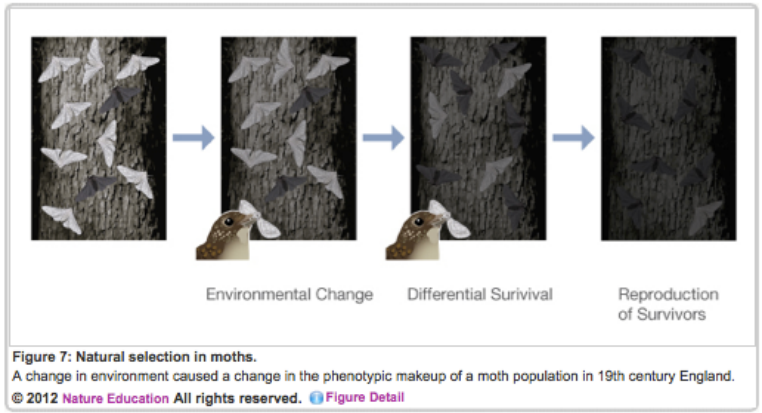


Figure 7: Natural selection in moths.
A change in environment caused a change in the phenotypic makeup of a moth population in 19th century England.

Phenotypic variation → key of survival

NATURAL SELECTION

The theory of evolution by natural selection is the cornerstone of the modern scientific understanding of life

- Gregory Mendel (1822-1884) → basic principles of heredity
- Neo-Darwinism arose in 1940s → mathematical interpretation of natural selection as and adaptive process in breeding population
- Other genetic mechanisms by which population evolved was discovered
- Natural selection remains the major mechanism of *speciation*: the process by which new species arise

The theory of evolution by natural selection is the cornerstone of the modern scientific understanding of life

- How does natural selection lead to speciation?
- Evolution operates in different scales: small (micro) and large (macro)
- Microevolution happens when genetic mechanisms of change, i.e. mutations, occurs and leads to altered gene frequency
- Macroevolution → larger and longer scales → divergence of species

olation of squirrels.
anyon over millions of years has separated a population of s
as a distinct appearance. The Abert's squirrel (left, with whit
bab squirrel (right, no white torso) lives on the north rim of th
geography, termed geographic isolation, may lead to the evo
/NPS. (right) **Courtesy of Allyson Mathis/NPS.**

Evolution: The Core Theme in Biology

Theodosius Dobzhansky (1900-1975)

“Nothing in biology makes sense except in the light of evolution”

Evolution explains the unity of life

- Evolution is a conservative process, meaning instead of forming each new species from scratch, evolution modifies the same basic design again and again

Evolution explains the unity of life

- For example, the similarity of the forelimb bones among different mammalian species
- Forelimb is roughly the same among many species because it is the result of evolution from a common ancestor
- HOMOLOGY
- Forelimb bones derived from or coded by a similar set of genes

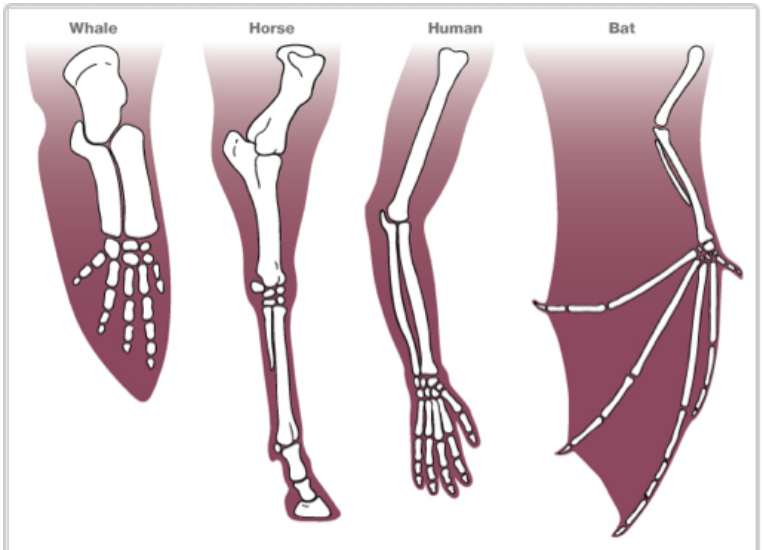


Figure 9: Homologies.
The forelimbs of various mammals use the same bones, slightly modified, for different purposes. The genes that code for the bones are also very similar. These similarities that arise from sharing a common ancestor are called homologies. The forelimbs in mammals are considered homologous structures.

Evolution explains the unity of life: DNA contains genetic information

- DNA → long, ladder-like strands → nucleotides (composed of bases)
- A single gene is a segment of a DNA strand with its bases arranged in a specific way
- Combined sequences of bases in a gene determines the gene's product
- DNA → mRNA → amino acid chain
- Ribosomes → machine to synthesis amino acid chains
- Amino acids → structural building blocks of all organisms

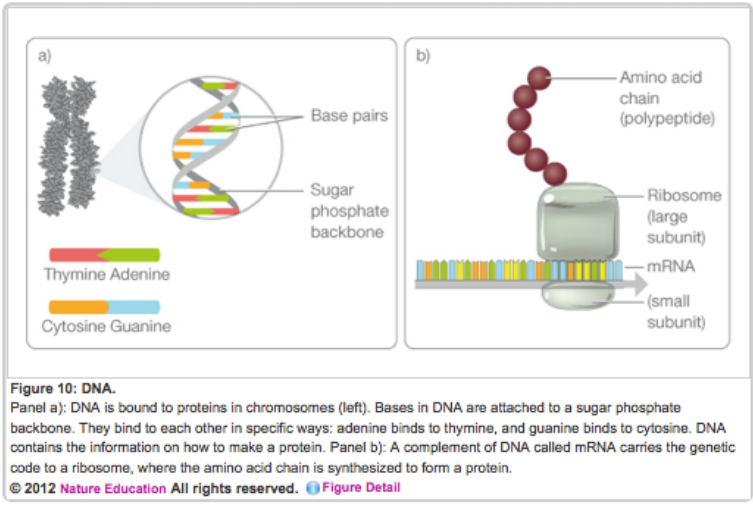


Figure 10: DNA.
Panel a): DNA is bound to proteins in chromosomes (left). Bases in DNA are attached to a sugar phosphate backbone. They bind to each other in specific ways: adenine binds to thymine, and guanine binds to cytosine. DNA contains the information on how to make a protein. Panel b): A complement of DNA called mRNA carries the genetic code to a ribosome, where the amino acid chain is synthesized to form a protein.

Evolution explains the unity of life: The genetic code

Codon	Amino acid	Codon	Amino acid	Codon	Amino acid	Codon	Amino acid
TTT	Phenylalanine	TCT	Serine	TAT	Tyrosine	TGT	Cysteine
TTC	Phenylalanine	TCC	Serine	TAC	Tyrosine	TGC	Cysteine
TTA	Leucine	TCA	Serine	TAA	STOP	TGA	STOP
TTG	Leucine	TCG	Serine	TAG	STOP	TGG	Tryptophan
CTT	Leucine	CCT	Proline	CAT	Histidine	CGT	Arginine
CTC	Leucine	CCC	Proline	CAC	Histidine	CGC	Arginine
CTA	Leucine	CCA	Proline	CAA	Glutamine	CGA	Arginine
CTG	Leucine	CCG	Proline	CAG	Glutamine	CGG	Arginine
ATT	Isoleucine	ACT	Threonine	AAT	Asparagine	AGT	Serine
ATC	Isoleucine	ACC	Threonine	AAC	Asparagine	AGC	Serine
ATA	Isoleucine	ACA	Threonine	AAA	Lysine	AGA	Arginine
ATG	Methionine	ACG	Threonine	AAG	Lysine	AGG	Arginine
GTT	Valine	GCT	Alanine	GAT	Aspartic acid	GGT	Glycine
GTC	Valine	GCC	Alanine	GAC	Aspartic acid	GGC	Glycine
GTA	Valine	GCA	Alanine	GAA	Glutamic acid	GGA	Glycine
GTG	Valine	GCG	Alanine	GAG	Glutamic acid	GGG	Glycine

Table 1. The genetic code. Sixty-four different combinations of three DNA bases are possible, yet there are only 20 amino acids. All but two of the amino acids (methionine and tryptophan) are able to be encoded by more than one codon. Some codons do not code for an amino acid but instead are "stop" signals, which signal the release of the amino acid from the ribosome. ATG, which codes for methionine, also signals "start." The genetic code is nearly universal; only a few exceptions are known to exist.

Evolution explains the unity of life: The basic structure of cell membrane

- Cells make up all organisms except viruses
- Cells are enclosed by cell membranes
- Lipid bilayer: hydrophilic → water soluble and hydrophobic → water insoluble
- Critical for the transport of substances across it

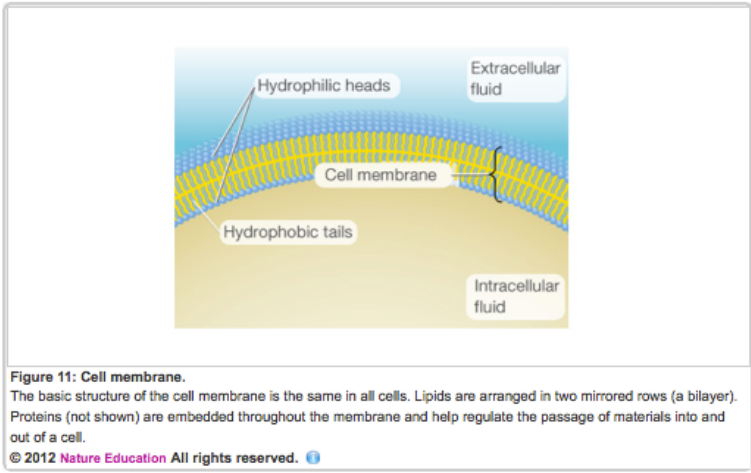


Figure 11: Cell membrane.
The basic structure of the cell membrane is the same in all cells. Lipids are arranged in two mirrored rows (a bilayer). Proteins (not shown) are embedded throughout the membrane and help regulate the passage of materials into and out of a cell.

Evolution explains the unity of life: The basic structure of cell membrane

- Metabolism refers to all the vital chemical reactions occurring within in an organism, such as processes involved in the breakdown of food into energy
- Many metabolic processes are the same in all cells, i.e. glycolysis
- How is energy released from glucose?

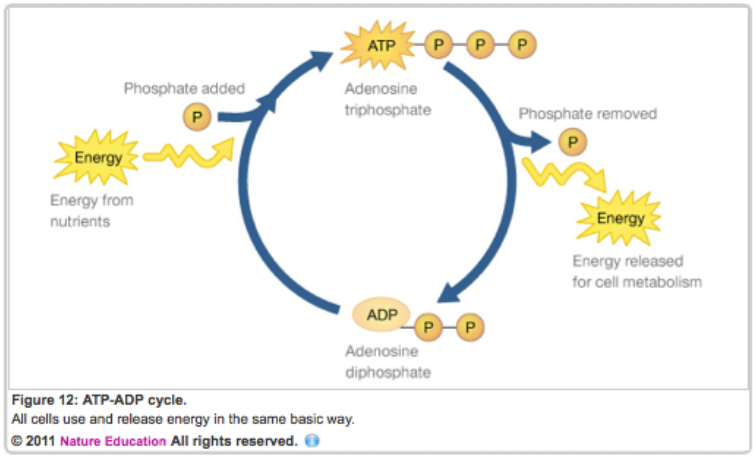


Figure 12: ATP-ADP cycle.
All cells use and release energy in the same basic way.

Evolution also explains the diversity of life

- Darwin used "descent with modification" to describe evolution → descent: unity, modification: life's diversity
- Fossil records: stories of speciation and extinctior
- Extinction occurs when a species cannot tolerate changes in its environment, i.e., when it cannot adapt
- Example: a meteorite

eorite crater.
crater in Arizona formed when a meteorite hit Earth 20,000 to 50,000 years ago. This s
imal debris into the atmosphere and altered only local environments. Scientists think thi
cts might have been at least partly responsible for some mass extinction events.
ASA.

Evolution also explains the diversity of life

- Evolution is not progressive, but it is a process that tailors organisms to the places in which they live
- Relatedness of species by studying fossils and the morphologies of living organisms
- Molecular biology (50s and 80s) provides new tools → comparing the rate of mutation of

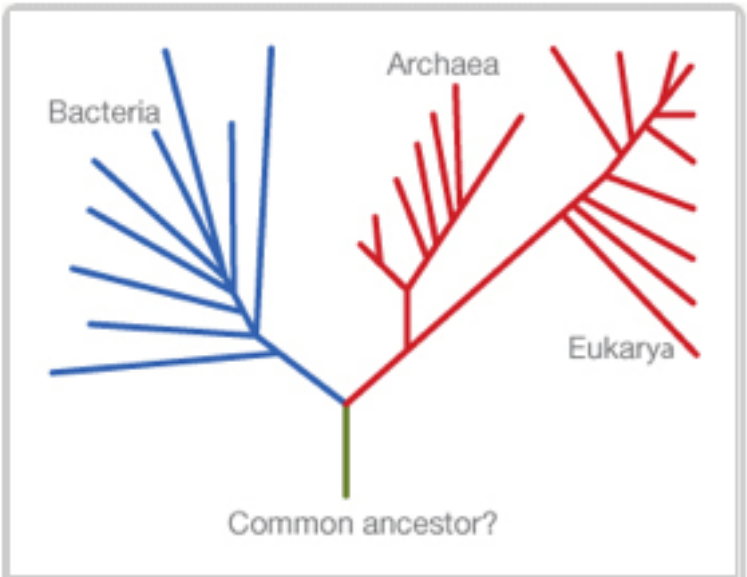
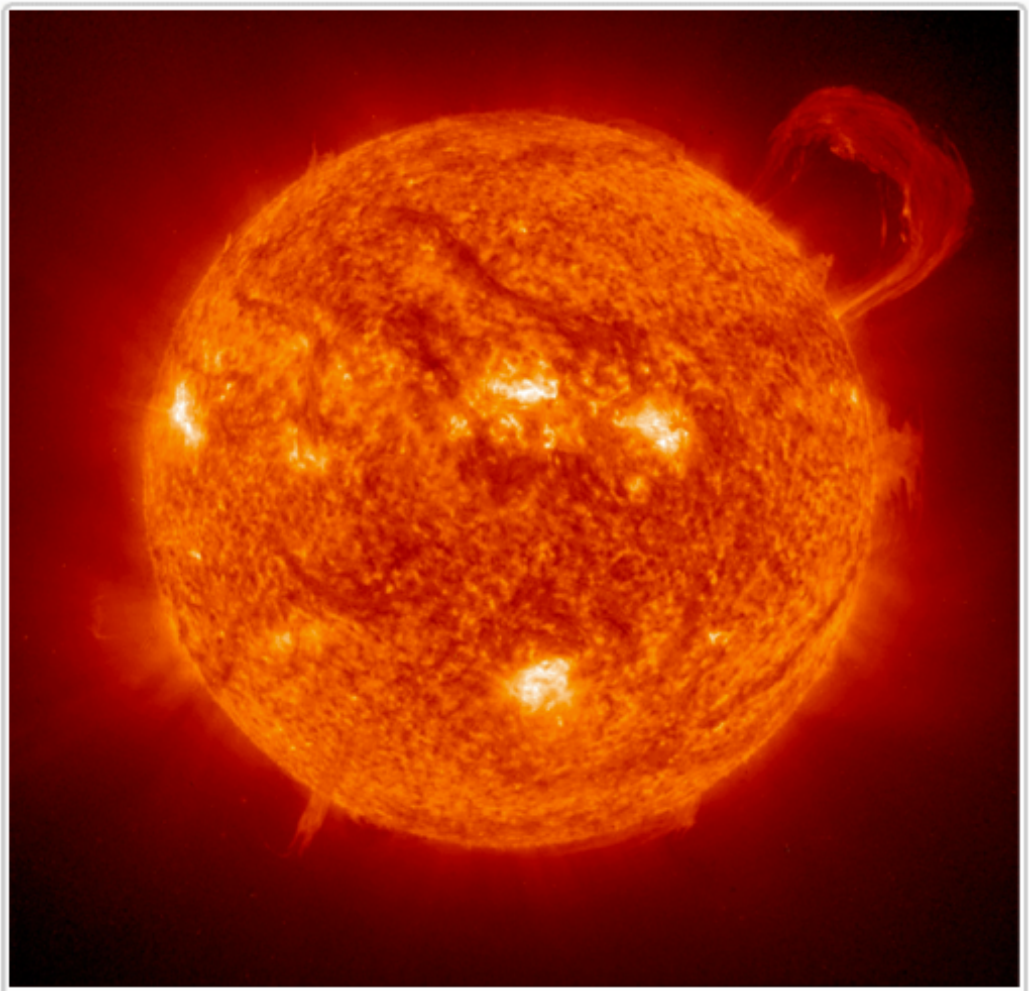


Figure 14: Three-domain tree of life.
Scientists separate organisms into three domains, Bacteria, Archaea, and Eukarya.

Energy and Matter



The Sun.
Nearly all ecosystems on Earth receive their input of energy from the Sun's radiating sunlight.
Courtesy of Jim Wilson/NASA.

Energy and Matter

- **Topics Covered in this Module**
  - Matter and Energy in the Earth System
- **Major Objectives of this Module**
  - Define energy and matter.
  - Explain how energy and matter interact on multiple levels of biological organization from cells to organisms to ecosystems to the Earth system.
  - Explain how organisms use energy and matter to form living structures and perform life processes.

Matter and energy in the Earth System

- **Matter** is a general term for the substances that make up all physical objects or materials
- Matter originated from the Big Bang and from nuclear reactions in the core of stars
- Earth → 4.5 billion years ago
- Earth contains a finite amount of matter
- How do countless generations of living things survive on a finite amount of matter?
- Answer: continual process of matter cycling (recycle)

Matter and energy in the Earth System

- **Energy** is the capacity to do work or cause change and not recycled within organisms
- Living system, from cells to ecosystems, requires a constant supply of new energy
- Energy takes many forms and may change from one from to another
- Ecosystems on Earth receive their input of energy from the Sun's radiation sunlight
- Stars emit electromagnetic energy (visible light, UV, infrared, X-rays, microwaves, radio waves, and gamma radiation)
- Electromagnetic energy travels as a stream of **photons**

Matter and energy in the Earth System

- Plants capture light energy and transform it into chemical
- Energy and matter are intimately linked
- Energy and matter continually interact on all scales in the universe
- For the purposes of studying life on Earth, this module focuses on the levels from atom to

Figure 1: A fern leaf capturing sunlight.
Plants transform the energy in sunlight to chemical energy that feeds all of the organisms in the ecosystem.
Courtesy of Randolph Femmer/NBII/life.nbii.gov.

Life processes emerge from interactions between energy and matter on the cellular level

- Cell is the basic unit of life in all organisms
- Life processes originate at the cellular level
- Cellular processes occur at the molecular scale
- Cells assemble molecules into structures that allow for the growth, maintenance, and reproduction of the organism
- Cells create, send, receive, and respond to molecular signals (interaction with environment)
- Like all work, cellular work requires an input of energy
- Cells transform or transfer energy from one type to another

Life processes emerge from interactions between energy and matter on the cellular level

- How does a cell compete its energy transactions?
- Cells of all organisms use the same molecule, **adenosine triphosphate (ATP)** → energy currency
- ATP → ADP, releasing energy
- ADP → ATP, capturing energy
- Cells break down glucose and other organic

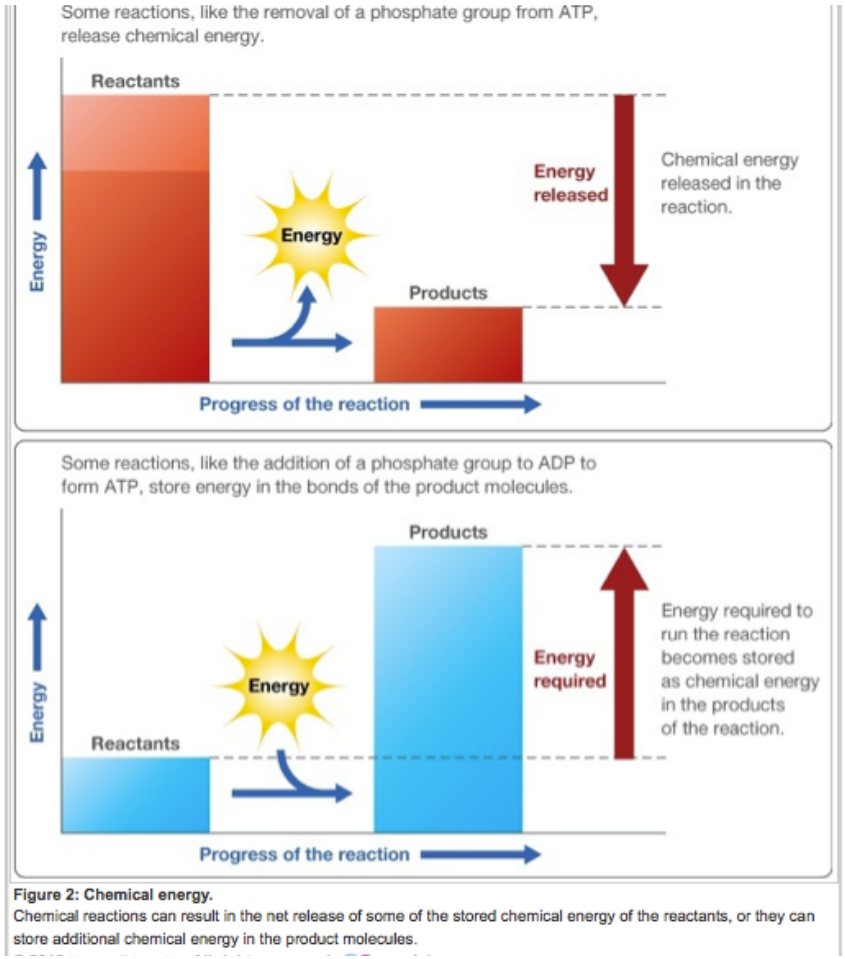


Figure 2: Chemical energy.
Chemical reactions can result in the net release of some of the stored chemical energy of the reactants, or they can store additional chemical energy in the product molecules.

Life processes emerge from interactions between energy and matter on the cellular level

- **Organic molecules** are compounds that contain carbon atoms, although some such compounds – such as carbon dioxide – are considered inorganic
- **Organic matter** is material derived from a previously or presently living organism
- Interactions between energy and matter → molecular and cellular interactions
- An organism's **metabolism** is the sum of all the chemical reactions occurring in every cell
- Metabolic processes are those processes that keep an organism alive

Energy and matter flow from one organism to another

- Energy and matter → **biosphere**
- Plants, algal, and bacterial cells → photosynthesis
- $CO_2 + H_2O$ → glucose + O_2
- Energy and matter → food chain by consumption
- Decomposers (bacteria and fungi) consume

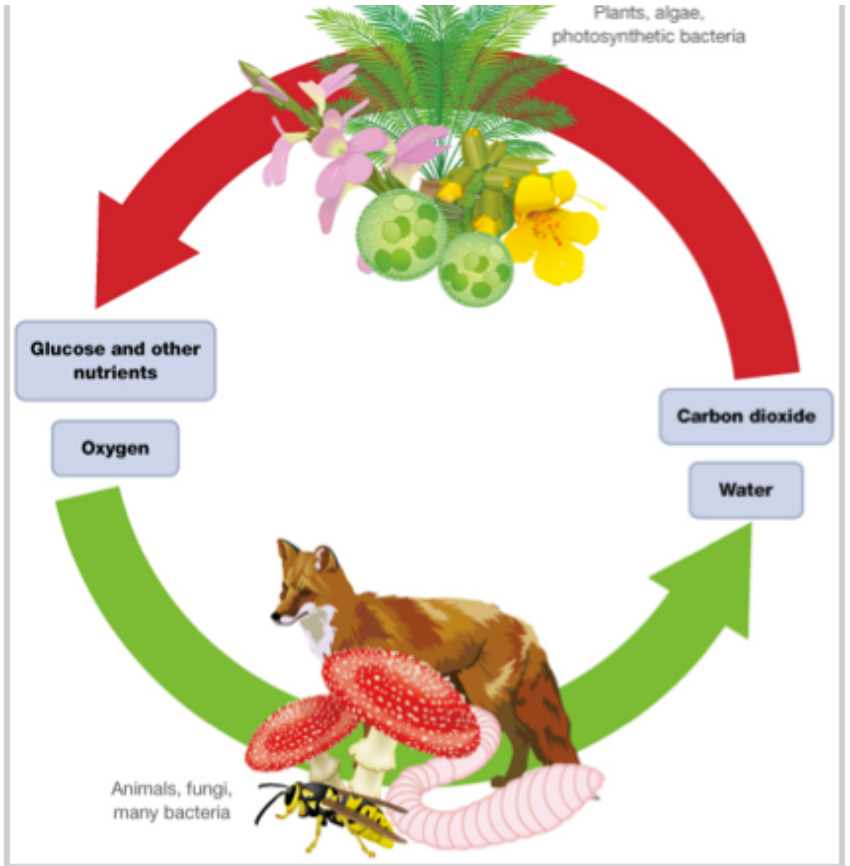
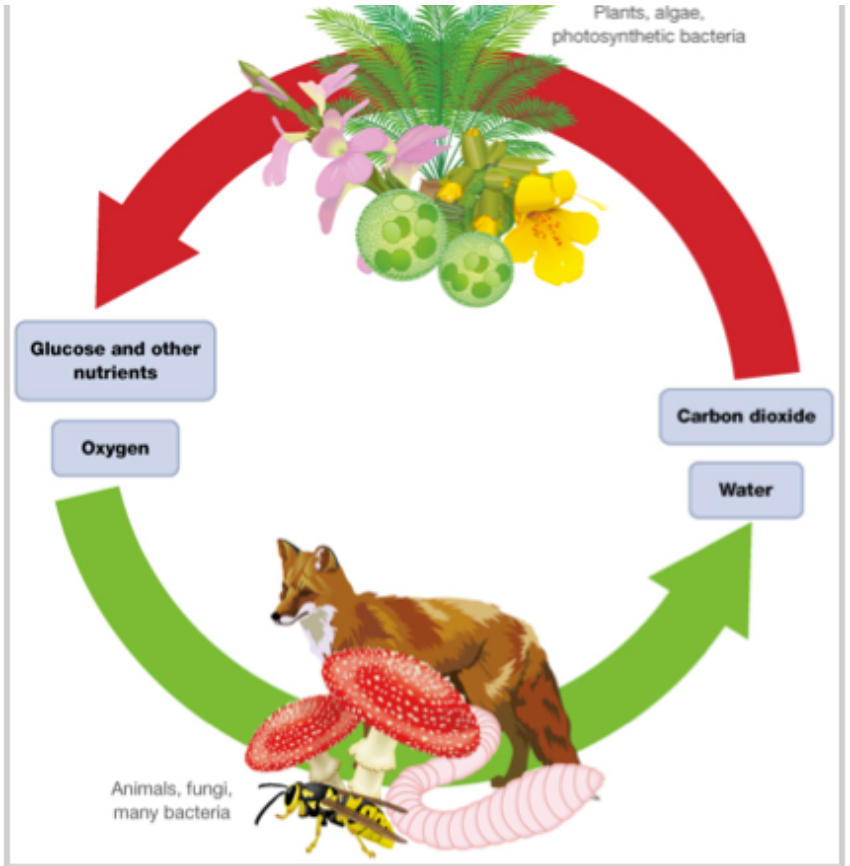


Figure 3: Matter cycling within ecosystems.
Matter is cycled through ecosystems via various processes. Organisms, including plants, algae, and photosynthetic bacteria, undergo photosynthesis (red arrow) to convert carbon dioxide and water into glucose and other nutrients. Animals and decomposers (such as fungi and many bacteria) transfer matter through processes such as cellular

Energy and matter flow from one organism to another

- Matter → cellular respiration and photosynthesis
- Cellular respiration involves the transfer of the energy released from the organic molecules to ATP (a form of ready fuel that cells are able to use to do work)
- CO_2 and H_2O are products of cellular



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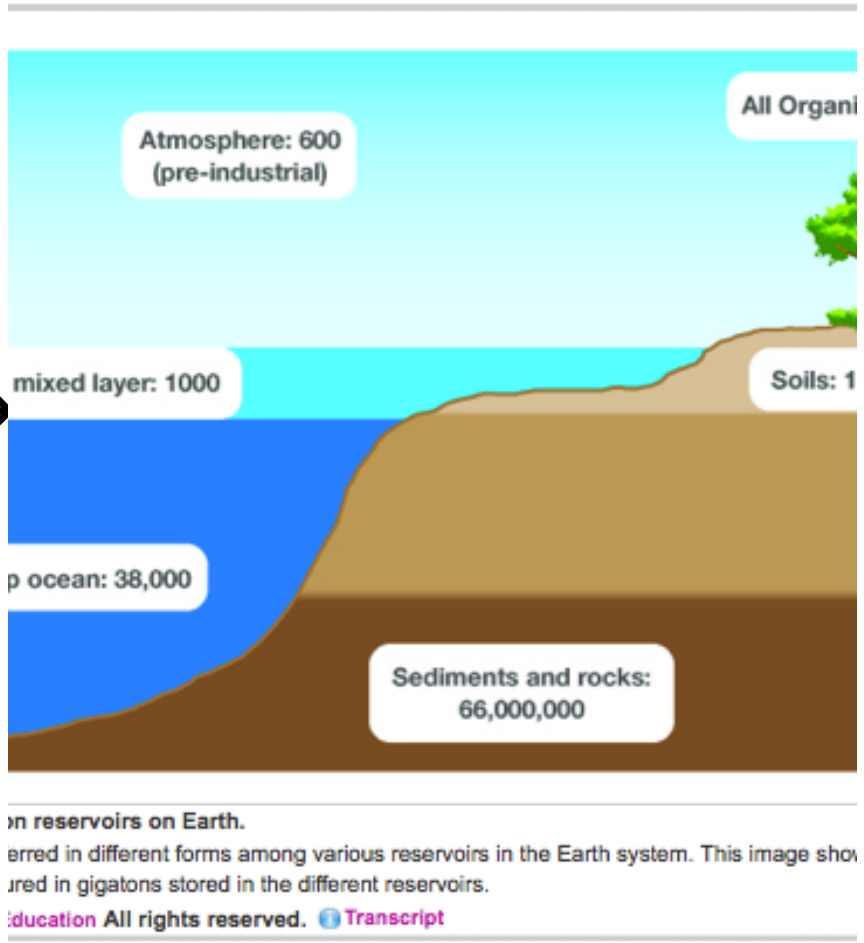
Matter cycles among living and nonliving elements of the Earth system

- Biogeochemical cycle → biological, geological, and chemical components
- Biogeochemical cycle → transfer of elements or molecules (C, P, N, and S) among different compartments or reservoirs of the Earth system, through the processes of



Energy and matter flow from one organism to another

- All life on Earth is carbon-based
- Carbon → 4 electrons → 4 covalent bonds
- Water as a source of hydrogen and oxygen atoms
- Oxygen incorporated into glucose actually comes from carbon dioxide
- Water is also critical to

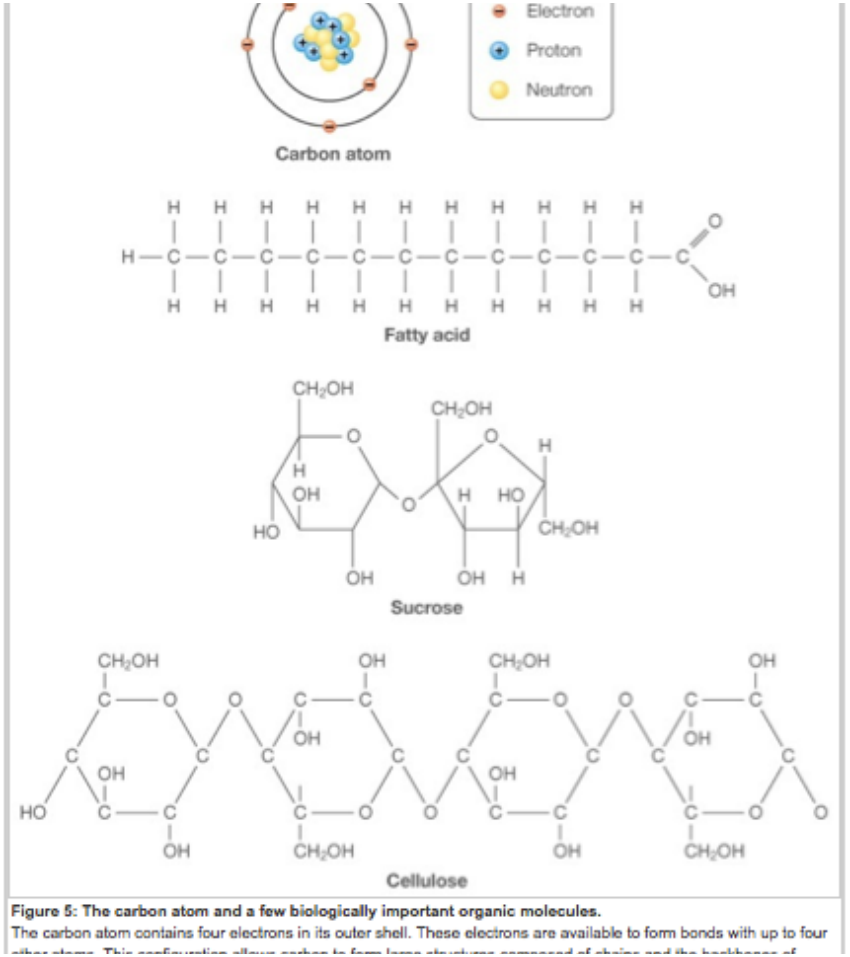
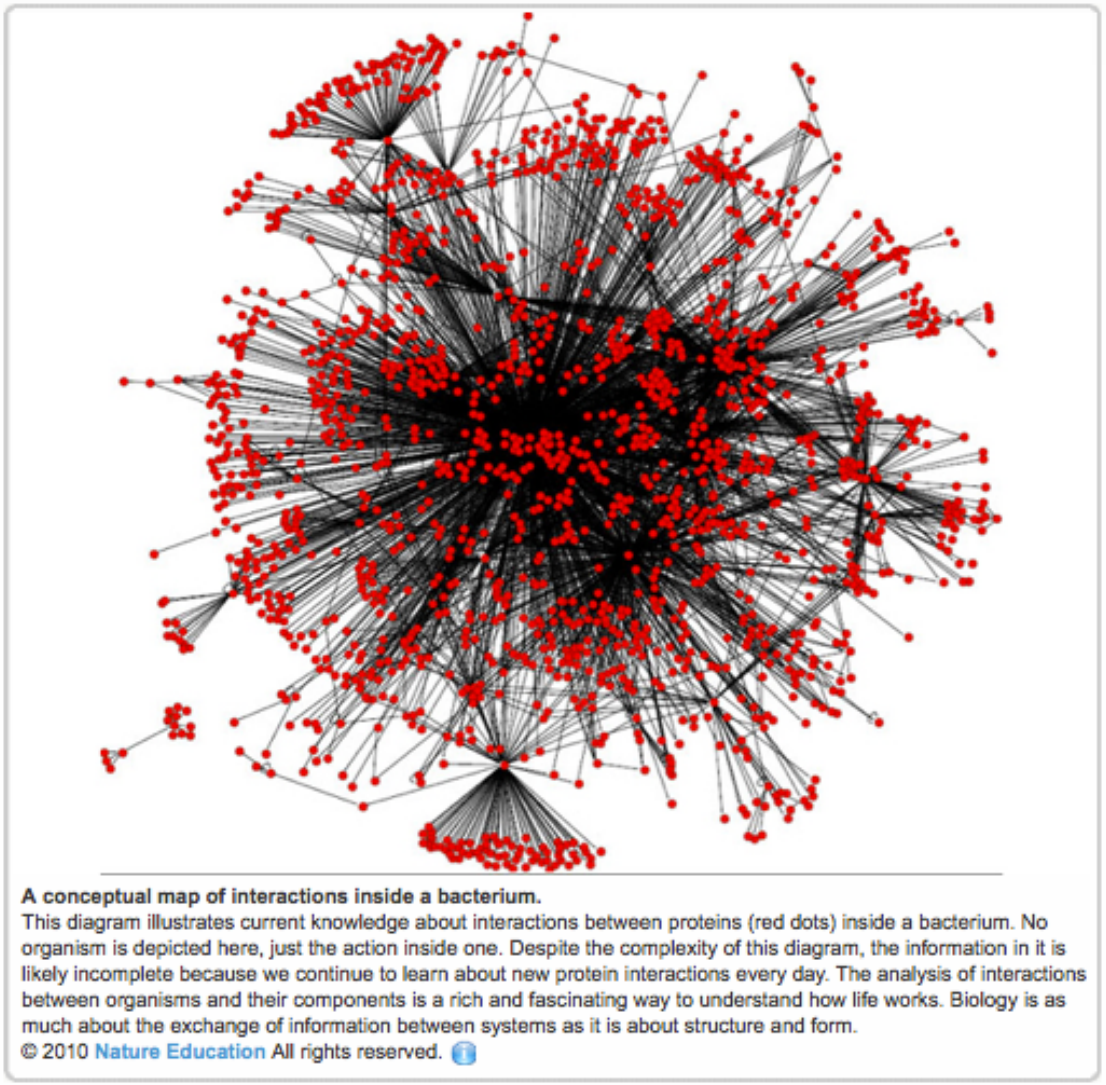


Figure 5: The carbon atom and a few biologically important organic molecules.
The carbon atom contains four electrons in its outer shell. These electrons are available to form bonds with up to four

Biological Information and Interactions



A conceptual map of interactions inside a bacterium.
This diagram illustrates current knowledge about interactions between proteins (red dots) inside a bacterium. No organism is depicted here, just the action inside one. Despite the complexity of this diagram, the information in it is likely incomplete because we continue to learn about new protein interactions every day. The analysis of interactions between organisms and their components is a rich and fascinating way to understand how life works. Biology is as much about the exchange of information between systems as it is about structure and form.

Biological Information and Interactions

- **Topics Covered in this Module**
  - Organisms Are Centers of Information Transfer
  - Genetic Information
  - Responding to Information
- **Major Objectives of this Module**
  - Describe how living things inherit genetic information.
  - Explain how cells receive, process and respond to signals from their environment.
  - Describe interactions that occur among organisms on a variety of scales.

Organisms are centers of information transfer

- Trees are actually complex information-processing
- The change in leaf color is a response of the trees to environmental changes (diminishing day length and light intensity)
- Seasonal changes triggers the breakdown of chlorophyll and other compounds and the shutdown of

Figure 1: Seasonal changes reflect the physiology of trees.
Bright colors radiating from the foliage of many deciduous trees, such as this one in the Appalachian Mountains, light up forests in the autumn. These colors reflect the transfer of physiological information within the tree and the response of the forest to the changes in day length.
Courtesy of Randolph Femmer/NBII/life.nbii.gov.

Genetic information

- All life on Earth depends on the constant exchange and processing of information
- Cells
- Genetic information
- Nucleic acids (RNA and DNA)
- Organelles
- Structure of nucleic acids
- Genes are the functional units of genetic information and contain instructions for the

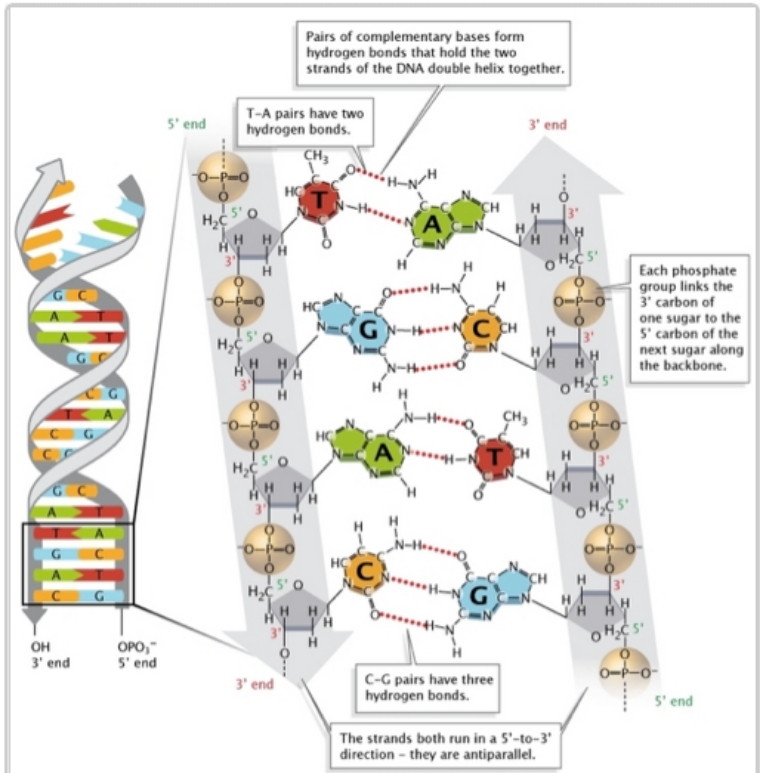


Figure 2: Structure of a DNA molecule.
DNA molecules have a double helical structure. This structure is similar to a ladder that has been twisted. The two strands of nucleotides that make up a DNA molecule each consist of a chain of alternating sugar and phosphate groups. The nitrogenous bases, which are attached to the sugar groups, project from the sugar-phosphate chain. The hydrogen bonds between base pairs, either TA or CG, form the rungs of the ladder that hold the two strands of a DNA molecule together.

The base sequence of the nucleotide strands of nucleic acids stores genetic information

- Nucleic acids are the "sentence, paragraphs and books" of biological information that encode the instructions for building and operating the immense variety of living things on Earth
- The set of instructions for each different kind of organism and every individual organism (except for identical twins and clones) is unique
- How does a molecule store and transmit so much information using a language with only three-letter words formed from four different letters?

Genetic information flows from DNA to RNA to proteins

- The central dogma of molecular biology (Francis Crick, 1958): the genetic information stored in DNA flows first to RNA and then to proteins
- Why is it important that cells accurately process genetic information?
- Human genes: 2%
- RNA: rRNA, tRNA, mRNA
- Transcription,

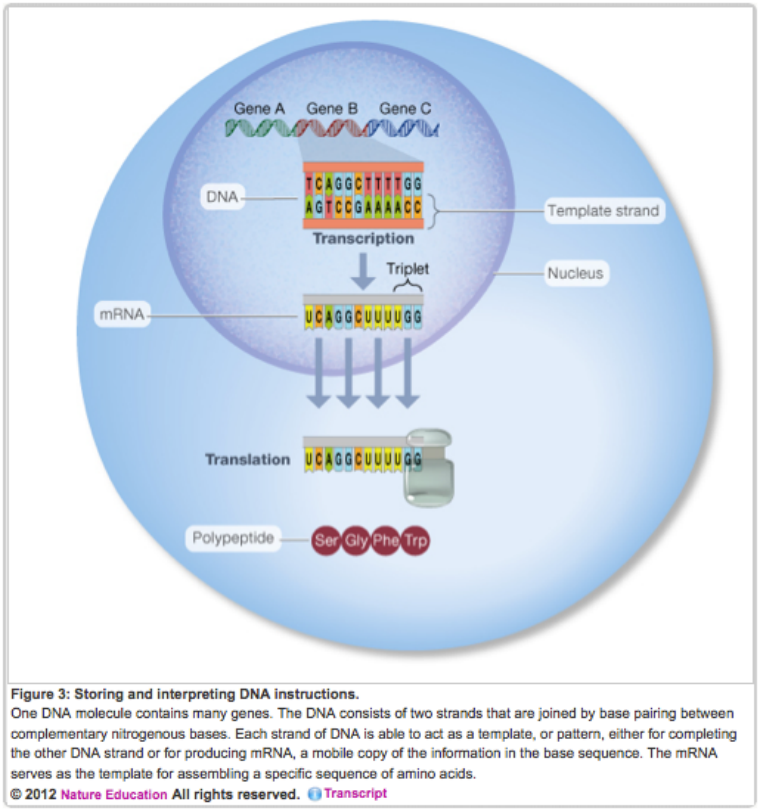


Figure 3: Storing and interpreting DNA instructions.
One DNA molecule contains many genes. The DNA consists of two strands that are joined by base pairing between complementary nitrogenous bases. Each strand of DNA is able to act as a template, or pattern, either for completing the other DNA strand or for producing mRNA, a mobile copy of the information in the base sequence. The mRNA serves as the template for assembling a specific sequence of amino acids.

Heredity of the flow of genetic information from one generation to the next

- Reproduction → transfer their genetic information to new generations, or offspring.
- Heredity or the transfer of genetic traits from one generation to the next, depends on the secure storage, accurate copying, and successful transmission of the information encoded in DNA
- Replication → mitosis or meiosis
- Mutations are any mistakes that occur during the copying of information encoded in DNA or the transfer and distribution of chromosomes to new cells (benefit or harmful, most cases neutral)
- Genetic mutations can contribute to genetic variation, and it is beneficial because it enables

Responding to information

- Living systems depends on external information
- Receive and process information from their environment (biotic and abiotic components)
- E.g., environment of a nucleic acid → the nucleus; environment of a cell → multicellular organism or a watery place
- Living systems are interconnected by the exchange of matter.

Figure 4: Earth's biological and physical systems.
When viewed from space, Earth appears to have two major types of environments: land and water. However, a closer look reveals that Earth's environment is a tapestry of interacting living and physical systems. Clockwise from the upper left, photographs show a rocky coastline forming a small cove; a savannah in Paraguay, with a line of acacia trees along the horizon; a series of green irregular polygons formed by mosses in an Arctic landscape; and a complex desert environment, with short and tall cacti and mixed vegetation.
Courtesy of Randolph Femmer/Andrea Grosse/Elizabeth A. Sellers/NBII/life.nbii.gov. Transcript

- Interaction between living systems and their environment occur at every level of biological organization

Individual organisms and their subsystems respond to interactions with each other and their environments

- What kinds of interactions occur at the molecular, cellular and organism levels of organization?
- At the molecular level → chemical reactions
- At the cellular level → cell signaling (information flows between subsystems within cells, between cells, and between cells and their environment)
- Cell signaling is a molecular process that allows cells to receive, process, transmit, and respond to information
- Cell signaling maintains mature organisms and their tissues
- In multicellular organisms, cells, organs, and organ systems constantly transfer information to maintain homeostasis, primarily through cell signaling

Groups of organisms and their members respond to interactions with each other and with their environments

- Population (mates and reproduce)
- Community (feeding relationships, e.g., competition, predation etc.)
- Ecosystem (biogeochemical cycle and energy flow)

Figure 5: A Florida mangrove swamp.
The network of mangrove roots in a mangrove swamp traps sediments and slows the runoff of pollutants, such as sewage and industrial and agricultural chemicals into the ocean. Mangrove swamps protect coral reef communities from suffocating sediments and harmful chemical substances.
Courtesy of Elizabeth A. Sellers/NBII/life.nbii.gov.

Future perspectives and open questions

- Modern biology combines the development and use of new techniques, equipment and ideas with the principles of information science
- Rely on information storage technologies, such as computers and databases, to store and analyze the complex sets of data gathered during research
- Systems biology: a multidisciplinary approach to the study of life with

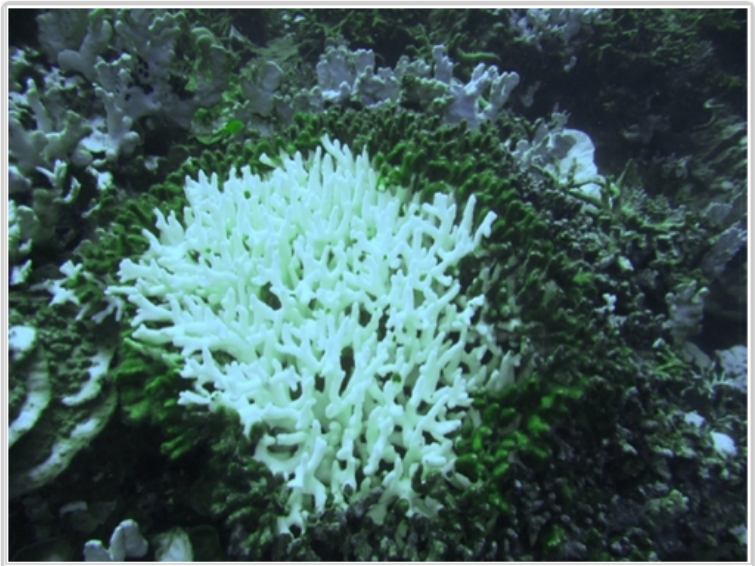


Figure 6: Coral bleaching and reef destruction.
Colorful coral reefs are healthy ecosystems, and stark white colors are usually a sign of declining health. This stag coral in Redang, Malaysia is dying, with coral bleaching emanating from the center. Increases in surface-water temperatures are a primary cause for this progressive disease in corals.

Assignments

Paper discussion: group of 3-4 students

Reading for the next lecture: Chapter 2 and 5 of
Campbell Biology 8th Edition

Quiz for next week: Chapter 2 of Campbell Biology 8th Edition