Big Biology!

(sometimes referred to as microbiology)

Big Ecology: Ecology through the Lens of History, from the Cosmos to the Methow

Class 3 of a series presented by the Methow Conservancy

February 11, 2012, Twisp, Washington

by George Wooten, Botanist

This report summarizes a slide show presentation held at the Twisp Pub in Twisp, Washington, during the winter of 2013. Big Biology! was the third class in the series of six talks. The talks were organized by the Methow Conservancy.

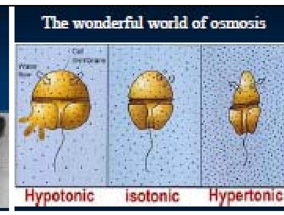
Goals of the course were:

1. To nurture an informed sense of wonder for life and the earth.
2. To tell the story of evolution in a way that offers a useful context for humans in the larger community of life.
3. To foster an ecological understanding of how life works.
4. To have fun.

Goals of the Biology lecture were:

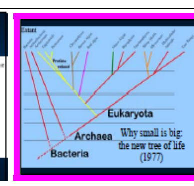
1. Basics - to review basic ecological principles of energy and nutrient flows.
2. Evolution - to discuss how the number and nature of species evolve over time.
3. Emergence - to describe how life is always creating something new.
4. Ecology - to understand how relationships between organisms and resources affect our lives.

Spotted Lake near Osoyoos contains magnesium sulphate (Epsom salt) that crystallize in circular patterns during cycles of evaporation (image from GoogleEarth). The lake lies in the Okanogan dolomites, laid down near the Permian-Triassic extinction event of 250 million years ago. These sediments continue south to Omak, where they contribute to the character of the Poison Lakes, including Hot Lake, a polymictic lake that reaches 150 degrees in the summer. Because of the salt concentrations, organisms living in Spotted Lake must tolerate extreme osmotic pressure. Numerous ceremonial cairns testify to long use as a healing area by natives. The lake contains 365 circular spots that provide enlightenment for each day of the year (Okanogan Nation Alliance).

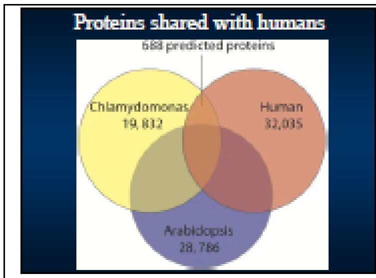


Halophiles have behavior based on positive and negative feedback. (Top) *Nodularia spumigena* (Cyanobacteria) collected by Alan Butler, of Orkney, Scotland. Cyanobacteria may be the most ubiquitous organisms on earth. (Bottom) *Halobacterium salinarum* (Archaea) uses photosynthesis for energy, using the pigment, bacteriorhodopsin, related to retinal pigments in humans. The whip-like flagella motors rotate continuously, occasionally switching into reverse, to seek food, light and nutrients. Image from Max Planck Institute of Biochemistry: www.biochem.mpg.de/en/eg/oesterhelt/web_page_list/Org_Hasal/

Watermelon snow (*Chlamydomonas nivalis*; snow algae) uses positive and negative feedback to modify its environment on Lyall glacier in the Washington Cascades. In the spring, snow algae use their flagella to swim toward daylight. At the surface, they lose their flagella and color themselves with carotenoid pigments for protection from intense sunlight. This in turn hastens the melting of ice into small pools where the algae can live and mate. Snow algae feed on detritus from wind-blown pollen and leachates from nearby vegetation. Blooms of snow algae are grazed by protozoans, ciliates, rotifers, nematodes, snow worms and springtails. These in turn are consumed by mites, spiders, insects and birds.

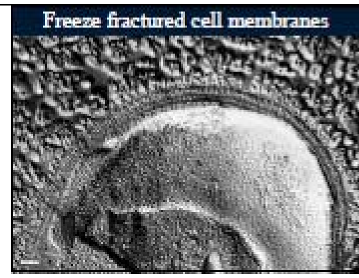


No last universal common ancestor (LUCA) of life is known. Although this classification has general acceptance, disagreements continue about the rank of the domains and about the LUCA. It is now generally agreed that many of the most primitive forms are polyphyletic, i.e., having multiple species as ancestors, confounding classification.

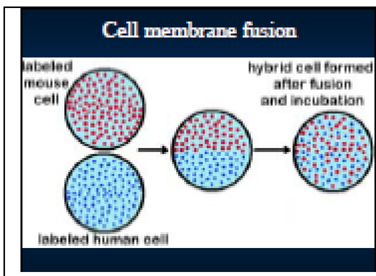


We have some of the same proteins found in plants and green algae. Originally classifications used only the differences between organisms to classify them. Newer methods use DNA and a technique called cladistics to classify by similarities of the gene products.

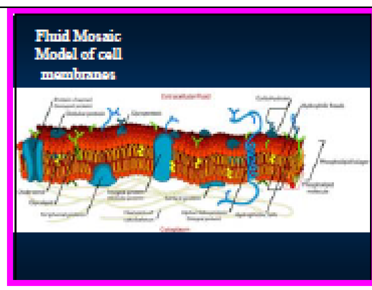
Euglena and Chlamydomonas. Eyespots and dual flagella are visible in both species.



Electron micrograph of freeze-fractured cell wall of *Synechocystis aquatilis* (Cyanobacteria). Several transmembrane proteins are visible. The thick ridge on the exterior (top) part of the cell are arrays of semi-crystalline proteins involved in the formation of stromatolites. Šmardaa, Jan; David Šmajsa; Jir Komrskab, Vladislav Krzyžánekb (2002) S-layers on cell walls of cyanobacteria. Micron, Volume 33, Issue 3, January 2002, Pages 257–277. See: http://www.sciencedirect.com/science/article/pii/S0968432801000312



Frye and Edidin demonstrated rapid intermixing of cell surface antigens after formation of mouse-human heterokaryons. (1970, J. Cell. Sci. 7, 319-335).



Fluid Mosaic Model of cell membrane organization. The cell membrane is a semipermeable lipid bilayer common to all living cells. Note that the Archaea have a use a different hydrophilic tail structure, but are built on the same principle. Image from Wikimedia Commons. See: http://en.wikipedia.org/wiki/Cell_membrane

Amoeba proteus pseudopods about to engulf the small green algae desmid, *Staurastrum*. Microphotograph by Wim van Egmond. See: http://www.microscopy-uk.org.uk/ and http://www.micropolitan.org/

An amoeba with diatoms outside and inside. See: http://blogs.scientificamerican.com/ocelloid

Amoeba with consumed green and blue-green algae. Image used with permission of Arturo Agostino See: http://www.microscopeitaly.it/

Cells of Petunia leaves (left) were merged with a protoplast from *Impatiens neuguinea* petals (right). The resulting hybrid has the chromosomes of both plants. Uses of somatic fusion include making potato plants resistant to potato leaf roll disease. This file is licensed under the Creative Commons Attribution-Share Alike 3.0.

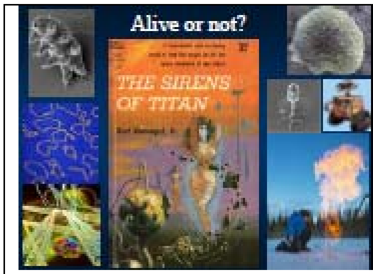
Can we generalize from bacteria to animals?

Working Definitions

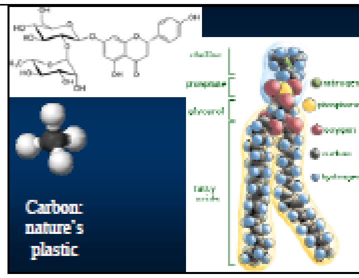
1. **An organism is any contiguous living system capable of the following functions**:

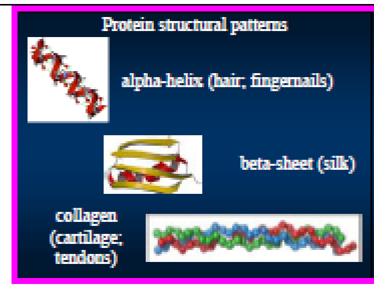
- Organization
- Metabolism (use of energy for consumption, processing, excretion)
- Response to stimuli
- Homeostasis (maintenance of a stable internal environment)
- Growth
- Reproduction
- Adaptation (maintenance and evolution of beneficial traits)

2. **In ecology, a community refers to a group of organisms in a specific place or time**.

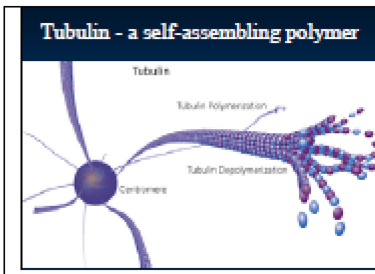


The bottom left photo is a 2009 file photo from the US effort to reduce methane and soot. The researcher has ignited methane trapped under a pond's ice cap in Alaska.

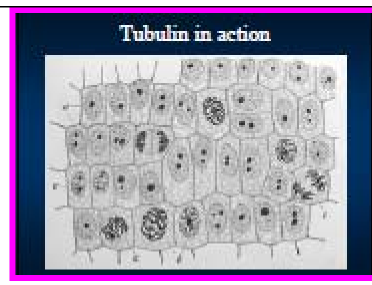




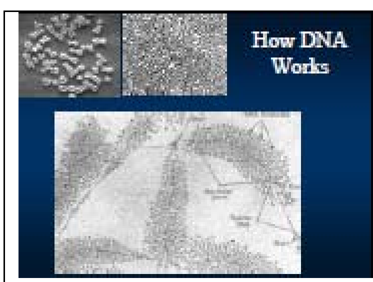
Most enzymes are proteins, but proteins can also provide structural functions.



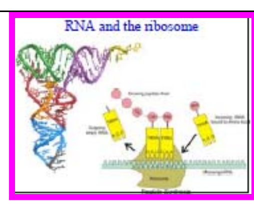
Tubulins are required for the spindles which form in mitosis and meiosis. They are also used for transport along axons, for cilia and flagella, and for the correct localization of organelles. Taxol, derived from yew trees, prevents a cell from dividing by binding to tubulin and causing the protein to lose its flexibility. The homology of tubulin to the bacterial replication and cytoskeletal protein FtsZ is a major argument against Lyn Margulis' theory of endosymbiont origin of flagella from ingestion of a spirochaete ancestor, as FtsZ is apparently found natively in Archaea, providing an endogenous ancestor to tubulin. Image from: http://www.sigmaaldrich.com/china-mainland/zh/life-science/metabolomics/enzyme-explorer/learning-center/structural-proteins/tubulin.html



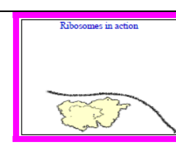
Cells in the growing root-tip of an onion, from a longitudinal section, enlarged 800 diameters. a. non-dividing cells, with chromatin-network and deeply stained nucleoli; b. nuclei preparing for division (spireme-stage); c. dividing cells showing mitotic figures; e. pair of daughter-cells shortly after division. Figure 2 of: Wilson, Edmund B. (1900) The cell in Development and Inheritance (second edition ed.), New York: The Macmillan Company. This image is in the public domain because the copyright is expired.



Clockwise from the top (Chromosomes, DNA, DNR being transcribed to mRNA).



Expression is the manufacture of a gene product. It involves 3 steps: replication, transcription and translation. (Left) X-ray structure of the tRNAPhe from yeast. (Right) Illustration of tRNA building peptide chain (illustrations from Wikimedia Commons).



A ribosome translating a protein that is secreted into the endoplasmic reticulum. (Moving GIF image from Wikimedia Commons). This process must work correctly for all the gene products of an organism. E. coli has 5,000 genes. The simplest known RNA virus contains 3 genes in about 300 base pairs.

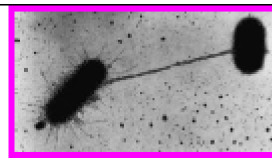
What was the last universal common ancestor (LUCA) of the three domains of life? The RNA World hypothesis states that RNA metabolism came before protein. The Protein World hypothesis states that proteins came first and later developed a genetic code based on RNA or DNA. The Iron–Sulfur world theory proposes that life originated on the surface of iron sulfide minerals in a volcanic hydrothermal flow at high pressure and high temperature. This theory holds that these structures could catalyze ever more complex organic compounds.

The Genetic Annealing Model proposes that there was no LUCA and that prior to the emergence of organisms, proto-organisms existed with a low levels of complexity, high mutation rates, and greater ability to exchange genes.

Featured Finest Images from Wikipedia: Aerial view of Grand Prismatic Spring; Yellowstone National Park. The spring is 300 feet wide at the widest. This photo shows steam rising from hot, sterile azure blue water, while on the margins, the vivid colors are the result of pigmented bacteria in microbial mats. The mats are colored from green to red, depending on the ratio of chlorophyll to carotenoids and on the temperature of the water which favors one bacterium over another.

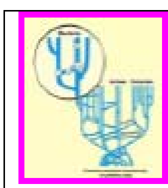
Molecular evolution across rugged Fitness Landscapes
Fitness landscapes are often conceived of as ranges of mountains, but they may also be likened to the likelihood of discovering hospitable islands while randomly floating across the ocean in a small boat. An evolving population typically climbs uphill in the fitness landscape through a series of small genetic changes, until a local optimum is reached.
“A universal common ancestor [of Eucaryotes, Bacteria and Archaea] is at least 10^{2860} times more probable than having multiple ancestors” - Hesman Saey, T. (14 May 2010). "All Modern Life on Earth Derived from Common Ancestor". Discovery News.

But this large number does not explain the obvious: How did life become so miraculously complex in less than a billion years, when evolution over the following 3 billion years did not make any of these spectacular leaps across vast and rugged fitness landscapes?



Bacterial conjugation involves transfer of part of the genome via a snippet of DNA called the F-Plasmid. The donor is called the F+ cell and the recipient is the F- cell. Transfer is initated when the F+ contacts the F- using a tube called the pilus. If conjugation is interrupted by a physical disturbance, the transfer may be incomplete and only the first parts of the gene sequences will become incorporated into the F- microbe. The first genes that get transferred are those that prepare for the transfer (relaxase) followed by protective genes, such as those for antibiotic resistance. Destructive genes may also be transferred. One of the last genes to be transferred is the gene for the F+ pilus itself, so that the recipient and donor change “sex” if the gene transfer goes that far. This illustrates the property of operons, or genes that must be expressed sequentially in order to function.

The nitrogen fixing bacteria and crown gall bacteria are capable of transferring genes to plant cells, genetically re-engineering the plant cells to produce proteins that only the bacteria can eat.



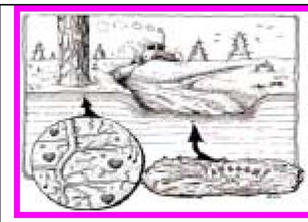
In 1977, Carl Woese (1928 – December 30, 2012) and George Fox overturned a universally held assumption about the basic structure of the tree of life. They showed that the Archaea are as distinct from bacteria as plants and animals. He wrote, “The further back in evolutionary time we look, the more the notion of an “organismal lineage”—indeed, the very definition of “organism” itself—comes into question. It is time to release this notion of organismal lineages altogether and see where that leaves us.”

Woese was the originator of the RNA world hypothesis. In developing the Genetic Annealing Model, Woese moved away from strict adherence to his RNA World theory to suggest that primordial life arose in an era of rapid evolution, while still allowing for horizontal gene transfer between organisms. Primordial organisms exhibited a far lower level of complexity due to an error-prone translation apparatus that produced high mutation rates and limited genome size.

Gene transfer from a parasitic flowering plant to a fern. Complex positive and negative feedback mechanisms are moderated in the mistletoe-Douglas fir-fern-fungus guild. Image of rattlesnake fern (*Botrychium virginianum*), by George Wooten

The moral of the story
* A community is a group of organisms
* There is no agreement on the definition of life, nor on the origin of life.
* Organisms are built from reusable protein subunits
* Biofeedback drives coevolution
* A community that shares resources can better survive tough times

Carl Woese wrote, "the ancestor cannot have been a particular organism, a single organismal lineage. It was communal, a loosely knit, diverse conglomeration of primitive cells that evolved as a unit, and it eventually developed to a stage where it broke into several distinct communities, which in their turn became the three primary lines of descent (bacteria, archaea and eukaryotes)". (Image from: The lion and the mouse from Aunt Louisa's Oft Told Tales, New York, 1870s; public domain; copyright expired).



Fungi communicate with trees via a vast underground communication network.

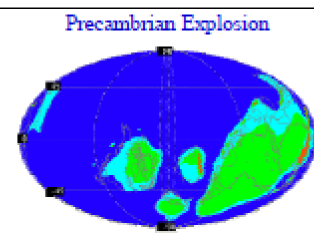
Fungi share sugar made by the their hosts in exchange for providing nutrients that allow the host seeds to germinate. When the host tree begins to die, other fungi become pathogenic and consume the entire tree. (Image by Jack Holden, Geologist, Omak, Washington)

Giant ichneumon wasps have long ovipositors that can penetrate several inches into logs to reach a suitable food source for the larvae that eventually hatch. Giant ichneumon wasps are familiar to firefighters, because the wasps are attracted for miles by the chemical "smell" of fried larvae. They will lay their eggs in the logs even while the logs are still burning. (Photo by George Wooten).

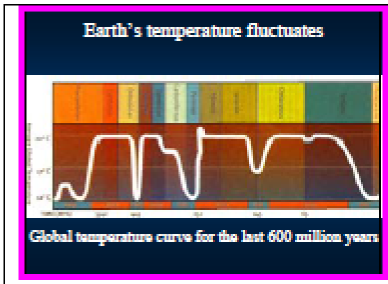
Beaver and aspen have coevolved to produce the right amount of lignins and tannins that will function positively as structural materials and food, while acting negatively to prevent the beavers from eating all the young aspen. (Photo by George Wooten).

Deer depend on bitterbrush for winter survival food. The tannins are not enough to stop the starving deer, but the plant protects itself by sprouting leaves under the snow where they are protected by the deer. (Photo by Gary Ott, Twisp, Washington).

The beetle carries the blue stain fungi in tiny petri dishes evolved on their shells. The beetle follows the stress chemicals released by dying trees. The first beetle to arrive burrows into the tree and raises her wings to inoculate the cambium. The tree responds by drowning her in sap. But there is not enough sap, the fungus will grow and stop the flow of sap, so that the next beetle can make it further and lay her eggs in a sap-free environment. Image from: Major Root Diseases And Their Insect Associates In Trees Of The Inland Northwest, by Drs. Arthur D. Partridge and Catherine L. Bertagnolli.



The Precambrian explosion of 530 million years was marked by the rapid appearance of most major animal phyla we know today. Explanations include environmental, developmental, and ecological changes. The map shows North America (left) and Siberia (middle) surrounded by tropical reefs, what is now called Scandinavia to the south and the rest of the continents joined together in the super continent Gondwana (right).



One of the environmental scenarios for the cause of the Cambrian Explosion holds that the Cambrian world emerged from a 300 million-years-long ice age called "snowball earth". During the ice age, warm water species were suppressed by ice caps extending to the equator, lowered sea level, and lowered oxygen levels, all reinforced by broad-scale ocean circulation patterns and high albedo that prevented light energy from being absorbed.

The ice age ended following large-scale release of CO_2 from volcanoes and extremophile bacteria. When the temperature rose, the ice melted. The ocean chemistry changed due to greater weathering of continental rocks, raising the level of dissolved ions like carbonate which forced ocean creatures to adapt. There was a temperature spike likely caused by the rapid release of the greenhouse gas methane clathrate. Eventually the temperature stabilized, but cycles of ice ages and rapid thawing were to come again, including one at the Permian-Triassic boundary that wiped out 90% of life. Image from Are We Becoming Dinosaurs, by Paleontologist David Trexler.

Methane ice worms living on methane clathrate at the bottom of the ocean. The worms are grazing on chemosynthetic bacteria that are consuming methane hydrate. Photo from NOAA Ocean Explorer. There is 3 times as much methane clathrate as there are oil and coal reserves on earth. As long as the ocean temperature remains cool, the methane will remain frozen on the bottom.