Virtual University

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BT201 Ecology, Biodiversity & Evolution-II

MSC ZOOLOGY

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MSC ZOOLOGY 4TH SEMESTER

1 Ecological Genomics Introduction, Bioinformatics

Biology and Informational Science

- The HGP changed how we view & practice biology.
- Biology is an informational science.
  - ✓ Digital genome
  - ✓ Environmental signals
- Biology has become a cross-disciplinary science.

Bioinformatics and intersecting discipline

- Mathematical sciences
- Computer science
- Life sciences

Developing the high throughput technologies and computational/mathematical tools required for this new biology

Why? Where? What? How?

Why: Ideas for what to produce these huge datasets? Biological background needed.

Where: Raw data need to store, IT platforms required.

What: Patterns in datasets that can be analyzed using computers. Various data models and their respective algorithms are needed.

How: Different resources need to be integrated.

What is Bioinformatics?

The field of biology specializing in developing *hardware* and *software* to store and analyze the huge amounts of data being generated by life scientists. (NIH). More than 20 different definitions can be found from Google!

Computational Biology?

Computational Molecular Biology?

Data integration

Various molecular biology databases

Bioinformatics applications

Data analysis

Key Challenge of Bioinformatics

The world of biology is very different from what it was even ten years ago. To bridge the considerable gap between technical data production and its use by scientists for biological discovery.

2 Gene discovery

(Genome analysis)

Gene Discovery

In a fully sequenced genome, genes are found by scanning the sequence using gene-predicting computer programmes and assigning putative functions by searching for similarities in already existing databases. For many organisms under investigation in ecological genomics, no genomic database is available and genes must be identified in other ways. There are some so-called pregenomic molecular approaches that may be used to identify ecologically important genes in incompletely characterized genomes.

From gene product to gene

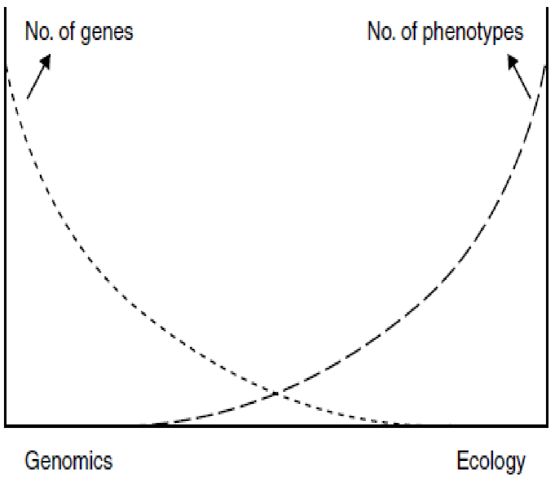
In some cases the primary structure of a gene product (a protein) may be the starting point of gene discovery. This holds especially for proteins that can be isolated relatively easily by some marker or bioassay, or proteins that are highly induced by some experimental treatment. As an example we discuss the isolation of the metal-lothionein (mt) gene in a species of springtail, orchesella sancta (hens Bergen et al. 1999). Attempts to pick up the gene by polymerase chain reaction (PCR) using primers from the then-known drosophila mt sequence remained unsuccessful.

3 Genomics Revolution Invading Ecology

- the suffix -ome :the collectivity of units (Lederberg and McCray 2001),
- example in coelome, the system of body cavities,
- biome, the entire community of plants and animals in a climatic region.
- In aiming to investigate many genes at the same time genomics differs from ecology, which although investigating many phenotypes, usually deals with only a few genes at a time.

The playing field of ecological genomics

In between genomics, with its focus on the single genome of a model organism, studying all the genes that it contains, and ecology, studying a few genes in many species.



The interactions between the genes within the genome and the dynamic character of the genome

sketched by Dover (1999) as an internal tangled bank.

 idea of Darwin (1859)

 Dover (1999 :

- 'external tangled bank' (the ecology)
- the 'internal tangled bank' (the genome)

The internal tangled bank

- It emphasizes the role of genetic turbulence (gene duplication, genetic sweeps, exon shuffling, transposition, etc.)
- illustrates that there is ample scope for 'innovation from within genetic turbulence

The genomics revolution

Three major technological developments of 1990s

- microtechnology
- computing
- communication.

Microecology. The possibility of working with molecules on the scale of a few micrometers, given by advances in laser technology, has been very important for one of genomics' most conspicuous achievements, the development of the gene chip.

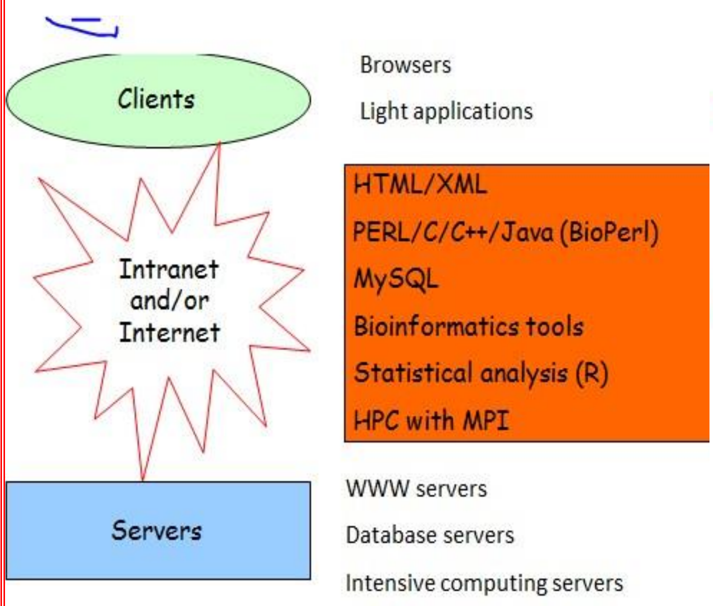
Three major technological developments

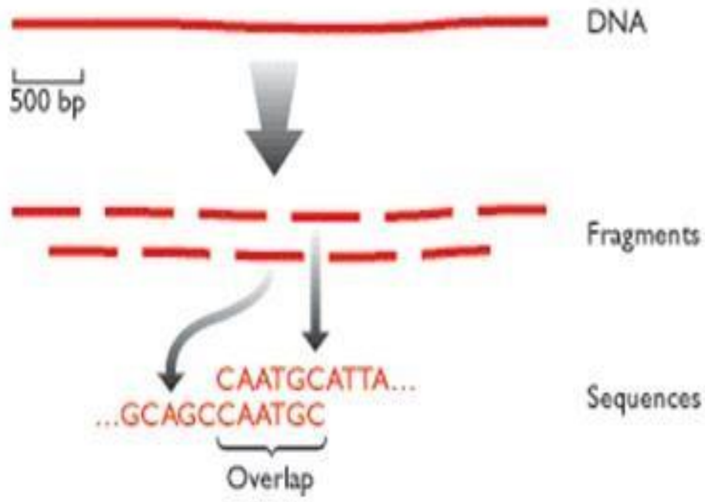
Computing technology

To assemble a genome from a series of sequences requires tremendous computational power. Extensive calculations are also necessary for the analysis of expression matrices and protein databases. Without the advent of high-speed computers and data-storage systems of vast capacity all this would have been impossible. Consulting genome databases all over the world has become such normal practice that the scientific progress of any genomics laboratory has become completely dependent on communication with the rest of the World Wide Web. The Internet has become an indispensable part of genomics. The essence of genomics is that it is the study of the genome and its products as a unitary whole.

4 Schematic platform for Bioinformatics

Sequence assembly by the shotgun approach





- Master sequence 🡐 short sequences, simply by examining the sequences for overlaps.
- No need any prior knowledge of the genome.

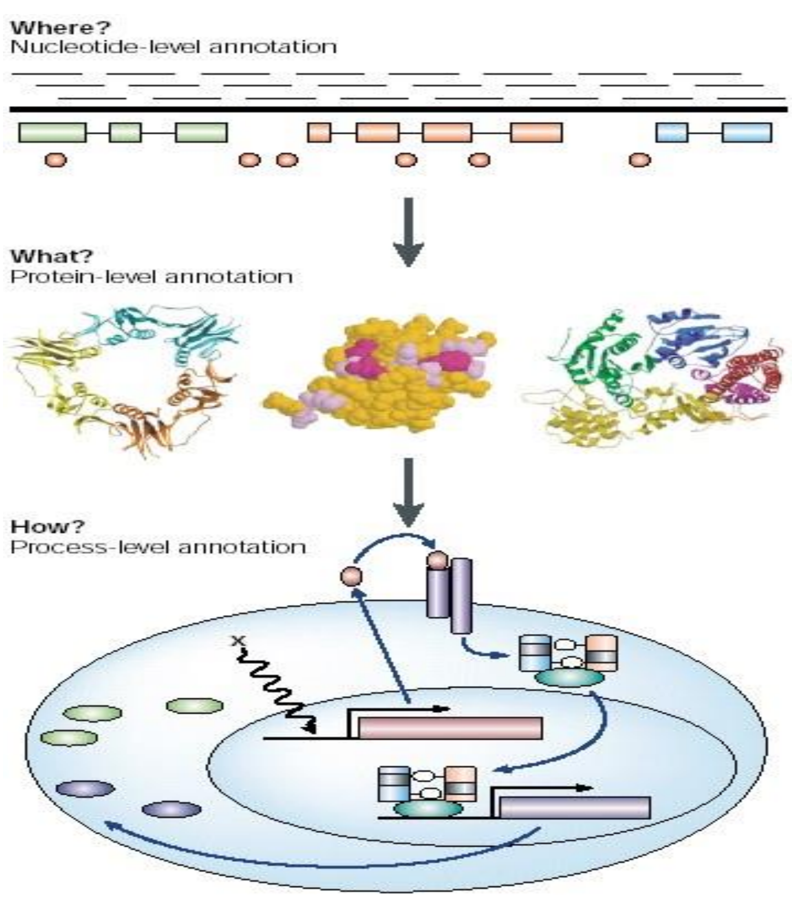
What is Gene?

CGGTTGAAAGCGGTAGCGTCCATGCGTATTACTCTTGAGCGGTCGAACCTTCTGAAATCGCT

GAACCACGTCCACCGGGTCGTCGAGCGTCGCAACACGATCCCGATCCTGTCCAACGTTCTGC

....ACTGAATTTTCTCA
GTTACGACATTTTGCCTTGTTTTTGCGCCAAATGGGATCAACAGTACGTAACAATTTTTTGAC

AATGACCAATACATCCGAGGGGAATCATGGCACTCAACCTGAAGCAACGGCTT



1. **Transcriptional control sites**
2. **Non-coding RNAs**
3. **mRNAs**

Evidence-based prediction

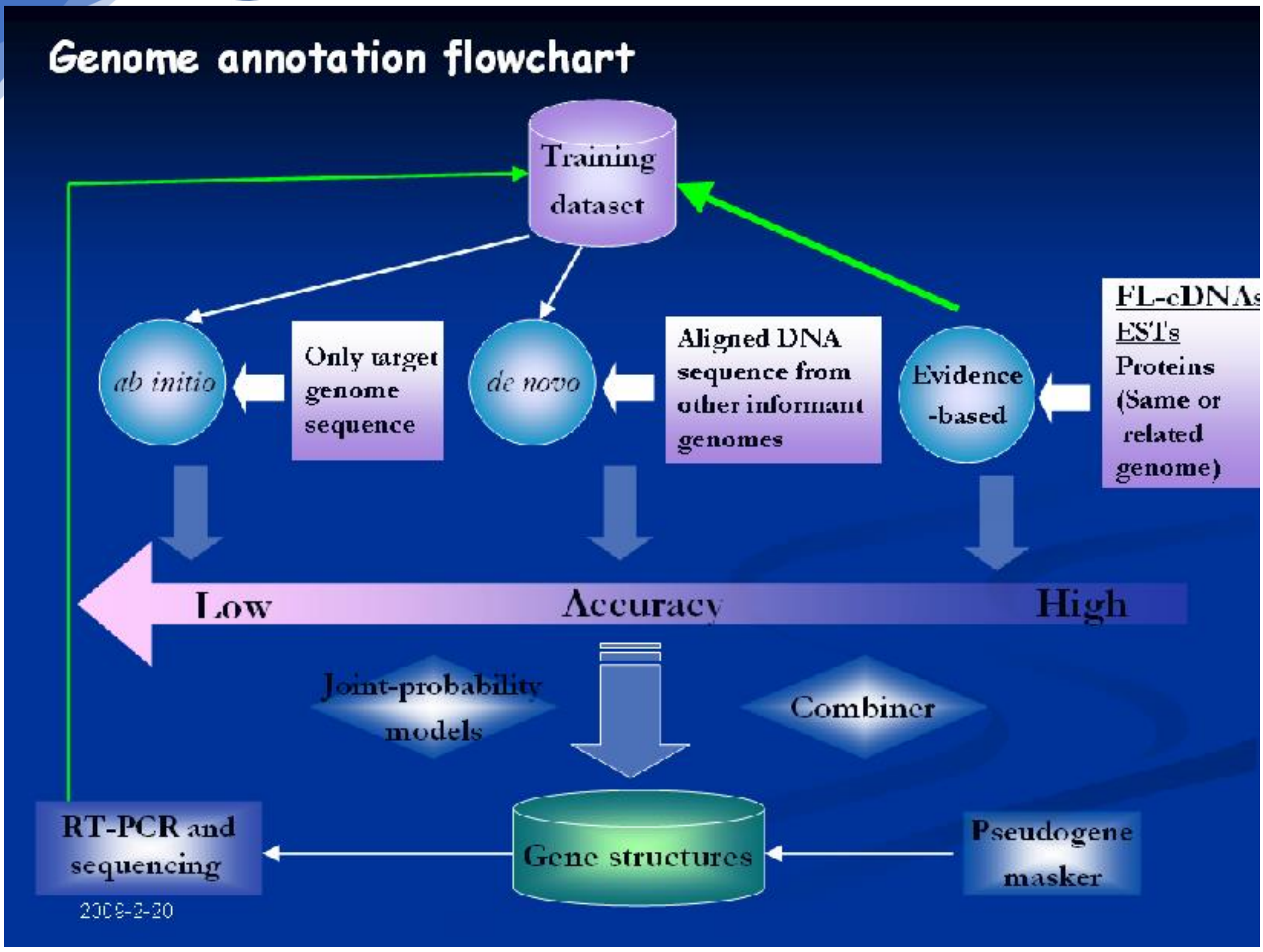
- Cis-alignment
- Trans-alignment
- *Ab initio / de novo* prediction

Three Layers of Genome Annotation.

From Stein, L. 2001. Nature
Reviews genetics 2:493-503

Some models

- Dynamic programming
- Hidden Markov Models (HMMs)
- Conditional random field (CRF)
- Support vector machines (SVMs)



5 Phylogenetics

Evolutionary theory states that groups of similar organisms are descended from a common ancestor. Phylogenetic systematics (cladistics) is a method of taxonomic classification based on their evolutionary history. It was developed by Willi Hennig, a German entomologist, in 1950.

Major reasons to use phylogenetics

1. **Understand the lineage of different species:** Organizing principle to sort species into a taxonomy
2. **Understand how various functions evolved:** Understand forces and constraints on evolution
3. **Perform multiple sequence alignment**
4. **Predict gene function (phylogenetic footprint)**

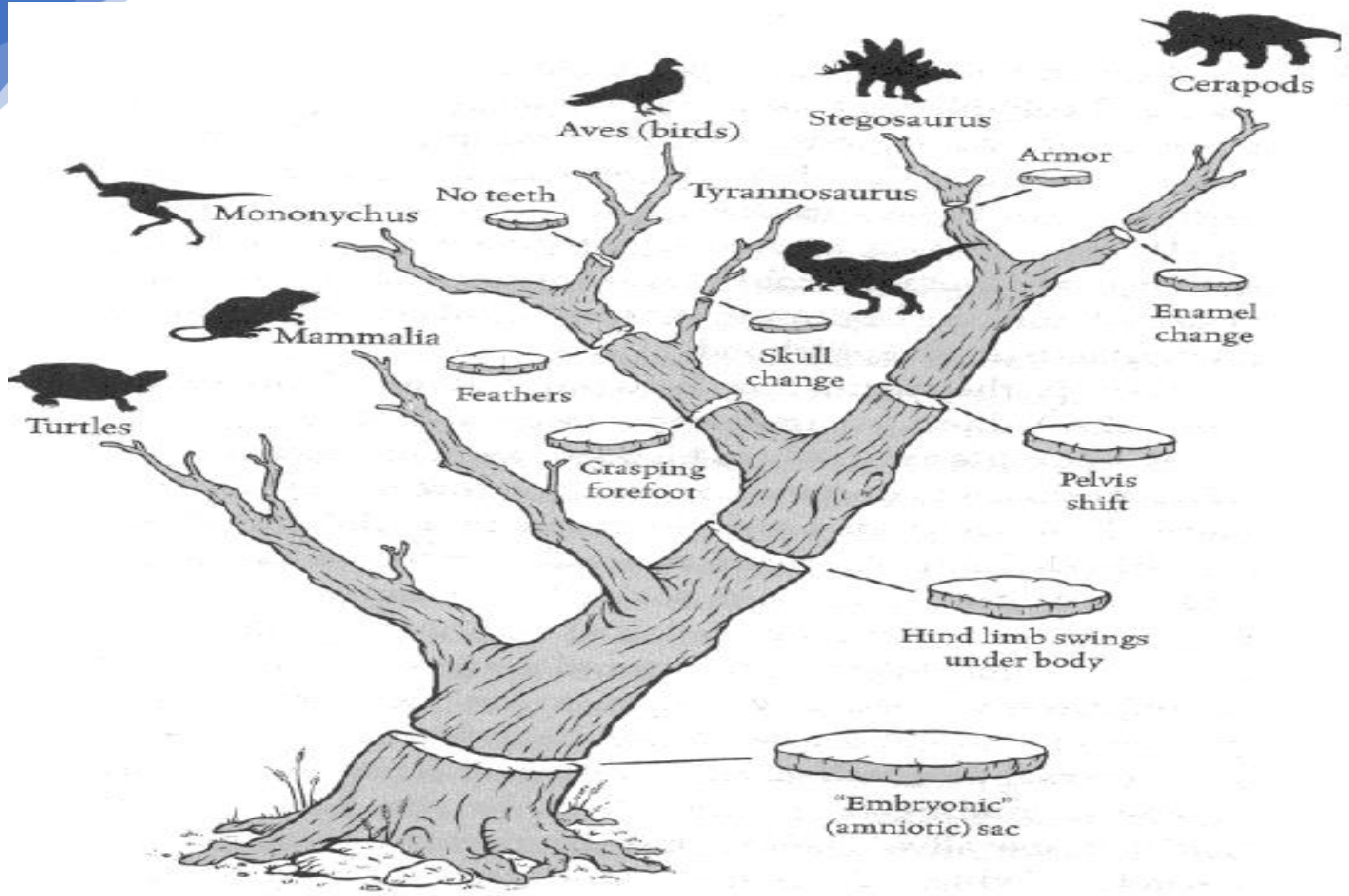
Species/Gene Trees

Species tree (how are my species related?)

- contains only one representative from each species
- when did speciation take place?
- all nodes indicate speciation events

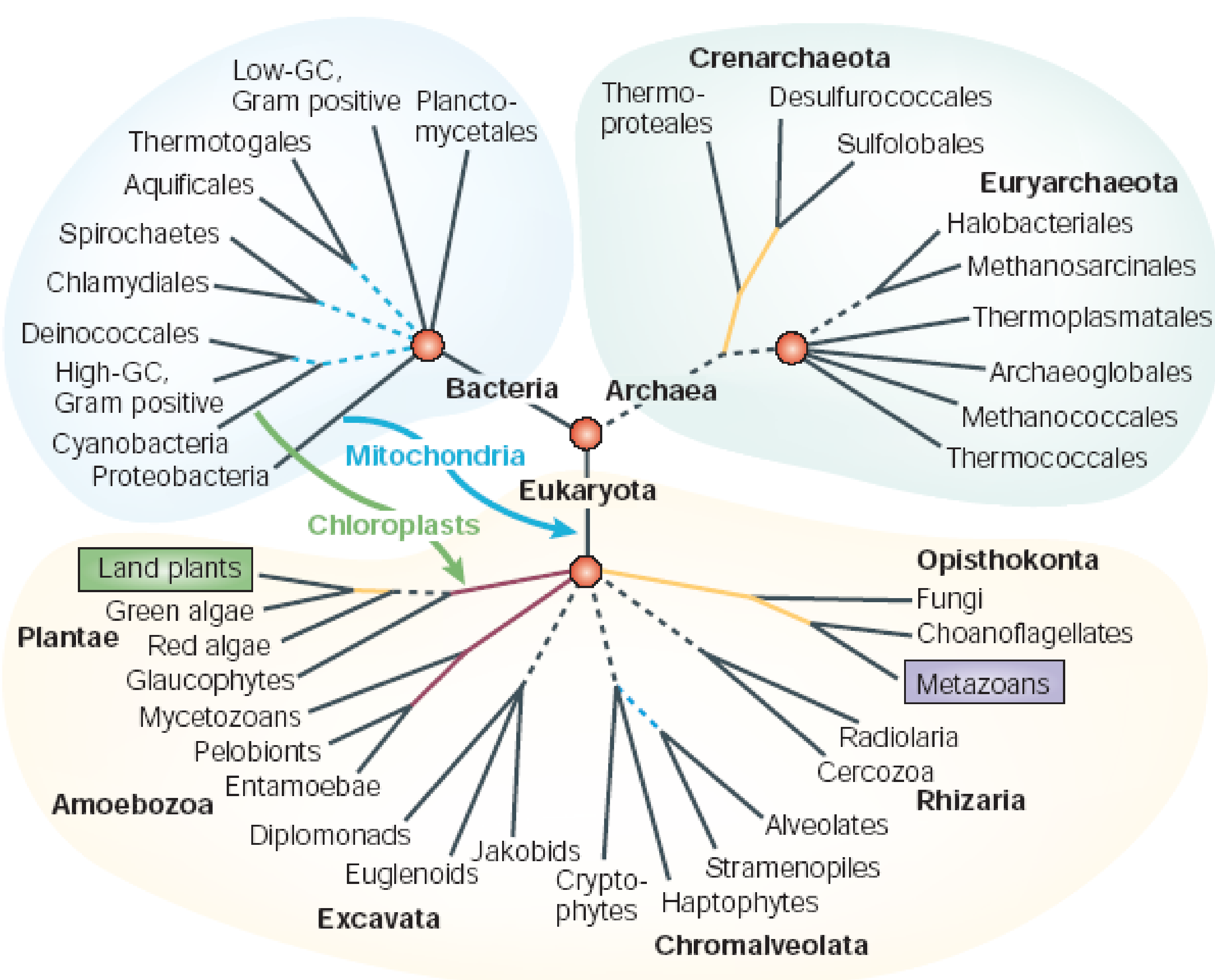
Gene tree (how are my genes related?)

- often contains a number of genes from a single species.
- nodes relate either to speciation or gene duplication events.



Phylogenomics: Genome trees

Explore genome evolution based on large data sets of DNA or protein sequences. Using entire genomes to infer a species tree (Eisen and Fraser 2003). Based on maximum genetic information and average out the anomalies. Has become the standard for reconstructing reliable phylogenies (Ciccarelli et al, 2006; Daubin et al. 2002).



6 Yeast, fly, worm, and weed Part 2

The international Human Genome Project

- The international human genome project initiated by the US national institutes of health and the US department of energy, was launched in 1990 with completion due in 2005. However, in the meantime a private enterprise, Celera genomics, embarked on a project with the same aim but a different approach and actually overtook the human genome project. The competition was settled with the historic press conference on 26 June 2000, when US president Bill Clinton, J. Craig venter of Celera genomics, and Francis Collins of the national institutes of health jointly announced that a working draft of the human genome had been completed.
- Many commentators have qualified this announcement as more a matter of public communication than scientific achievement.
- At that time the accepted criterion for completion of a genome sequence, namely that only a few gaps or gaps of known size remained to be sequenced and that the error rate was below 1 in 10 000 bp, had not been met by far. The euchromatin part of the genome was not completed until mid-2004, although that milestone was again considered by some to be only the end of the beginning (stein 2004). Nevertheless, the human genome project can be regarded as one of the most successful scientific endeavours in history and the assembly of the 3.12 billion bp of DNA, requiring some 500 million trillion sequence comparisons, was the most extensive computation that had ever been undertaken in biology.
- The number of organisms whose genome has been sequenced completely and published is now approaching 300
- Bacteria dominate the list, as the small size of their genomes makes these organisms well-suited for whole-genome sequen-cing.
- By june 2005, no fewer than 730 prokaryotic organisms and 496 eukaryotes were the subject of ongoing genome sequencing projects.

List of complete and published genomes (not including viruses) by June 2005

Taxonomic group	No. of genomes	Remarks on species
Bacteria total	211	Many common laboratory models and pathogens
Archaea total	21	Several methanogens and extremophiles
Eukarya*		
Myxomycota	1	Dictyostelium discoideum (slime mould)
Entamoeba	1	Entamoeba histolytica (amoeba causing dysentery)
Apicomplexa	6	Four Plasmodium and two Microsporidium species

Taxonomic group	No. of genomes	Remarks on species
Kinetoplastida	2	Trypanosoma brucei, Leishmania tropica (parasites)
Cryptomonadina	1	Guillardia theta (flagellated unicellular alga)
Bacillariophyta	1	Thalassiosira pseudonana (marine diatom)
Rhodophyta	1	Cyanidioschyzon merolae (small unicellular red alga)
Plants	4	Chlamydomonas reinhardtii (green alga), Populus trichocarpa
		(black cottonwood), Arabidopsis thaliana (thale cress),
		Oryza sativa var. japponica, var. indica (rice)

Taxonomic group	No. of genomes	Remarks on species
Fungi	14	Including Saccharomyces cerevisiae (baker's yeast)
Animals		
Nematoda	2	Caenorhabditis elegans (free-living roundworm), Caenorhabditis briggsae
Insecta	4	Bombyx mori (silk worm), Drosophila melanogaster (fruit fly),
		Anopheles gambiae (mosquito, malaria vector), Apis mellifera (honey bee)
Tunicata	1	Ciona intestinalis (sea squirt)

Taxonomic group	No. of genomes	Remarks on species
Pisces	3	Takifugu rubripes (puffer or fugu fish), Tetraodon nigroviridis (puffer fish),
		Danio rerio (zebrafish)
Aves	1	Gallus gallus (red jungle fowl)
Mammalia	5	Rattus norvegicus (brown rat), Mus musculus (house mouse),
		Canis familiaris (domestic dog), Pan troglodytes (chimpanzee),
		Homo sapiens (human)
Animals: total	16	
Eukarya: total	47	
Total	279	

7 Yeast, fly, worm, and weed Part 3

Previously established reputation

Yeast, C. Elegans, drosophila, mouse, and rat.

species had already proven their usefulness as models before the genomics revolution and were adopted by genomicists because so much was known about their genetics and biochemistry, and, perhaps just as important, because a large research community was interested, could support the work, and use the results

Genome size

- One of the first questions that is asked when a species is considered for whole-genome sequencing is,
    - what is the size of its genome?
- A relatively small genome was a major advantage for a sequencing project.
- The genome size of living organisms ranges across nine orders of magnitude, from 103 bp (0.001 mbp) in RNA viruses to nearly 1012 bp (1 000 000 mbp) in some protists, ferns, and amphibians.
- The puffer fish, takifugu rubripes, was indeed chosen because of its relatively small genome (one-eighth of the human genome).

Possibility for genetic manipulation

- The possibility of genetic manipulation was an important reason why Arabidopsis, Drosophila, and mouse became such popular genomic models. The ultimate answer about the function of a gene comes from studies in which the genome segment is
  - ✓ knocked out,
  - ✓ downregulated, or
  - ✓ overexpressed
- against a genetic background that is the same as that of the wild type.
- the introduction of constructs in the genome that can report activity of certain genes by means of signal molecules is very important. This can only be done if the species is accessible using recombinant- DNA techniques.

Medical or agricultural significance

- Many bacteria and parasitic protists were chosen because of their pathogenicity to humans
- Other bacteria and fungi were taken as genomic models because of their potential to cause plant diseases (phytopathogenicity).
- The sequencing of rice was motivated by the huge importance of this species as a staple food for the world population (adam 2000).
- Some agriculturally important species have great relevance for ecological questions; for example, the bacterium sinorhizobium meliloti, a symbiont of leguminous plants, is known for its nitrogen-fixing capacities, but it also makes an excellent model system for the analysis of ecological interactions in nutrient cycling, together with its host medicago truncatula.

Possibility for genetic manipulation

- Foreign DNA can be introduced using transposons; for example, modified p-elements that can ‘jump’ into the DNA of drosophila, or bacteria such as agrobacterium tumefaciens that can transfer a piece of DNA to a host plant. DNA can also be introduced by physical means, especially in cell cultures, using electroporation, microinjection, or bombardment with gold particles. Another popular approach is post-transcriptional gene silencing using RNA interference (rnai), also called inhibitory RNA expression.
- The question can be asked, should the possibility for genetic manipulation be an argument for selecting model species in ecological genomics? We think that it should, knowing that the capacity to generate mutants and transgenes of ecologically relevant species is crucial for confirming the function of genes. Ecologists should also use the natural variation in ecologically relevant traits to guide their explorations of the genome (koornneef 2004, tonsor et al. 2005). A basic resource for genome investigation can be obtained by using natural varieties of the study species, and developing genetically defined culture stocks

8 Yeast, fly, worm, and weed Part 4

Biotechnological significance.

- Many bacteria and fungi are important as producers of valuable products,
- **for example**
  - ✓ antibiotics,
  - ✓ medicines,
  - ✓ vitamins,
  - ✓ soy sauce,
  - ✓ cheese,
  - ✓ yoghurt,
  - ✓ and other foods made from milk.
- There is considerable interest in analyzing the genomes of these (pu¨hler and selbitschka 2003).
- Other bacteria are valuable genomic models because of their capacity to degrade environmental pollutants;
- **For example,**
  - the marine bacterium **Alcanivorax borkumensis** is a genomic model because it produces surfactants and is associated with the biodegradation of hydrocarbons in oil spills (ro¨ling et al. 2004).

Evolutionary position

- Whole-genome analysis of organisms at crucial or disputed positions in the tree of life can be expected to contribute significantly to our knowledge of evolution.
- The sea squirt, **ci. Intestinalis**, was chosen as a model because it belongs to a group, the Urochordata, with properties similar to the ancestors of vertebrates.
- The study of this species should provide valuable information about the early evolution of the phylum to which we belong ourselves.
- Many other organisms, although not on the list for a genome project to date, have a strong case for being declared as model species for evolutionary arguments. These include the velvet worm, Peripatus, traditionally seen as a missing link between the arthropods and annelids, but now classified as a separate phylum in the panarthropoda lineage (nielsen 1995), and the springtail, folsomia candida, formerly regarded as a primitive insect, but now sug-gested to have developed the hexapod bodyplan before the insects separated from the crustaceans (nardi et al. 2003).

Comparative purposes

- Over the last few years, genomicists have realized that assigning functions to genes and recognizing promoter sequences in a model genome can greatly benefit from comparison with a set of carefully chosen reference organisms at defined phylogenetic distances.
- Comparative genomics is developing an increasing array of bioinformatics techniques, such as
    - ✓ synteny analysis,
    - ✓ phylogenetic footprinting,
    - ✓ and phylogenetic shadowing
- by which it is possible to understand aspects of a model genome from other genomes.
- One of the main reasons for sequencing the chimpanzee's Genome was to illuminate the human genome, and a variety of fungi were sequenced to illuminate the genome of **S. Cerevisae.**

Ecological significance

- It will be clear that ecological arguments have only played a minor role in the selection of species for whole-genome sequencing, but we expect them to become more important in the future.

9 Yeast, fly, worm, and weed Part 5

Biodiversity

- The new range of models should embrace diverse phylogenetic lineages, varying in their physiology and life-history strategy.
- For example, the model plants arabidopsis and rice both employ the C3 photosynthetic pathway. To complement our genomic knowledge of primary production, new models should be chosen among plants utilizing C4 photosynthesis or crassulacean acid metabolism (CAM). Considering the diversity of life histories, species differing in their mode of reproduction and dispersal capacity should be chosen; for example, hermaphoditism versus gonochorism, parthenogenesis versus bisexual reproduction, etc

Ecological interactions.

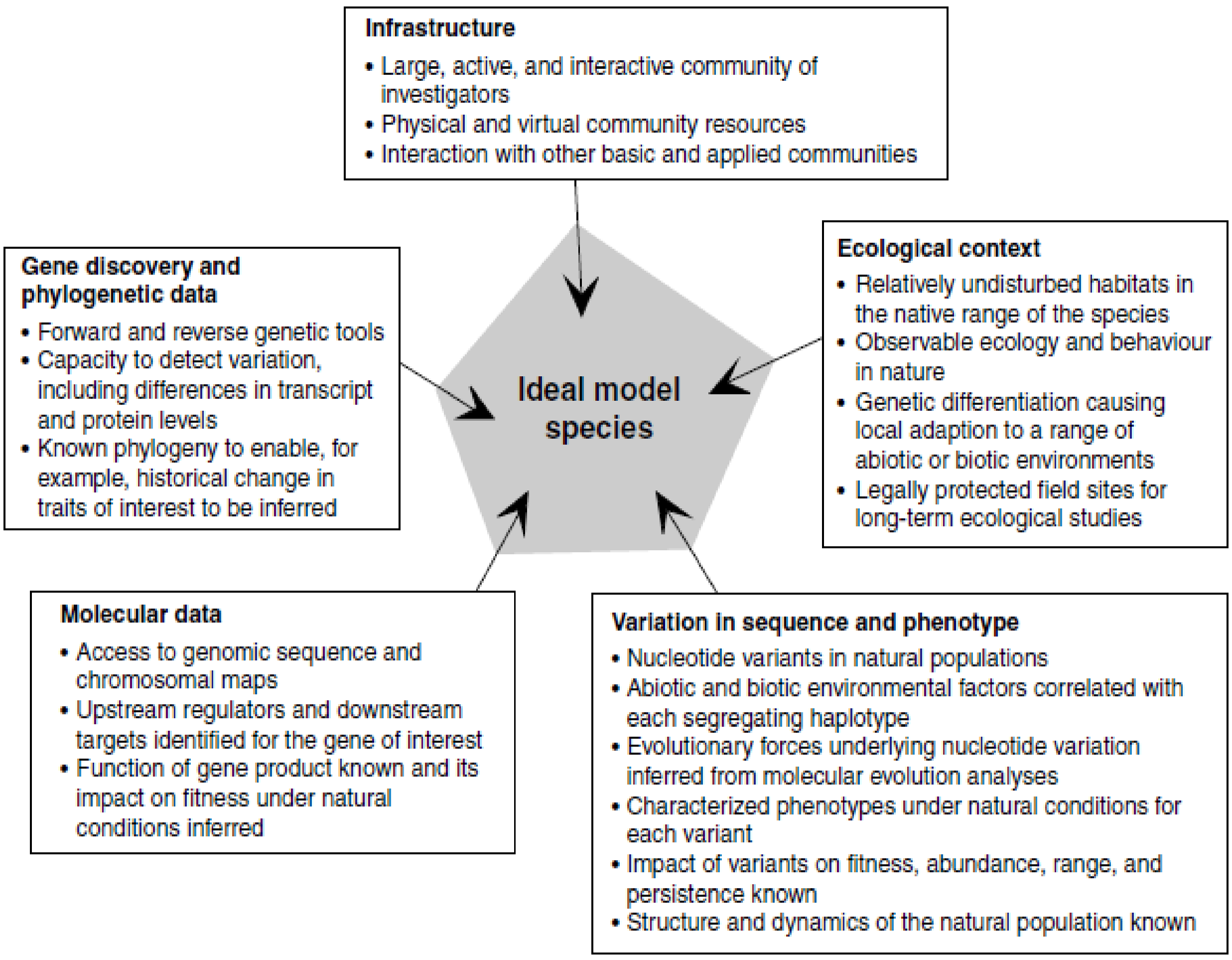
- Species that take part in critical ecological interactions (mutualisms, antagonisms) are obvious candidates for genomic analysis.
- One may think of mycorrhizae, nitrogen-fixing symbionts, pollinators, natural enemies of pests, parasites, etc.
- The most obvious strategy for analysing such interactions would be to sequence the genomes of the players involved and to try and understand interactions between them from mutualisms or antagonisms in gene expression.

Suitability for field studies.

- The wealth of knowledge from experienced field ecologists should play a role in deciding about new 'ecogenomic' models.
- Not all species lend themselves to studies of behaviour, foraging strategy, habitat choice, population size, age structure, dispersal, or migration in the field, simply because they are too rare, not easily

spotted, difficult to sample quantitatively, impossible to mark and recapture, not easy to distinguish from related species, or inaccessible to invasive techniques

Figure 1.5 Criteria in evolutionary and ecological functional genomics for a model species, according to Feder and Mitchell-Olds (2003). At present few species satisfy all criteria. Reproduced by permission of Nature Publishing Group.



DNA microarrays

- With their associated massive generation of data on expression profiles, are one of the most tangible features of modern genomics and are often seen as holding the greatest promise for solving problems in ecology.
- However, not all ecologists are convinced that microarray-based transcription profiling is the best way to advance the genomics revolution into ecology.
- Commercial microarrays are available only for genomic model species, whereas the interest of ecologists is with species that are important in the environment and amenable to ecological studies; these two interests do not necessarily coincide.
- Ecologists have two options.
  - One is to develop their own micro-arrays, starting with spotted cDNAs of unknown sequence, doing a lot of tedious sequencing work, and gradually finding out more about the genome of their study species.
  - Another option is to apply transcriptome samples of non-models to micro-arrays of model species.
- For example, arabidopsis may function as a model for other species of the brassicaceae, and drosophila as a model for other higher insects. Obviously, how useful such an approach is will depend on how far the sequences of model and non-model diverge. This will not be the same for all parts of the genome and therefore there is some doubt on the validity of cross-species hybridization, although there will certainly be situations where it works well.

Because of the immediately attractive upswing created by the genomics revolution, and the large financial resources made available in many industrialized countries, adjacent fields of science have adopted similar terms, leading to a great proliferation of designations such as

- ✓ transcriptomics,
- ✓ proteomics,
- ✓ and metabolomics,

- Such that some biologists have complained that what was molecular biology before is now named after one of the ‘omics’ but in fact is still molecular biology.
- Zhou et al. (2004) proposed a classification of genomics according to
    - three main categories:
        - approach (structural or functional),
        - scientific discipline (evolutionary genomics, ecological genomics, etc.),
        - And object of study (plant genomics, microbial genomics, etc.).

The list includes

- obvious terms such as
    - pharmacogenomics and
    - cardiogenomics, and
- **awkward ones**
    - such as saccharomics (the study of all the carbohydrates in the cell) and
    - vaccinomics (the use of bioinformatics and genomics for vaccine development).
    - The three most common extensions of genomics are transcriptomics, proteomics, and metabolomics.

11 -Omics speak Part 2

Transcriptomics

- Transcriptomics is the study of all the transcripts that are present at any time in the cell.
- In principle the transcriptome includes messenger RNAs (mRNAs) in addition to ribosomal RNAs (rRNAs), transfer RNAs (tRNAs), and small nuclear RNAs (snRNAs), but transcriptomics is usually limited to mrna, the template for translation into protein.
- The main activity in transcriptomics is to obtain a profile of global gene expression in relation to some condition of interest.
    - Which genes are turned ‘on’ and ‘off’ during certain phases of the cell cycle?
    - Which genes are upregulated by certain physiological conditions?
    - Which genes change their expression in response to adaptation to the environment?
    - The study of transcriptomes is part of functional genomics, because it does not look at the DNA as such, but at its functions.
- In general, it is expected that there are more transcripts than there are protein encoding genes in the genome, even when considering only those genes that are actually transcribed.

This is due to the mechanism of alternative splicing:

- the generation of different mRNAs from the same premRNAs during the removal of introns.
- RNA editing (posttranscriptional insertion or deletion of nucleotides, or conversion of one base for another) is another reason for incongruence between the genome and the transcriptome.

12 -Omics speak Part 3

Proteomics

- Proteomics is the study of all the proteins in the cell.

- Mass spectrometry may also be used to determine the amino acid sequence of a protein.
- For this application, the protein is cleaved with a protease, for example trypsin, which generates a collection of fragments characteristic of the protein.
- These fragments may be compared to an in silico (computer-simulated) digestion derived from the genome and the known cleavage sites of the protease.
- The proteome provides a different picture of a cell's activities to the transcriptome.
- Several authors have indeed wondered about the lack of correlation between mrna and protein abundances.
- One of the reasons for this is the existence of control mechanisms at the ribosomes, where mrna is translated to peptides. Translational control allows the cell to select only certain mrnas for translation and block others.
- The selection is often dependent on environmental conditions, so this mechanism allows for physiological adaptation on the level of the proteome, even though the transcriptome remains the same.
- Another issue is posttranslational modification or protein processing, processes that can greatly affect the function of a protein, for example by acetylation or ubiquitination of the n-terminal residue, hydroxylation of prolines, or cleavage of the molecule into smaller units.
- The proteome and the genome are linked by many feedback mechanisms, because some proteins are transcription factors necessary for gene activation, others are enzymes involved in transcription or translation, and still others are structural components of chromosomes. So, in a molecular biology context, the living cell can only be understood fully by considering genome, transcriptome, and proteome together.

13 -Omics speak Part 4

Metabolomics

- Metabolomics is the study of all low molecular weight cellular constituents.
- Usually only metabolites belonging to a limited category are included, for example all soluble carbohydrates, or all metabolites that can be measured by a certain analytical technique such as pyrolysis gas chromatography or infrared spectrometry.
- No single method can measure the thousands of different chemical compounds that may be present at any time in a cell, because of the greatly diverging chemical properties (hydrophilic versus hydrophobic compounds, acids versus bases, reactive versus inert compounds, etc.).
- The metabolome requires a diversity of analytical approaches to obtain a complete picture.

List of some of the more common omics

Term	Object of study
Pathogenomics	Genomes of human pathogens: analysis of genes involved in disease generation
Pharmacogenomics	Genomic responses to drugs, analysis of expression profiles that indicate similarity of action across compounds,
	analysis of genetic polymorphisms that determine a person's disposition to drug action
Toxicogenomics	Mode of action of toxic compounds, development of expression profiles that indicate similarity of toxic
	action across compounds
Ecotoxicogenomics	Genomic responses of organisms exposed to environmental pollution
Ionomics	All mineral nutrients and trace elements in an organism, for example using inductively coupled plasma
	mass spectrometry (ICPMS)

14 Gene discovery Part 1

- In a fully sequenced genome, genes are found by scanning the sequence using gene-predicting computer programmes and assigning putative functions by searching for similarities in already existing databases

- For many organisms under investigation in ecological genomics, no genomic database is available and genes must be identified in other ways.
- There are some so-called pre-genomic molecular approaches that may be used to identify ecologically important genes in incompletely characterized genomes.

From gene product to gene

- In some cases the primary structure of a gene product (a protein) may be the starting point of gene discovery.
- This holds especially for proteins that can be isolated relatively easily by some marker or bioassay, or proteins that are highly induced by some experimental treatment.
- As an example we discuss the isolation of the metal-lothionein (mt) gene in a species of springtail, orchesella cincta (hensbergen et al. 1999).
- Attempts to pick up the gene by polymerase chain reaction (PCR) using primers from the then-known drosophila mt sequence were unsuccessful, which was

15 Gene discovery Part 2

In some cases the primary structure of a gene product (a protein) may be the starting point of gene discovery. This holds especially for proteins that can be isolated relatively easily by some marker or bioassay, or proteins that are highly induced by some experimental treatment.

- Working backwards from protein structure to gene characterization is very laborious and may only be applicable in cases where ecological functions can be associated a priori with a suspected protein
- The laborious edman degradation technique has now been replaced mostly by sequencing using mass spectrometry, in which masses are estimated for peptides generated from proteolytic digests of the protein, while the fragment pattern obtained is compared with entries in a database that include sizes predicted from the genomic sequence. work backwards from protein structure to gene characterization, and in some ecological applica-tions this may be the only way to begin genomic explorations.

16 Structure and function in communities

- The relationship between ecosystem processes and species richness in communities,

  Lawton (1994: 'what do species do in ecosystems?' ecological genomics opens new avenues to explore this question.
- Scientific evidence concerning genome diversity in the environment and the function of genomes in nutrient cycles. because microorganisms are in a key position at many crucial links of nutrient cycles, most of this chapter will deal with the ecological genomics of microorganisms.
- Different ecological communities can be pretty different in terms of the types and numbers of species they contain. For instance, some arctic communities include just a few species, while some tropical rainforest communities have huge numbers of species packed into each cubic meter.
- One way to describe this difference is to say that the communities have different structures. **Community structure** is essentially the composition of a community, including the number of species in that community and their relative numbers^11start superscript, 1, end superscript. It can also be interpreted more broadly, to include all of the patterns of interaction between these different Species.

17 How do we measure community structure?

How do we measure community structure?

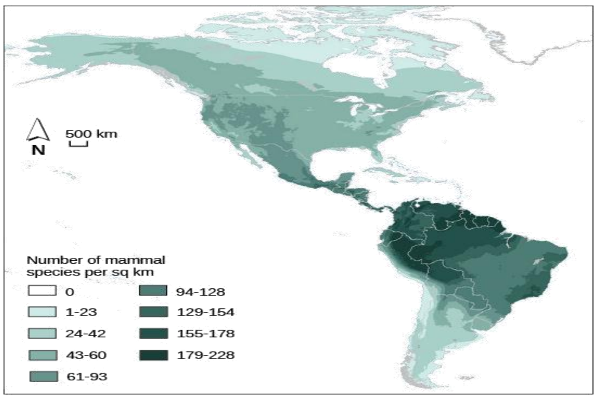
Two important measures ecologists use to describe the composition of a community are species richness and species diversity

- Species richness
- Species diversity

Species richness

Species richness is the number of different species in a particular community.

If we found 30 species in one community, and 300 species in another, the second community would have much higher species richness than the first. Communities with the highest species richness tend to be found in areas near the equator, which have lots of solar energy (supporting high primary productivity), warm temperatures, large amounts of rainfall, and little seasonal change. Communities with the lowest species richness lie near the poles, which get less solar energy and are colder, drier, and less amenable to life. This pattern is illustrated below for mammalian species richness (species richness calculated only for mammal species, not for all species). Many other factors in addition to latitude can also affect a community's species-richness.



Map shows the spatial distribution of mammal species richness in North and South America. The highest number of mammal species, 179-228 per square kilometer, occurs in the Amazon region of South America. Species richness is generally highest in tropical latitudes, and then decreases to the north and south, with zero species in the Arctic regions.

Species diversity

Species diversity is a measure of community complexity.

It is a function of both the number of different species in the community (species richness) and their relative abundances (species evenness). Larger numbers of species and more even abundances of species lead to higher species diversity. **For example:**A forest community with 20 different kinds of trees would have greater species diversity than a forest community with only 5 kinds of trees (assuming that the tree species were even in abundance in both cases).

A forest community with 20 different kinds of trees in even abundances would have greater species diversity than a forest community with the same number of species in very uneven abundances. In general, ecologists think that more diverse ecological communities are more stable (that is, more able to recover after a disturbance) than less diverse communities. However, the diversity-stability relationship isn't a universal rule, and there are some cases where other factors (besides species diversity) are more important in determining community and ecosystem stability superscript.

18 What factors shape community structure

The structure of a community is the result of many interacting factors, both abiotic (non-living) and biotic (living organism-related).

Here are some important factors that influence community structure:

- The climate patterns of the community's location.
- The geography of the community's location.
- The heterogeneity (patchiness) of the environment
- The frequency of disturbances, or disruptive events.
- Interactions between organisms.

A community's structure can also be shaped by the chance events that happened during its history. For instance, suppose that a single seed blows into the dirt of a particular area. If it happens to take root, the species may establish itself and, after some period of time, become dominant (excluding similar species). If the seed fails to sprout, another similar species may instead be the lucky one to establish itself and become dominant.

The climate patterns of the community's location:

Global climate patterns (variation in temperature, solar energy input, etc. With distance from the equator) can affect community structure. So can more local climate patterns, such effects created by mountain ranges, bodies of water, and even streams and valleys. The predictability or variability of climate can also affect community structure – for instance, some species may be unable to survive in a region with sporadic droughts or sporadic drops below freezing.

The geography of the community's location:

Geographical features of the area in which the community is found can affect community structure. For instance, island communities that are further away from a mainland tend to have smaller numbers of species than those that are closer to the mainland. This reflects that the chance event of a species arriving from the mainland is less likely when the island is more distant.

The heterogeneity (patchiness) of the environment:

If there is more variation, or heterogeneity, in a community's environment, this may allow for greater species richness because there are more distinct habitats to be occupied. **For example**, imagine a community occupying a field, and another occupying a field that is dotted with piles of rock. The second community may have greater species richness because species that can live in the rocks (but not in the open field) will be present, in addition to those species that can live in the field.

The frequency of disturbances, or disruptive events.

The frequency of disruptive events (including storms, wildfires, and landslides) can affect the structure of a community. The **intermediate disturbance hypothesis** suggests that communities with a medium (intermediate) level of disturbance may have greater species diversity than communities with very frequent or very rare disturbances.

Interactions between organisms:

All of the interspecies interactions that can occur between organisms (competition, predation, and various forms of symbiosis) have the potential to shape a community. For instance, two species that compete intensively with one another may be unable to coexist in the same community, or a prey species may be unable to persist in a community that contains a highly effective predator.

19 Foundation and keystone species

Some species have unusually strong impacts on community structure, preserving the balance of the community or even making its existence possible. These "special" species include foundation and keystone species.

Foundation species

A foundation species plays a unique, essential role in creating and defining a community. Often, foundation species act by modifying the environment so that it can support the other organisms that form the community.

Kelp (brown algae) is a foundation species that forms the basis of the kelp forests off the coast of california. Kelps create environments that allow the survival of other organisms that make up the kelp forest community .The corals of a coral reef are another foundation species. The exoskeletons of living and dead coral make up most of the reef structure, which protects other species from waves and ocean currents. Beavers, which modify their environment by building dams, can also be seen as a foundation species.

Keystone species

A keystone species is a species that has a disproportionately large effect on community structure relative to its biomass or abundance. Keystone species differ from foundation species in two main ways: they are more likely to belong to higher trophic levels (to be top predators), and they act in more diverse ways than foundation species, which tend to modify their environment.

Different sources use different definitions for keystone and foundation species. If your class requires you to know these definitions, make sure to consult your book or teacher for the definition you should use. In some sources, foundation species are viewed as a subcategory of keystone species.

20 Invasive Species

- Invasive species are species that have been introduced into areas outside their native range and can cause—or have caused—harm in their new area
- Invasive species may outcompete native species for resources or habitat, altering community structure and potentially leading to extinctions.
- Asian carp illustrate the potential impact of invasive species. Introduced into the united states by humans, these fish species have colonized waterways and may threaten native fish populations, and fisheries, in the great lakes.

KuDZu , an Example of invasive species

Kudzu is one dramatic example of what can happen when a species gets introduced into a new ecosystem where it has abundant resources and few predators. The kudzu plant was introduced to the united states from asia in the late 1800s as an ornamental plant, and it and was planted widely in the south in the early 1900s to reduce soil erosion. What the people who planted this vine did not know was that it would rapidly take over the landscape, growing as much as a foot a day and enshrouding ground, shrubs, trees, and even houses and old cars in a suffocating girdle of vines. Invasive species like kudzu are example of how ecological changes, including those caused by humans, can alter communities and ecosystems. In this article, we'll look in more detail at what an invasive species is and how invasive species can disrupt ecosystems—often reducing the numbers of native species and altering the overall structure of the community.

What is an invasive species?

An *invasive species* is a species that has been introduced to an area outside of its native range and has the potential to cause harm—or has already caused harm—in its new location, many invasive species are found in the united states, and a few examples are shown in the pictures below. Whether you're enjoying a forest hike, taking a summer boat trip, or just walking down a city street, chances are that you've encountered an invasive species.

Case study: Asian carp

Let's take a look at what's arguably the kudzu of the aquatic world: the asian carp. Since they were introduced to the united states in the 1970s, asian carp have rocketed in numbers thanks to their vast appetite and speedy reproduction, now forming up to 95% of the biomass in some mississippi and illinois rivers. Not only that, these fish have led to an international lawsuit about waterway access between the united states and canada! This is a dramatic example of what can happen when an invasive species gets a foothold in a new place.

Where did this story begin? Asian carp—which are not a single species, but a group of related species—were introduced to the united states in the 1970s they were imported largely by fisheries and sewage treatment plants, which used the carp's filter feeding abilities to rid ponds of excess plankton. However, some fish escaped. By the 1980s, these fish had colonized waterways of the mississippi river basin, including the illinois and missouri rivers. Because they are big eaters and fast reproducers, asian carp can often outcompete native fish species with whom they share habitats and food sources. Black carp eat mussels and snails, limiting their availability for native fish and damaging shellfish populations. Another asian carp species, the silver carp, eats plankton, a key food for many native fish species in their larval and juvenile stages.^22start superscript, 2, end superscript. Although asian carp can be eaten, the fish are bony and are generally not a desired food in most parts of the united states. The great lakes and their prized salmon and lake trout fisheries are also threatened by the asian carp. These invasive fish have already colonized rivers and canals that lead into lake michigan, including the major supply waterway linking the great lakes to the mississippi river.

To keep the carp from leaving this canal, electric barriers have been used to discourage migration. However, the threat is serious enough that several states and canada have sued to have the chicago channel permanently cut off from lake michigan. We don't yet know whether the asian carp will prove to be mostly a nuisance—like invasive species such as the zebra mussel— or whether it will ultimately destroy the largest freshwater fishery in the world. The story of the asian carp shows how population and community ecology, fisheries management, and politics can intersect and how ecology can have very real importance for the human food supply and the US economy.

21 Introduction to the Animal kingdom

Animals are

- Multicellular
- Eukaryotic
- Hetrotrophs
- Organisms with cells without cell walls

All animals carry out the following functions:

- Feeding: animals “eat” or “ingest” their food
- Respiration: taking in oxygen and giving off carbon dioxide
- Circulation: to move materials around inside of body
- Excretion: system to eliminate bodily wastes
- Response: after sensing changes in environment, animals respond to change
- Movement: Although some do not move, most animals are motile (able to move)

- Reproduction: carrying on genetic code in offspring

Invertebrates:

- Makes up 95% of Animal species
- Don't have a backbone or vertebral column
- Examples: Worms, Insects, Crabs, Starfish & Jellyfish

Vertebrates:

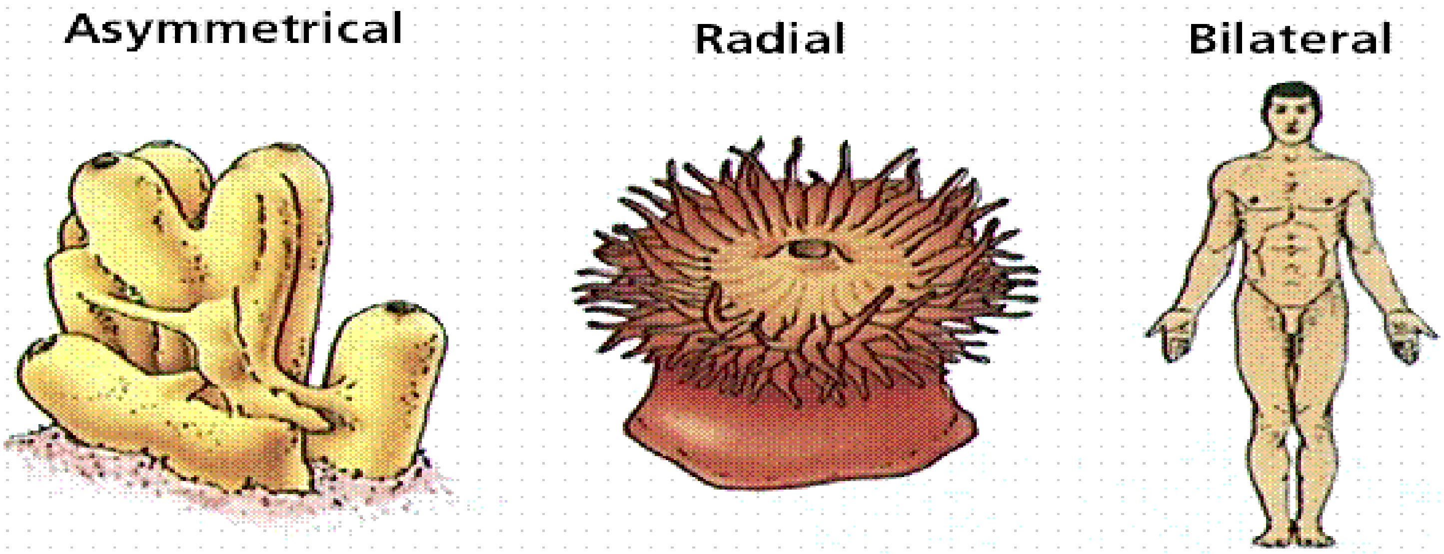
- Makes up only 5% of all animal species
- They have a bac kbone or vertebral column
- Examples: Humans, Fish, Reptiles, Amphibians & Birds

Body Symmetry

Categorizes animals based on 3 basic body plans:

- **Asymmetrical**: lacking an organized body plan; **only in the sponges.
- **Radial Symmetry:** body plan of an organism that can be divided into two equal halves when **any line** is drawn through its center (examples: starfish, jellyfish, and sea anemones).
- **Bilateral Symmetry:** body plan of organism that can be divided into two equal halves by only **one** line drawn through its center (examples: crabs, insects, fish and humans)

Symmetry Review



22 Features of protists

Characteristics of Protists

- ✓ Eukaryotes
- ✓ unicellular

3 Main groups of protists;

- ✓ Protozoans
- ✓ algae
- ✓ fungus-like

1. Protozoans

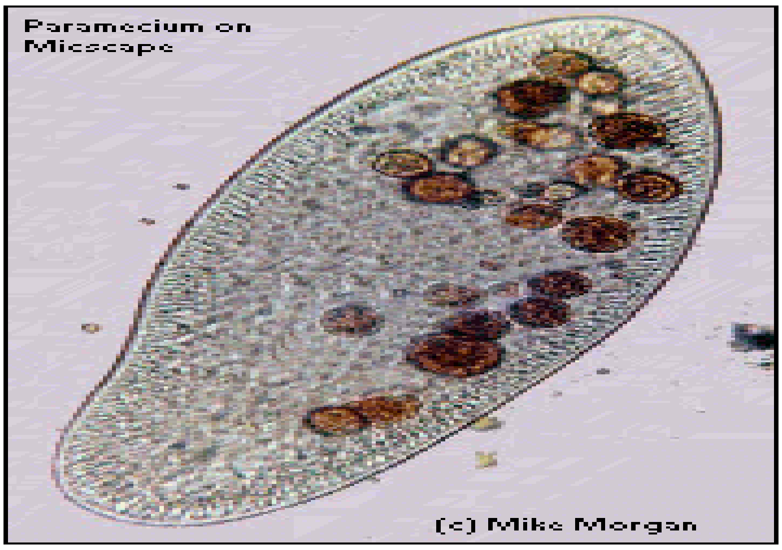
Animal like protists

Protozoans - Animal like

Grouped by movement

- ✓ pseudopods

- ✓ cilia
- ✓ flagella
- ✓ parastites - no movement



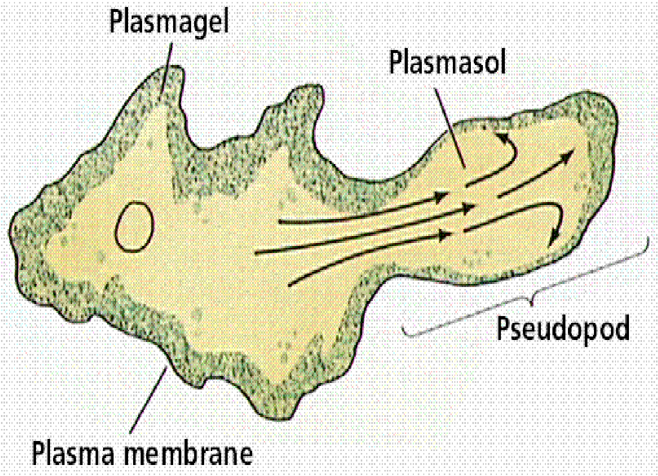
Protozoan Characteristics

- ✓ No cell wall
- ✓ Free-living or parasitic
- ✓ Consumers
- ✓ Habitat – aquatic (ponds,lakes, oceans)
- ✓ Examples: amoeba, paramecium, dinoflagellates

Example 1: Protozoans – amoebas

- Amoebas
  - shapeless, aquatic

Pseudopods in Amoebas

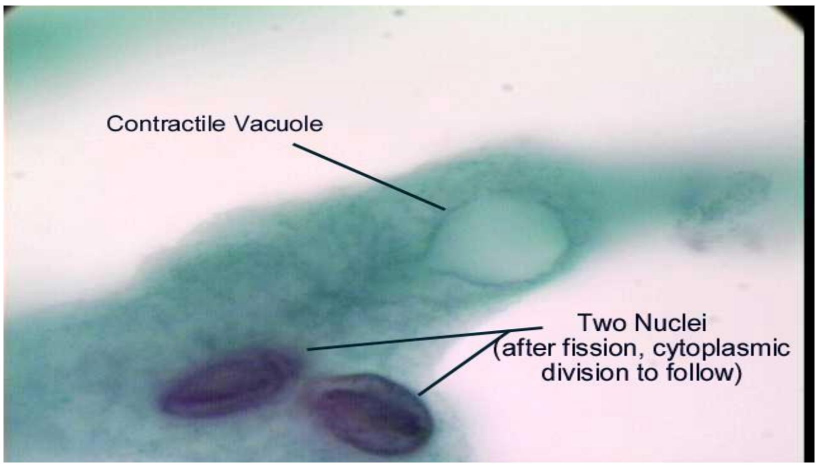


How Amoebas Eat ?

- feeding structures-
  - food vacuole
  - digestive enzymes
  - diffusion

Getting Rid of Waste

- Contracting vacole – collect excess water from inside the cell and gets rid of it.



Reproduction of Amoeba

- asexual reproduction
  - Binary fission

Dysentery (an illness)

- Inflammation of the large intestine
- Diarreha and vomiting
- Caused by an amoeba

2. Example 2: Protozoans: Ciliates

- Locomotion - Cilia

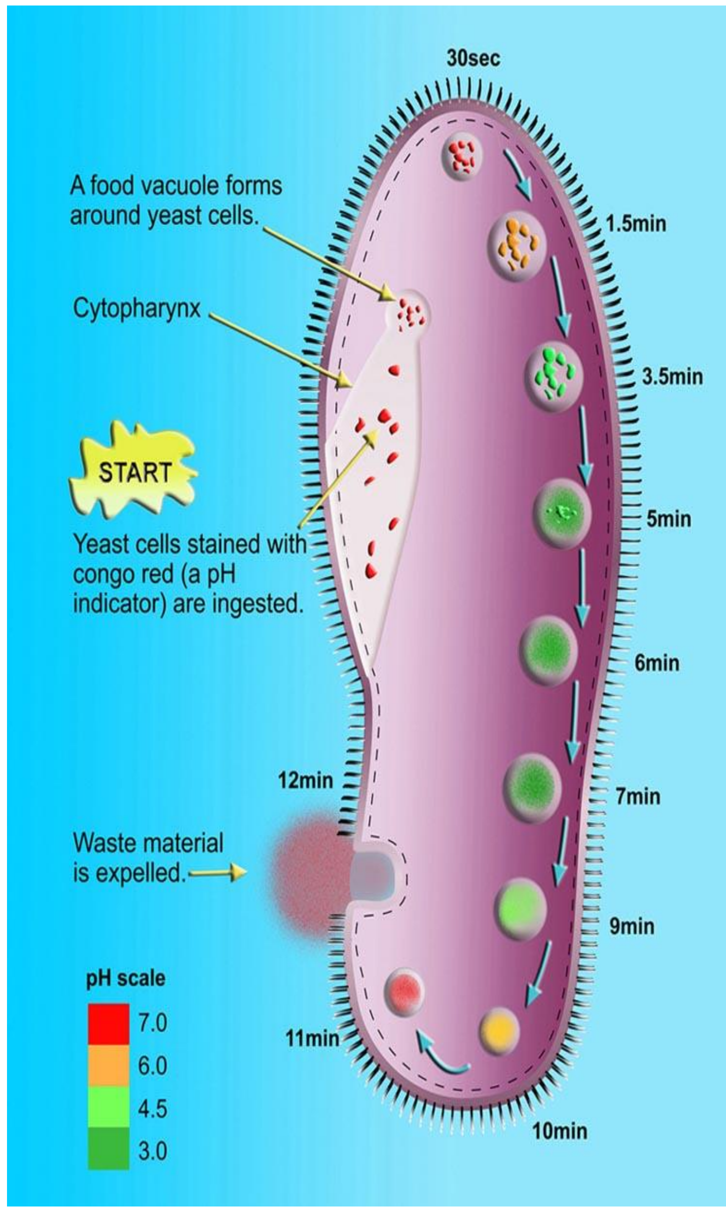
1. Paracmecium - fresh water ciliate

How do Paramecium eat?

- Feed on bacteria
    - Food enters oral groove,
    - moves to the food vacoule,
    - anal pore

Paramecium Reproduction

- **Asexual**- create identical organisms
- <u>**Conjucation**</u> - sexual reproduction
    - ***exchange of genetic information***
    - ***Not identical - adds diversity***



3. Example 3: Protozoans - Flagellates

- Locomotion - use flagella
- Exmaples:

2. Trypanosoma - causes African Sleeping Sickness

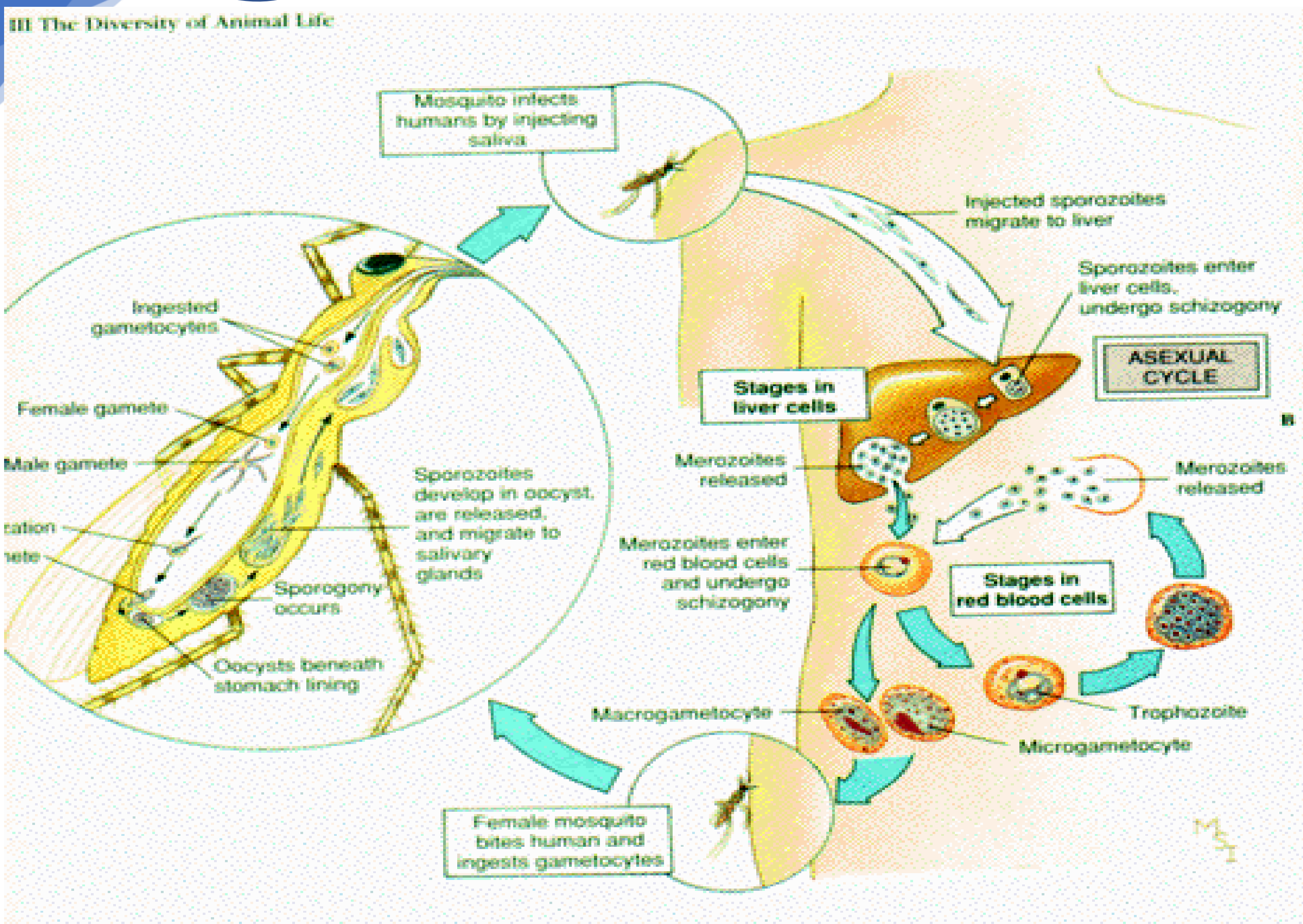
- spread by tsetse fly

4. Example 4: Protozoan - sporozoans

- Locomotion - parasitic
- reproduction
    - spores

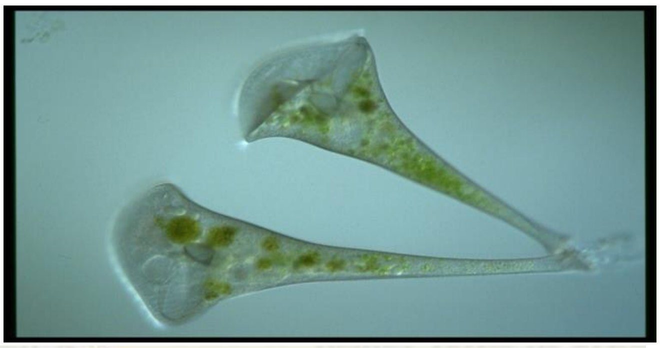
Plasmodium - Causes Malaria

- Spread by mosquito
- Quinine – drug used to treat malaria



Vorticella

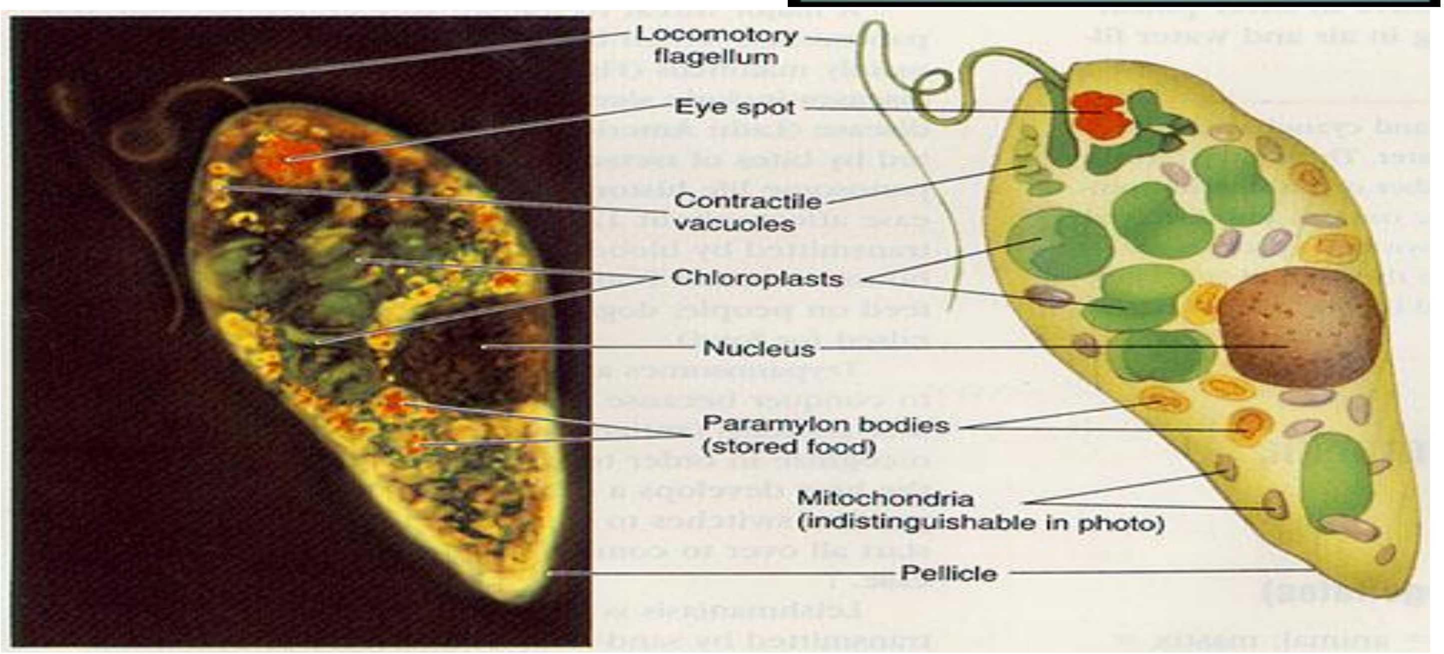
- Attaches to and spins its cilia to create a vortex (water movement”



Stentor

2. Euglena – 2nd group in protists

- Both plant-like and animal-like



Euglenoids

- - contain chlorophyll
- - move by flagella
- - Euglena (unique)-
    - eyespot,

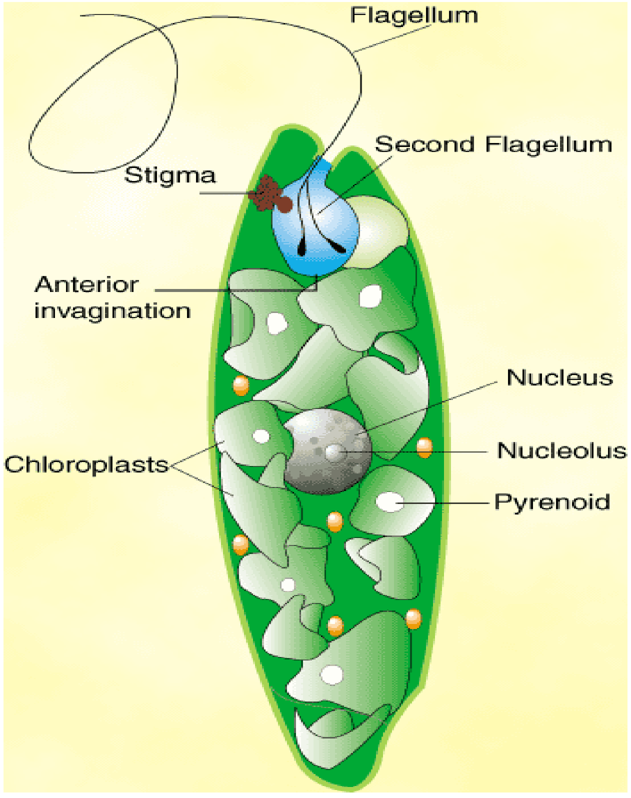
- chloroplast,
- flagellum

Algae

Plant like protists

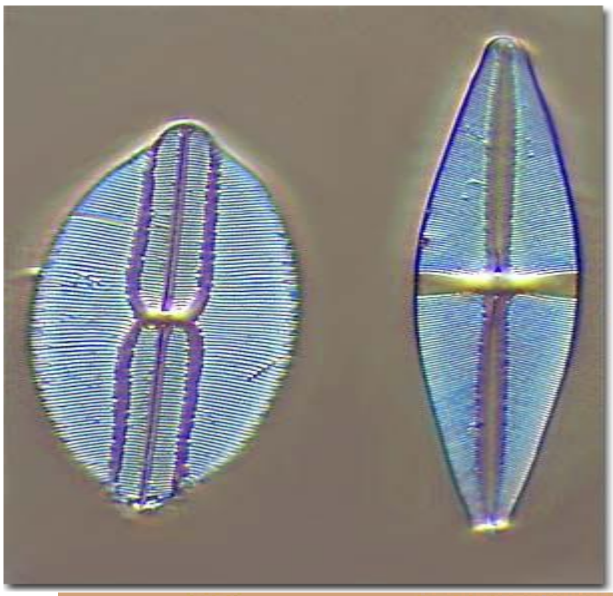
B. Algae - plant-like

- Photosynthetic
- Multi-cellular and unicellular
- Classified by pigments (Types of Algae)
  - red
  - brown
  - Green+
  - Examples; Volvox, diatoms, spirogyra



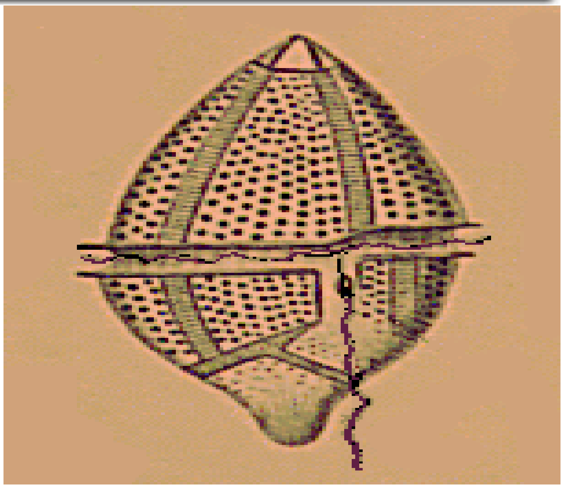
1. Diatoms

- - float in water
- - photosynthesis
- - unicellular
- - silica shells
- Commercial value**:** Insulating materials, Abrasives , Ceramics, Filtering



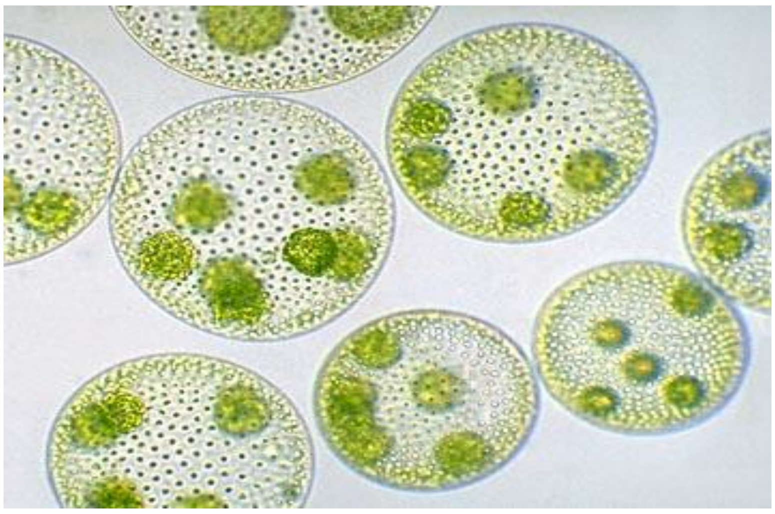
2. Dinoflagellates

- - move by two flagella
- - autotrophs
- - green glow and red tides

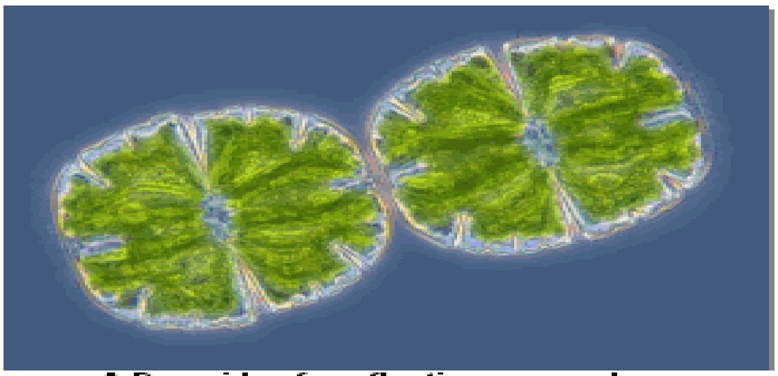


3. Green Algae (Lab 37)

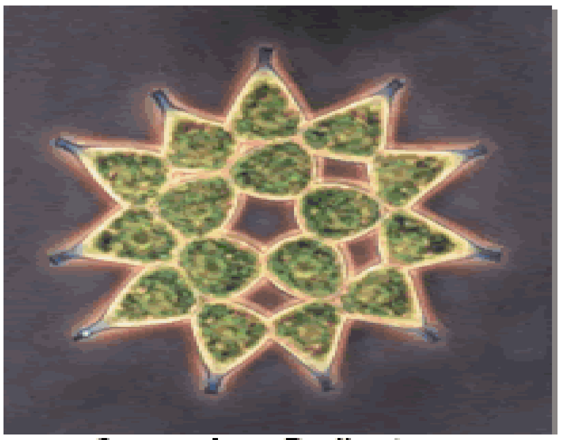
- Most freshwater
- Food Source – called Plankton
- Some are:
  - Free-living
  - Colony
  - filament



Free-Floating –



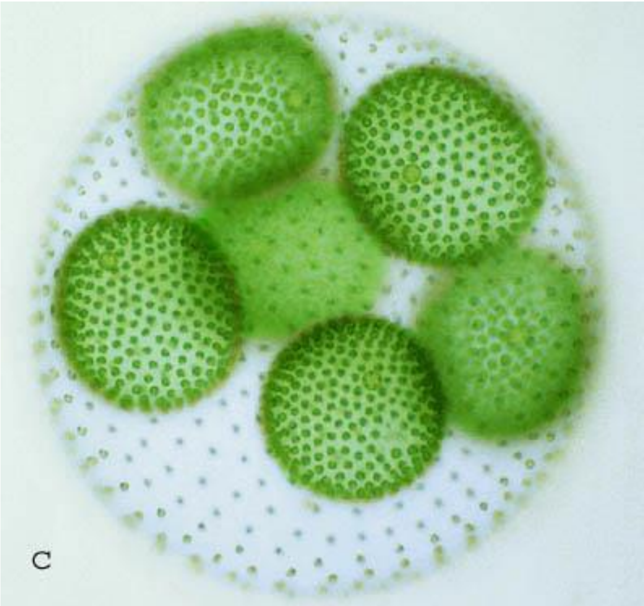
A Desmid: a free-floating green alga



Green alga -*Pediastrum*

- Filament type – exist as a thread

Colony –



Label and Draw

- ✓ Ulothrix
- ✓ Zygnema
- ✓ Spirogyra
- ✓ Hydrodictyon
- ✓ Peridinium
- ✓ chlamydomonas

Red and Brown Algae

- ✓ All multicellular
- ✓ Marine
- ✓ Kelp – a form of brown algae
- ✓ Red algae – used in food.

Fungus Protists

Slime Molds

- - plasmodium- visible slime mass
- - moves
- - no cell membrane
- - many nuclei
- - grow on damp organic matter - decompose
- - form a stalk, release spores
- - Reproduce - asexual reproduction, making spores

Fungus Like Protists

- Classified by how they reproduce

- slime molds
- mold and mildew - disease causing

Mildew and Water Molds

- - fuzzy growths
- - found on bathroom tiles
- - live off of dead material
- - potato famine- 2 million people died in Ireland
- - caused immigration to the United States

Origins and Importance of Protists

- Green algae

Importance of :

- green algae - oxygen source
- food source -
  - plankton
  - zooplankton
  - phytoplankton

23 Protozoa

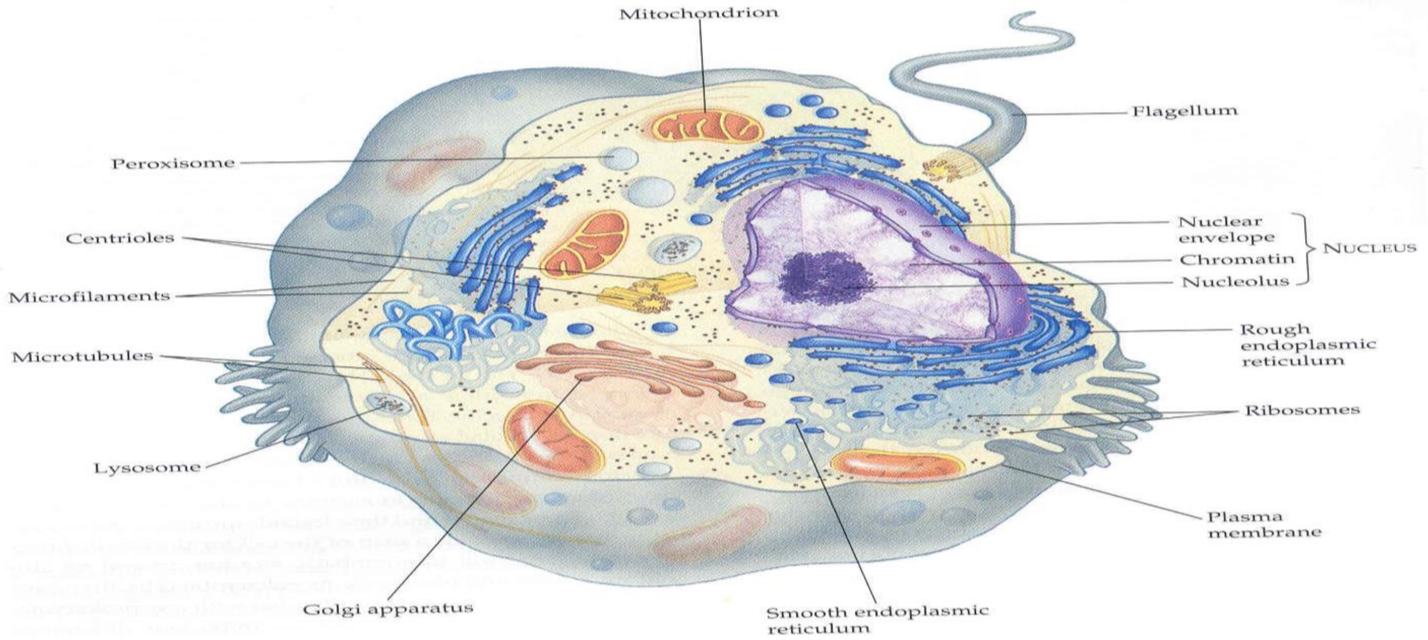
Ciliates

Amoeboid Protozoans

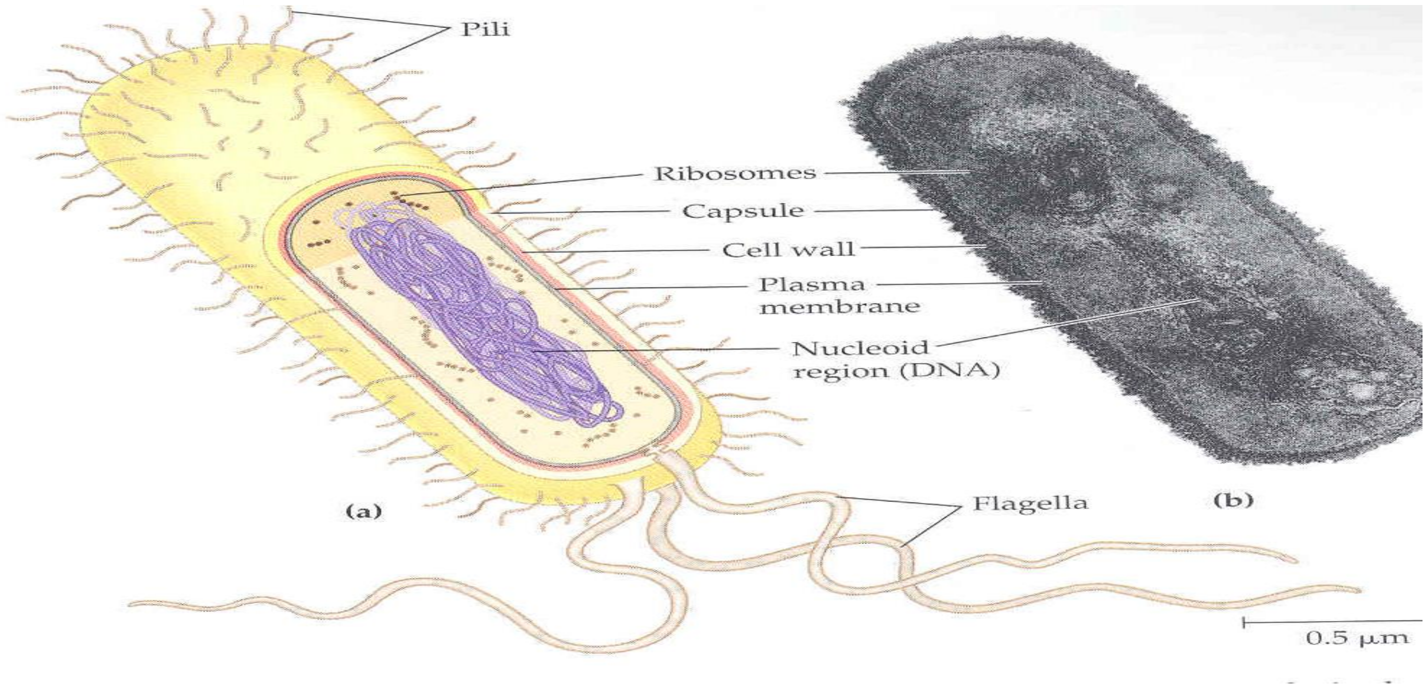
Flagellated Protozoans

Kingdom Protozoa

- Defining Characteristics
  - All are unicellular **eukaryotes**
  - What is a **prokaryote**?
  - Many species are both **heterotrophic** and **autotrophic** simultaneously or at different stages of the lifecycle
- Eukaryote Cell



Prokaryote Cell



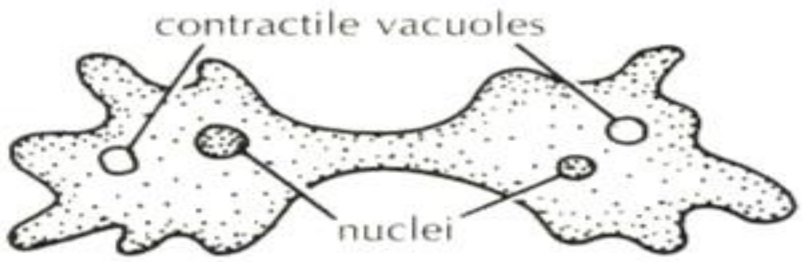
Adaptability

- Protozoans are ecologically important primary producers, consumers and as vital links in the food chain
- Humans are greatly effected by parasitic protozoans either directly or indirectly
    - Effects range from irritating - fatal
        - Malaria (*Plasmodium spp.*) worldwide epidemic

Reproduction

- Asexual reproduction
    - Replication of chromosomes and the splitting of the parent into two or more parts
    - Binary fission
    - Multiple fission
    - Budding
- Protozoans are problematic in their associations as colonial forms

Asexual Reproduction



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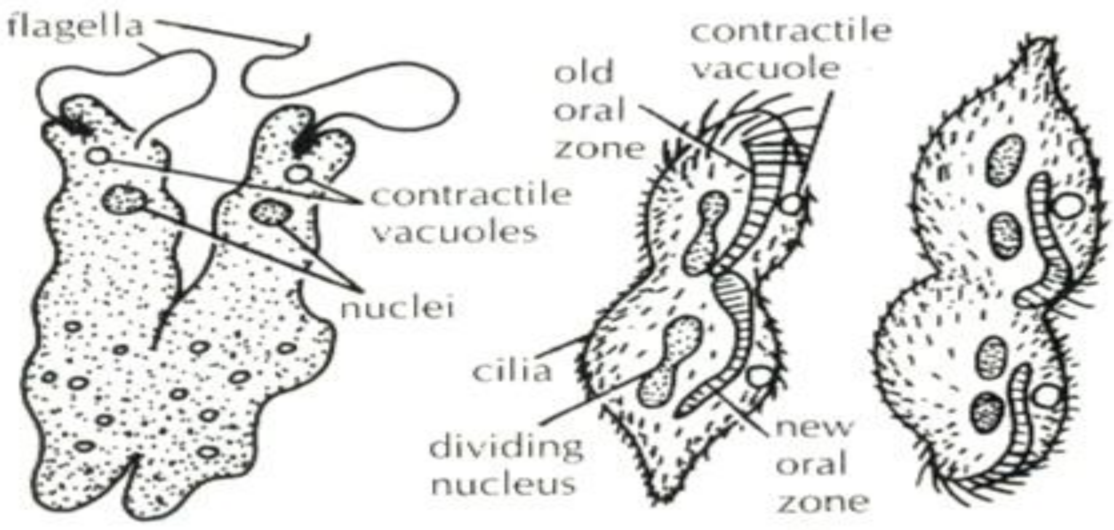


Classification

Kingdom Protozoa

Phylum Ciliophora (Ciliates)

The Sarcodinids (Amoeboid Protozoans)

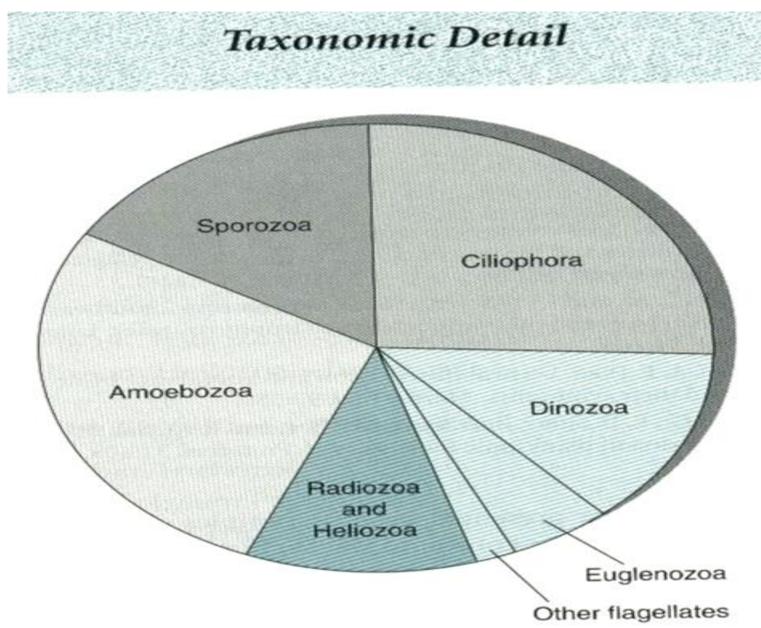
Phylum Foraminifera

Phylum Radiozoa

The Flagellated Protozoans

Phytoflagellated protozoans

Zooflagellated protozoans



1. Phylum Ciliophora

Body externally ciliated in at least some lifecycle stages. Have the highest degree of subcellular specialization and are considered advanced protozoans. E.g paramecium, verticilla

Cilia

Hair-like structures by which the organism moves, collects food and senses their surroundings . Fastest of all the protozoans

Ciliate Biology

- Oral groove
- Cytostome
- Cytoproct
- Contractile vacuole

Ciliate Lifestyles

- 65% of all ciliate species are free-living and mobile

- Some ciliates form colonial aggregations and have sessile habits
- Other ciliates have symbiotic relationships in invertebrates and vertebrates

2. The Sarcodinids (Amoeboid Protozoans)

Contains 4 phyla: Foraminifera, Radiozoa, Amoebozoa, and Heliozoa. Most reproduce asexually through binary fission. Characterized by pseudopodia. Food is usually captured by phagocytosis. Body types range from free flowing to rigid with skeletal supports

A. Phylum Foraminifera

Individuals secrete multi-chambered tests, generally made of calcium carbonate ($CaCo_3$)

Foraminiferans

Extremely abundant, most are benthic and marine. Feed on diatoms and algae, very slow movers. Organisms are extremely common and form ooze

- White cliffs of Dover are foraminiferan tests
- Extremely abundant, most are benthic and marine
- Feed on diatoms and algae, very slow movers
- Organisms are extremely common and form ooze White cliffs of Dover are foraminiferan tests

B. Phylum Radiozoa

Radiolarians

Have shells made of silicon dioxide that can be very intricate. Feed on diatoms and other phytoplankton. Benthic individuals move by use of pseudopodia. Can occur in large concentrations that form ooze as well.

3. The Flagellated Protozoans

Characterized by the possession of a definite body shape and the possession of one or more flagella. Most species are free-living and mobile. E.g Noctiluca

1. Phytoflagellated Protozoans

Have chlorophyll and obtain energy directly from the sunlight. Some are strictly autotrophic or heterotrophic. Some are a combination of both.

E.g *Euglena*, dinoflagellates, chlamadomonas, ceratium

Dinoflagellates

Know for bioluminescence and highly **toxic red tides**: Dense aggregations produce saxitoxin killing fish and crustaceans

Also contaminates shellfish causing diarrheic shellfish poisoning. Some benthic dinoflagellates produce a neurotoxin that accumulates in tropical fish called Ciguatera

2. Zooflagellated Protozoans

1. Free-living forms

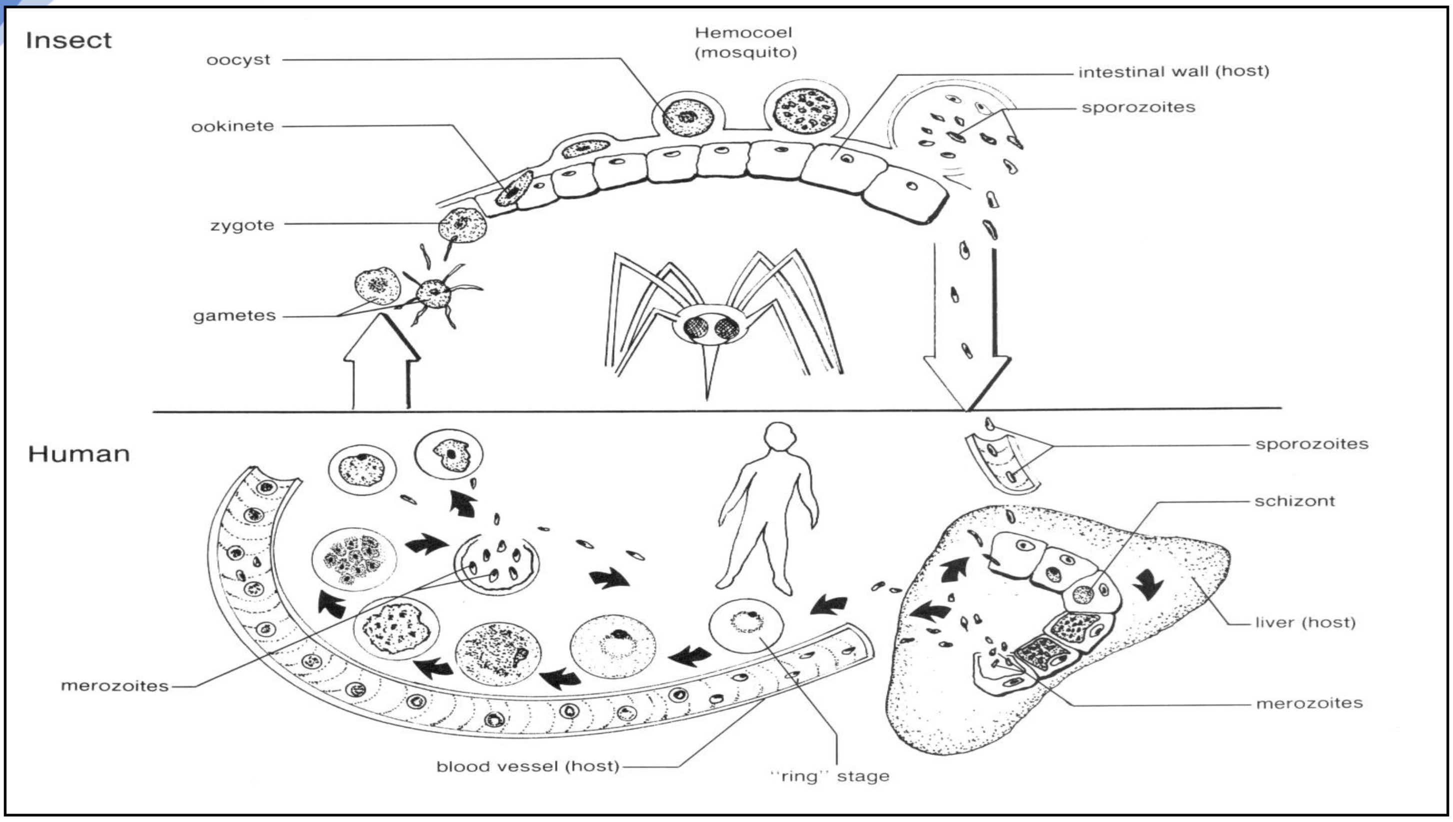
Most individuals are sessile and have a single flagellum that beats to obtain food and nutrients

2. Parasitic forms

25% of zooflagellate spp. are parasitic in humans, invertebrates, and other vertebrates. Usually have complex lifecycles with intermediate hosts. Malaria is caused by the genus *Plasmodium* technically a member of the phylum Sporozoa.

Chanoflagellates are example of Zooflagellated prptozoans.

Malaria (*Plasmodium)*



24 Phylum Arthropoda

- ✓ jointed foot"
- ✓ Largest phylum
- ✓ 900,000 species
- ✓ 75% of all known species

Insects, spiders, crustaceans, millipedes, scorpions, ticks, etc

Most successful phylum ecologically diverse. Present in all regions of the earth. Adapted to air, land, freshwater, marine, other organisms

Reasons for success

- Versatile exoskeleton
- Efficient locomotion
- Air piped directly to cells (terrestrial)
- Highly developed sensory organs
- Complex behavior
- Metamorphosis

Exoskeleton

External: not enveloped by living tissue

Protection

Secreted by underlying epidermis

- Waterproof barrier
- Chitin +/- calcium, lipoproteins

Modifications

- Can be site for muscle attachement
- Energy stores- flying
- Sensory receptors
- Gas exchange
- Bristles

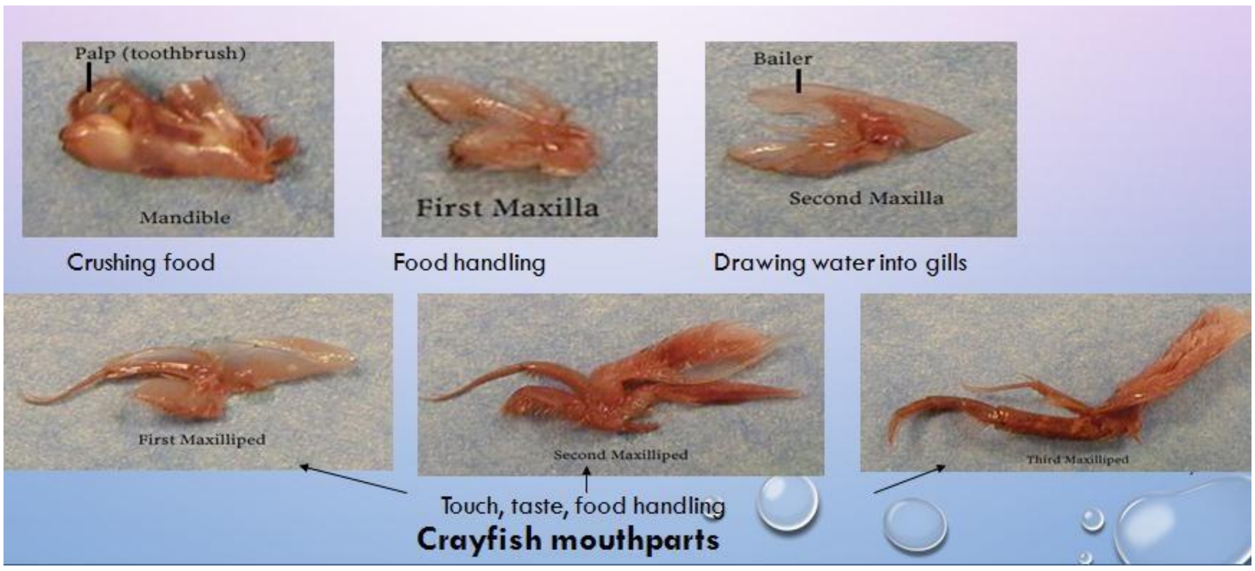
Soft and permeable or hard, impermeable

- Between segments of body/appendages= thin + flexible
- Must be shed (ecdysis= molting) to allow growth
- Relatively heavy: Limits size

1. Efficient locomotion

Tagmatization, more specialized than annelids

- Regions= tagma/tagmata
- Jointed appendages



2. Air piped directly to cells

- More efficient than most other invertebrates
- Most have efficient tracheal system of air tubes; some breathe by gills
- Limits size

3.Highly developed sense organs

- Sight, touch, smell, hearing, balance, chemical reception

4. Complex behavior patterns

- Complex, organized activities
- May be innate (unlearned) or learned

5. Limited intraspecific competition

- Many arthropods undergo metamorphosis

  1. meta= between/after; morphē= form; osis= state of

- Different stages (ie. larva, adult) have different nutrition/habitats □ no competition

Other Characteristics of Arthropods

- Bilateral, triploblastic, schizocoelous
- No septa

Arthropod Groups

1. Subphylum Trilobita

- extinct trilobites

2. **Subphylum Chelicerata**

- horseshoe crabs, spiders, ticks, mites, and some extinct groups

3. **Subphylum Myriapoda**
   - centipedes, millipedes
4. **Subphylum Crustacea**
   - crabs, lobsters, shrimps, barnacles
5. **Subphylum Hexapoda**
   - Insects

Subphylum Trilobita

- tri= three; lobos= lobes
- Divided into 3 longitudinal regions
- Extinct
- Oval, flattened

Subphylum Chelicerata

- Horseshoe crabs, spiders, ticks, mites, scorpions

Cephalothorax (prosoma)

- Fused head and thoracic region

Abdomen (opisthosoma)

- contains digestive, reproductive, excretory, and respiratory organs

Appendages attached to cephalothorax

- Pair of chelicerae (clawlike feeding appendages)
- Pair of pedipalps (usually sensing or feeding)
- four pairs of legs (5 in horseshoe crabs)
- No antennae

- Most suck liquid food from prey

Class Arachnida

- Spiders, ticks, scorpions
- Most are predaceous
- Most are harmless/beneficial to humans
- Some spiders (ie. black widow, brown recluse spider) give painful, dangerous bites
- Scorpion sting can be painful, dangerous
- Some ticks and mites spread disease, cause irritation
- Lyme disease caused by tick

More on spiders:_Order Araneae Spiders

- cephalothorax and abdomen shows no external segmentation
- tagma are joined by a narrow pedicel
- All predaceous
- Mostly insects
- Chelicerae have fangs

• Prey capture among the spiders

- ✓ Some species are cursorial predators
- ✓ stalk and ambush their prey
- ✓ they usually have well-developed eyes
- ✓ Some are web-building spiders
- ✓ Eyes not as well developed
- ✓ sensory hairs for detecting vibrations
- ✓ Many spiders (and mites) producing silk
- ✓ trappingUsed for prey, building nests, forming egg cases
- ✓ silk glands that open to the exterior part of the abdomen through spinnerets
- ✓ Many species have evolved poison glands associated with the chelicerae
- ✓ Spider venom is used to subdue prey
- ✓ Venom liquifies tissues with a digestive fluid
- ✓ Spider sucks up soupy prey

• Spiders: Class Araneae

- Spider love: Spiders, like most arthropods, are dioecious: Mating habits
- Pheromones- chemicals that elicit behavioral change: Rituals- males pluck female's web (pattern is species-specific)
- Male builds small web, deposits sperm: Collects sperm in cavities of pedipalps
- Pedipalps have ejaculatory duct + embolus: inserts pedipalps into female genital opening Eggs laid in silk case Carried, attach to web, bury.
- Wolf spider parental care- after the eggs hatch, the young ride on mom for several days.
- Young spiders disperse by silk lines (ballooning)

• Brown recluse

- Violin-shaped stripe on back
- Necrotoxin: Hemolytic

- *Loxosceles reclusa*

Necrosis of tissue

The Crustaceans

Phylum Arthropoda **Subphylum Crustacea**

- crusta= shell
- Lobster, crayfish, shrimp, crab, water flea, barnacles
- Aquatic (mostly marine), a few terrestrial forms
- Major ecological and economical importance
- Biramous appendages (at least primitively), 2 main branches
- Only arthropods with 2 pairs of antennae
- Great specialization of appendages: Mouthparts chewing, grinding, handling
- appendages strengthened for walking or protection (chelipeds, pincer-like claws)
- Respiration: gills (usually)
- Compound eye is typical of phylum

What's the difference between a crayfish and a lobster

Same Order, but different families, Lobsters are bigger, Lobsters are marine; crayfish live in freshwater creeks, ditches, or lakes

Barnacles:

living and nonliving substrates, most species secrete $CaCO_3$ shell, Head reduced, rudimentary abdomen

Krill: Component of plankton, Major food for whales.

25 Phylum Annelida

Class Polychaeta • Class Clitellata

Phylum Annelida Annelid Characteristics

Defining Characteristics

- ✓ One or more pairs of chitinous setae
- ✓ The phylum includes polychaetes, earthworms, leeches, and vestimentiferans
- ✓ True segmented worms
- ✓ Metameric segmentation

Body Structure

The body is a tube within a tube**.** The coelom is important to annelids for:The epidermis is what secretes the tough cuticle

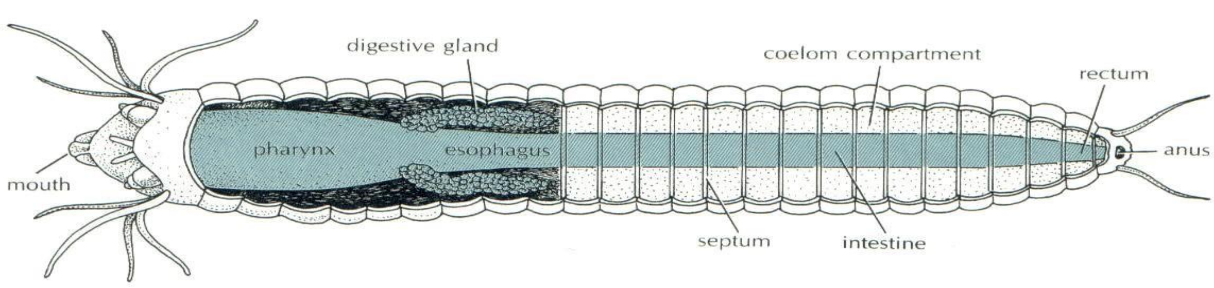
Locomotion

On each side of the animal is a parapod (parapodia) consisting of fleshly lobes, which are supported by chitinous rods. Each parapod have setae, which can be sharp (protection), and aid in locomotion

Feeding

Annelids range from carnivores, herbivores, scavengers, deposit feeders, and filter feeders. With very few defenses, many remain in a burrow or secreted tube. Carnivores can capture prey with strong jaws and quickly drag it back to its burrow. Can use a muscular pharynx = eversible proboscis.

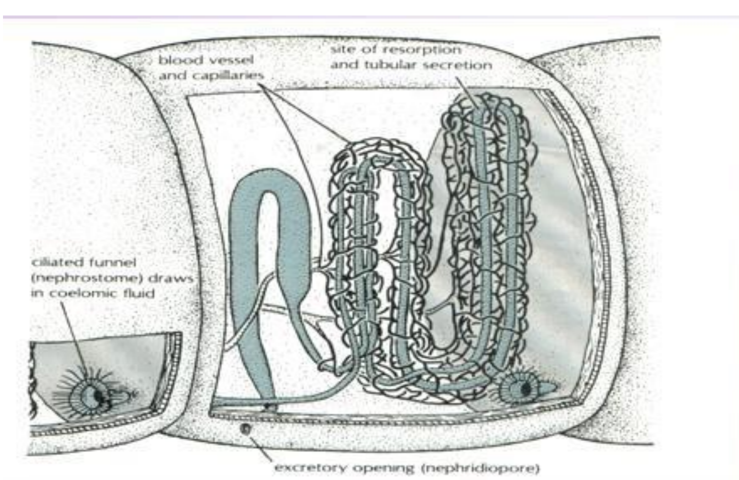
Digestive System

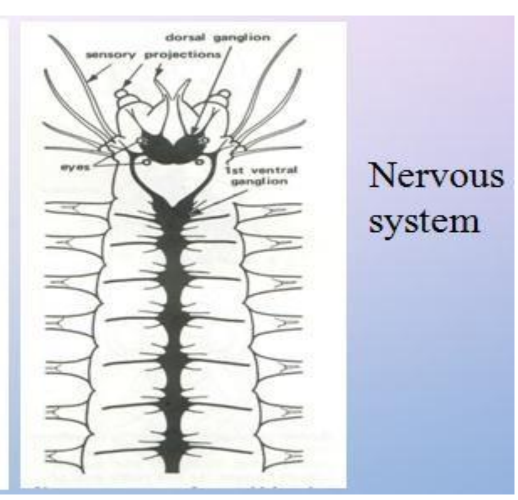


Circulatory System

Blood flows entirely in closed vessels. Some spp. have hearts. Blood contains hemoglobin, which increases oxygen carrying ability.

Excretory & Nervous System





REPRODUCTION

Sexes are usually separate with gonads occurring in each segment. Some species have gonad specific segments. Breeding is usually seasonal (spring or fall). As gametes mature they fill the coelom and are released by the nephridia. Fertilization can be internal or external. Trochophore larvae develop, which are remarkably similar to the Molluscs

Taxonomic Summary

- **Phylum Annelida Class Polychaeta**

  Family Siboglinidae

  Class Clitellata

- Subclass Oligochaeta. Subclass Hirudinea

1. Class Polychaeta

Some tube species lack parapodia but it is believed to have been lost. Parapodia differ from species to species and play an important role in identification

Reproduction

Dioecious with gametes released into the coelom. Many species reproduce *en masse* at the surface at night. Moonlight and artificial light attract spawning masses

Epitokes

These are given the task of reproduction. Some individuals bud epitokes from the body and remain in the habitat. Some species lack a free-swimming or plankton stage, and are produced in protective gelatinous egg masses

Family Siboglinidae

Gut tissue forms an organ (trophosome) that becomes filled with chemosynthetic bacteria. Segmentation confined to small rear portion of animal (the opisthosoma). Small intriguing class of tube dwelling worms found throughout the worlds oceans

Trophosome

The major organs (gonads and trophosome) are found in the coelom. The trophosome of all species contains closely packed bacteria and play a crucial role in nutrition. The last segment is the opisthosoma, which has many segments and septa like polychaetes

Chemosynthetic Bacteria

The most interesting aspect of pogonophora is the lack of a digestive system. Bacteria in the trophosome fix the chemicals leaving the vents. The bacteria can occur at concentrations of 10 billion per gram of trophosome tissue

2. Class Clitellata

1. Subclass Oligochaeta

- Pronounced cylindrical glandular region of the body = clitellum
- Second largest class in the phylum Annelida
- Most spp. are earthworms, very few are marine

Polychaetes and Oligochaetes

Oligochaetes differ from polychaetes in several ways: No parapods, fewer setae (if at all), Hermaphroditic with sex cells produced in a separate section. No larval stages

2. Subclass Hirudinea

- Posterior sucker
- Predominately freshwater, but do occur in all seas and moist soil

- • Leeches do not burrow or crawl, lack parapods and setae

LEECH ANATOMY

Leeches do not burrow or crawl, lack parapods and setae. Anterior sucker is small and contains the mouth. Anterior sucker creates a wound with saw like jaws. Leeches drink other animals' blood, usually vertebrates. Can be carnivores, or scavengers; leeches are not set in their feeding habits

Blood Sucker

The salivary glands excrete hirudin which prevents the blood from coagulating. May also secrete an anesthetic and substance to dilate small blood vessels. Blood is broken down by symbiotic bacteria that is then used by the leeches. Leeches were commonly used in the 19th century for bloodletting . Recent medical uses are to relieve pressure after vascular tissue is damaged. Snake bites or the reattachment of a finger or ear.

Leech Reproduction

- Leeches are simultaneous hermaphrodites that lack a free-living larvae stage
- Fertilization is internal through copulation
- Development occurs in a cocoon similar to the Oligochaetes

26 Echinodermata

A complex series of fluid filled canals with numerous flexible feeding and locomotory appendages. 5 pointed radial symmetry in adult

Echinoderms Skeleton

Have an internal skeleton of calcium carbonate. Ossicles vary in size and structure and are manufactured by specialized cells

Water vascular system

A separate coelom is used with interconnecting fluid filled tubes and canals. A ring canal circles the mouth and gives off 5 radial canals. The radial canal is exposed and runs along the ambulacral groove

Tubefeet

The ampullae is a small ball that sits above the tube foot. Contraction and expansion of the ampulla accomplishes movement

Mutable connective tissue

Another unique Echinodermata characteristic is the presence of mutable connective tissue

Taxonomic Summary

- Phylum Echinodermata
- Class Crinoidea
- Class Concentricycloidea
- Class Stelleroidea
- Subclass Asteroidea
- Subclass Ophiuroidea
- Class Echinoidea
- Class Holothuroidea

Sea Stars

The oral surface of each arm has a single ambulacral groove. Have a large coelom where all the main organs occur

Reproduction

Can reproduce asexually by disk division. Sexual Reproduction: Dioecious with sperm or eggs produced in 2 or more gonads in each arm. Larval stage = bipinnaria

Regeneration

Many species autotomize, leaving predators with a nutritious souvenir while they escape. Most spp. can regenerate from fragments that include the disk

Ingestion and Digestion

Feed on alga material, encrusting bryozoans or scavenge. Food is chopped by 5 sharp pointed teeth. The digestive system is long to deal with vegetable manner. The anus is located aborally

Reproduction: Most conspicuous organs are those responsible for reproduction. At spawning the entire coelom will fill with sperm or eggs. **Pluteus** larva is formed

Ossicles

Although somewhat soft they do have an internal skeleton. The skeletal elements (ossicles) are microscopic with complex shapes. May compose up to 80% of the dry body weight

Defense

Many spp. have powerful toxins in the body wall “Cuverian tubules”. Sticky and toxic tentacles which are shot out the anus. Also eviscerates to avoid predation. Internal organs regenerate after a period of time

27 chordates,

A chordate is an animal belonging to the phylum chordata; they possess a notochord, a hollow dorsal nerve cord, pharyngeal slits, an endostyle, and a post-anal tail, for at least some period of their life cycle. Chordates are deuterostomes, as during the embryo development stage the anus forms before the mouth. They are also bilaterally symmetric coelomates. In the case of vertebrate chordates, the notochord is usually replaced by a vertebral column during development, and they may have body plans organized via segmentation. By the end of the cambrian period, 540 million years ago, an astonishing variety of animals inhabited earth’s oceans. One of these types of animals gave rise to vertebrates, one of the most successful groups of animals. Chordates are **bilaterian** animals that belong to the **clade** of animals known as **deuterostomia**. Two groups of invertebrate deuterostomes, the urochordates and cephalochordates are more closely related to vertebrates than to invertebrates.

Phylum Chordata

Chordates have:

- Bilateral symmetry
- A coelom
- Deuterostome development: Radial, indeterminate cleavage, Enterocoelous coelom development
- Metamerism
- Cephalization.

Five distinctive characteristics define the chordates:

- Notochord
- Dorsal tubular nerve cord
- Pharyngeal pouches (gill slits)
- Endostyle
- Postanal tail

All are found at least at some embryonic stage in all chordates, although they may later be lost.

1. Notochord

The notochord is a flexible, rod-like structure derived from mesoderm. The first part of the endoskeleton to appear in an embryo. Place for muscle attachment. In vertebrates, the notochord is replaced by the vertebrae. Remains of the notochord may persist between the vertebrae.

2. Dorsal Tubular Nerve Cord

In chordates, the nerve cord is dorsal to the alimentary canal and is a tube. The anterior end becomes enlarged to form the brain. The hollow cord is produced by the infolding of ectodermal cells that are in contact with the mesoderm in the embryo. Protected by the vertebral column in vertebrates.

3. Pharyngeal Pouches and Slits

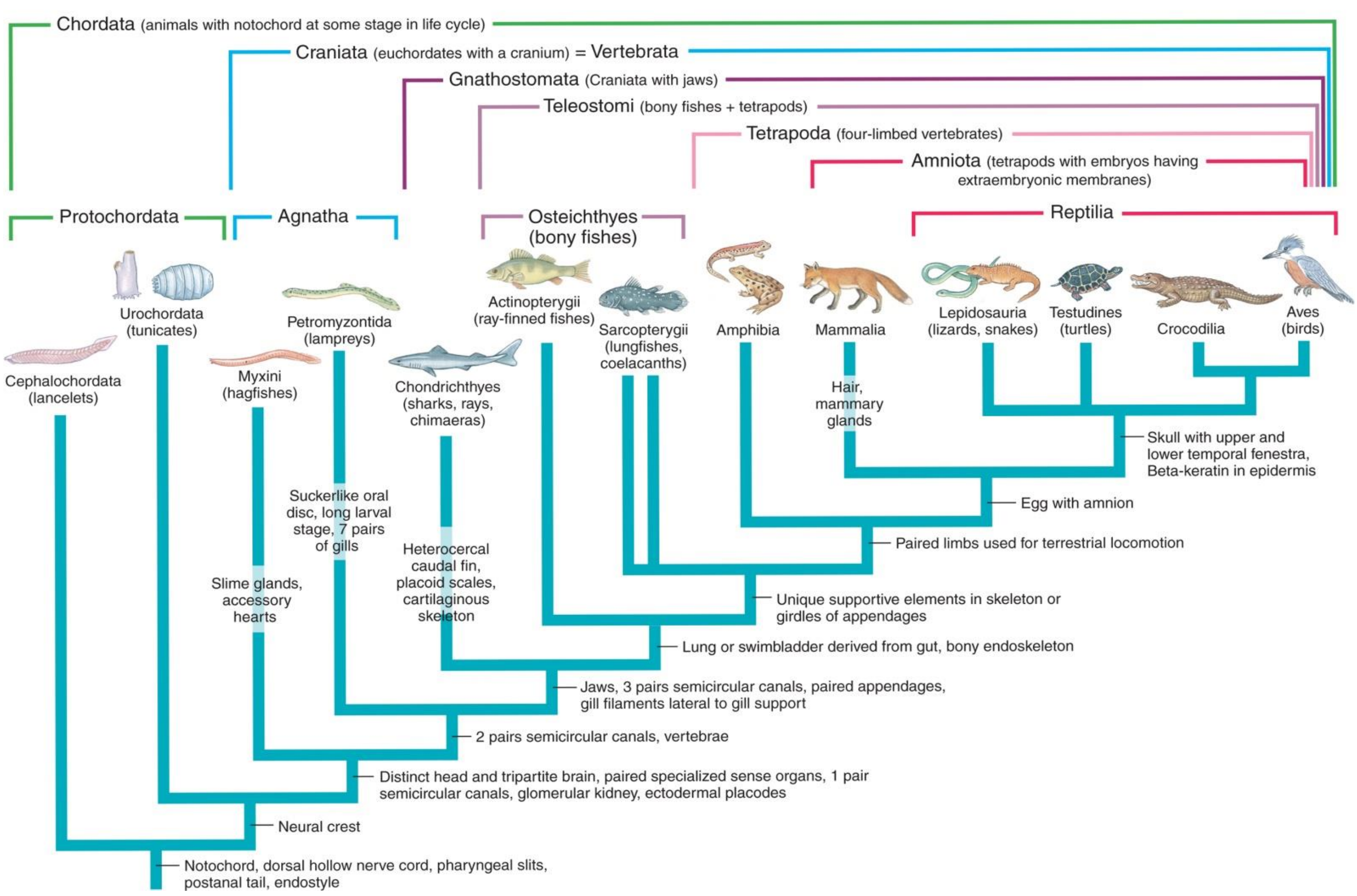
Pharyngeal slits are openings that lead from the pharyngeal cavity to the outside. They are formed when pharyngeal grooves and pharyngeal pouches meet to form an opening. In tetrapods, the pharyngeal pouches give rise to the Eustachian tube, middle ear cavity, tonsils, and parathyroid glands. The perforated pharynx evolved as a **filter feeding apparatus**. Later, they were modified into **internal gills** used for respiration.

4. Endostyle or Thyroid Gland

The endostyle in the pharyngeal floor secretes mucus that traps food particles. Found in protochordates and lamprey larvae. Secretes iodinated proteins. Homologous to the iodinated-hormone-secreting thyroid gland in adult lampreys and other vertebrates.

5. Postanal Tail

The postanal tail, along with somatic musculature and the stiffening notochord, provides motility in larval tunicates and amphioxus. Evolved for propulsion in water. Reduced to the coccyx (tail bone) in humans.



28 reptiles and birds.

- Vertebrate
- Feathers
- Wings (but not all fly)
- Scale-covered legs
- Homoeothermic (keeps their body temperature at one temperature)
- Endothermic (warm blooded)

Designed for flying

- Ornithologist – zoologists that study birds

The following characteristics equip birds for flying:

- Compact, lightweight, and very strong skeleton
- Lightweight beaks and skulls.
- A nearly rigid backbone that gives a solid support for the strenuous muscle activity required for flying
- Hollow spaces in the skeleton that provide room for air sacs, which contribute to the efficiency of the respiratory system and make the bird lighter.
- Bipedal ("two-footed") anatomy, which leaves the wings free for flying.
- A prominent ridge, or keel, on the breastbone to allow for the attachment of flight muscles by strong tendons.
- Three bones in the shoulder to support each wing.
- An efficient circulatory system, including a four-chambered heart.
- Powerful muscles to power the wings during flight.
- Three toes pointing forward and one toe pointing backward.
- Leg has a special design that allows the bird to stay on their perch even if they are sleeping.

Perching Birds

Leg has a special design that allows the bird to stay on their perch even if they are sleeping.

- Thrushes
- Robins
- Bluebird
- Goldfinch
- House sparrow
- Humming bird
- Woodpecker

Birds of Prey

Especially acute eyesight they have sharp, powerful talons (grasping and killing their prey)

- Hooked beak
- Vultures
- California condor
- Sea eagle
- Bald eagle
- Golden eagle
- Hawks
- Osprey
- Falcons
- Owls

Swimming and Wading Birds

Many have water repellent feathers they have webbed or lobed feet for swimming. Some birds have very long legs designed for wading

- Ducks
- Geese
- Storks
- Herons
- Flamingos
- Cranes
- Egrets

Game Birds

Have been hunted for food and sport. Large flight muscles (breast meat) allow them to burst into flight

- Quail
- Pheasant
- Partridge
- Grouse
- Doves
- Turkey

Tropical Birds and Flightless Birds

1. Tropical Birds

Live in the world's tropical forests, brightly colored and many have large unusual beaks

- Parakeets
- Toucans
- Macaw

2. Flightless birds

Have wings or wing-like structures. Usually equipped with powerful legs for running

- Ostrich
- Emu
- Kiwi
- Penguins

Extinct birds:

Some became extinct because of the pressures put on their habitat. Some have been extinct for thousands of years

- Dodo
- Moa
- Great auk
- Passenger pigeon
- Archaeopteryx
- Diatryma

Class Reptilia

Reptiles are tetrapod (four-limbed vertebrate) animals in the class reptilia, comprising today's turtles, crocodilians, snakes, amphisbaenians, lizards, tuatara, and their extinct relatives. The study of these traditional reptile orders, historically combined with that of modern amphibians, is called herpetology.

- Order chelonia
- Order crocodilia
- Order squamata
- Order rhynchocephalia

Order Chelonia

Turtles and tortoises

Shell consists of fused boney plates: Carapace (dorsal, top) and Plastron (ventral, lower).

Earliest fossils dated to 200 m.Y.A. 250 species worldwide, Variety of habitats, Most species ribs and spine fused to inner surface of carapace, Pelvic and pectoral girdles lie within the ribs, Sharp beak instead of teeth, Shell and limbs reflect habitat

Order Crocodilia

This includes Crocodiles, alligators, caimans, and gavial. Most closely related to dinosaurs. Heavy bodied, mostly aquatic. Carnivorous

Order Squamata

Lizards and snakes

- Upper jaw is loosely joined to the skull.
- Jacobson's organ

Lizards

Only 2 species venomous

- Gila monster
- Bearded lizard
- Autotomy
- Snakes

Backbone of 100 – 400 vertebrates

- Pair of ribs attached to each vertebra

Seize and swallow prey

Constrictors

Venom

- Fangs back of mouth
- Elapid, inject poison through fixed fangs in front
- Vipers, inject venom using large mobile fangs

Order Rhynchocephalia

Ancient order inhabit few small islands of new Zealand. 24 inches in length. Spiny crest that runs down the animal's back. Tolerate cool temp, burrow during day and hunt at night.

29 Plant biodiversity

Gymnosperm- naked seeds,

Angiosperms- flowering plants

Plant biodiversity, vital to ecosystems, food crops, and medicine production, is threatened by habitat destruction and species extinction. Plant biodiversity is invaluable because it balances ecosystems, protects watersheds, mitigates erosion, moderates climate, and provides shelter for animals. Threats to plant biodiversity include the increasing human population, pollution, deforestation, and species extinction. Plant extinction is progressing at an alarming rate; this, in turn, affects other species, which also become extinct because they depend on the delicate ecological balance. Efforts to preserve plant biodiversity currently include heirloom seed collections and barcoding DNA analysis.

Biodiversity of Plants

Heirloom seed
Seeds which are not of agricultural importance yet hold traditional importance; these seeds are kept in seed banks and are still maintained by some gardeners and farmers

Barcoding
A taxonomic method that uses a short genetic marker in an organism's DNA to identify it as belonging to a particular species

Biodiversity

The diversity (number and variety of species) of plant and animal life within a region

Threats to Plant Biodiversity

1. Plants play a key role in ecosystems. They are a source of food and medicinal compounds while also providing raw materials for many industries. Rapid deforestation and industrialization, however, threaten plant biodiversity. In turn, this threatens the ecosystem.

2. Biodiversity of plants ensures a resource for new food crops and medicines. Plant life balances ecosystems, protects watersheds, mitigates erosion, moderates climate, and provides shelter for many animal species.

3. The explosion of the human population, especially in tropical countries where birth rates are highest and economic development is in full swing, is leading to human encroachment into forested areas. To feed the larger population, humans need to obtain arable land which leads to massive clearing of trees. The need for more energy to power larger cities and economic growth results in the construction of dams, the consequent flooding of ecosystems, and increased emissions of pollutants. Other threats to tropical forests come from poachers who log trees for their precious wood. Ebony and Brazilian rosewood, both on the endangered list, are examples of tree species driven almost to extinction by indiscriminate logging.

4. The number of plant species becoming extinct is increasing at an alarming rate. Because ecosystems are in a delicate balance and because seed plants maintain close symbiotic relationships with animals, whether predators or pollinators, the disappearance of a single plant can lead to the extinction of connected animal species. A real and pressing issue is that many plant species have not yet been cataloged; their place in the ecosystem is unknown. These unknown species are threatened by logging, habitat destruction, and loss of pollinators.

They may become extinct before we have the chance to begin to understand the possible impacts resulting from their disappearance. Efforts to preserve biodiversity take several lines of action, from preserving heirloom seeds to barcoding species. Heirloom seeds come from plants that were traditionally grown in human populations, as opposed to the seeds used for large-scale agricultural production. Barcoding is a technique in which one or more short gene sequences, taken from a well-characterized portion of the genome, are used to identify a species through DNA analysis.

30 History of Biodiversity

Biodiversity is the result of 3.5 billion years of evolution. The origin of life has not been definitely established by science, however some evidence suggests that life may already have been well-established only a few hundred million years after the formation of the earth. Until approximately 600 million years ago, all life consisted of

- Archaea
- Bacteria
- Protozoans and similar single-celled organisms

Historical Milestones of Biodiversity

- The history of biodiversity during the phanerozoic (the last 540 million years), starts with rapid growth during the cambrian explosion—a period during which nearly every phylum of multicellular organisms first appeared. Over the next 400 million years or so, invertebrate diversity showed little overall trend and vertebrate diversity shows an overall exponential trend.
- This dramatic rise in diversity was marked by periodic, massive losses of diversity classified as mass extinction events. A significant loss occurred when rainforests collapsed in the carboniferous.
- The worst was the permian-triassic extinction event, 251 million years ago.
- Vertebrates took 30 million years to recover from this event.
- The fossil record suggests that the last few million years featured the greatest biodiversity in history.
- However, not all scientists support this view, since there is uncertainty as to how strongly the fossil record is biased by the greater availability and preservation of recent geologic sections
- Some scientists believe that corrected for sampling artefacts, modern biodiversity may not be much different from biodiversity 300 million years ago., Whereas others consider the fossil record reasonably reflective of the diversification of life.
  - Estimates of the present global macroscopic species diversity vary from 2 million to 100 million, with a best estimate of somewhere near 9 million, the vast majority arthropods. Diversity appears to increase continually in the absence of natural selection.

31 Importance of Biodiversity

Biodiversity has a number of functions on the Earth.

These are as follows:

- Maintaining balance of the ecosystem:
- Recycling and storage of nutrients,
- combating pollution, and stabilizing climate, protecting water resources,
- forming and protecting soil and maintaining Eco-balance.
- Intrinsic value
- A philosophical concept of the value of something independent of its value to anyone or anything

Provision of biological resources

- Provision of medicines and pharmaceuticals, food for the human population and animals, ornamental plants, wood products, breeding stock and diversity of species, ecosystems and genes.
- Quinone is a drug used for the treatment of malaria which is obtained from the Cinchona genus of plants.

Social benefits:

Recreation and tourism, cultural value and education and research. The role of biodiversity in the following areas will help make clear the importance of biodiversity in human life:

Biodiversity and food:

80% of human food supply comes from 20 kinds of plants. But humans use 40,000 species for food, clothing and shelter. Biodiversity provides for variety of foods for the planet.

Biodiversity and human health

The shortage of drinking water is expected to create a major global crisis. Biodiversity also plays an important role in drug discovery and medicinal resources. Medicines from nature account for usage by 80% of the world's population.

Biodiversity and industry

Biological sources provide many industrial materials. These include fiber, oil, dyes, rubber, water, timber, paper and food.

Biodiversity and culture

- Biodiversity enhances recreational activities like bird watching, fishing, trekking etc. It inspires musicians and artists.

32 Modern plant breeding

Modern facilities in molecular biology are now used in plant breeding.

Modern plant breeding may use techniques of molecular biology to select, or in the case of genetic modification, to insert, desirable traits into plants. Application of biotechnology or molecular biology is also known as molecular breeding.

Steps of plant breeding

The following are the major activities of plant breeding:

- Collection of variation
- Selection
- Evaluation
- Release
- Multiplication
- Distribution of the new variety
- Selling to people
- Marker assisted selection

Genetic modification

Transgenic plants

Genetic modification of plants is achieved by adding a specific gene or genes to a plant, or by knocking down a gene with RNAi, to produce a desirable phenotype. The plants resulting from adding a gene are often referred to as transgenic plants. If for genetic modification genes of the species or of a crossable plant are used under control of their native promoter, then they are called cisgenic plants. Sometimes genetic modification can produce a plant with the desired trait or traits faster than classical breeding because the majority of the plant's genome is not altered.

Traits improved by Transgenic techniques and breeding

- Water use efficiency
- Nutrient use efficiency (particularly nitrogen and phosphorus)
- Weed competitiveness
- Tolerance of mechanical weed control
- Pest/disease resistance
- Early maturity (as a mechanism for avoidance of particular stresses)
- Abiotic stress tolerance (i.e. drought, salinity, etc...)
- Addressing global food security through plant breeding
- Increased yield without expansion
- Breeding for increased nutritional value
  - Breeding for tolerance

33 Reasons for Loss of biodiversity

The earth's biodiversity is in grave danger In the present era, human beings are the most dangerous cause of destruction of the earth's biodiversity. In 2006, the terms threatened, endangered or rare were used to describe the status of many species. The "evil quartet" identified by Jared Diamond is overkill, habitat destruction, secondary extinctions and introduced species. Factors identified by Edward Wilson are described by the acronym- HIPPO standing for habitat destruction, climate change, invasive species, pollution, human overpopulation and overharvesting

Habitat destruction is a major cause for biodiversity

Habitat loss is caused by deforestation, overpopulation, pollution and global warming. Species which are physically large and those living in forests or oceans are more affected by habitat reduction. Some expert's estimate that around 30% of all species on earth will be extinct by 2050. According to the International Union for Conservation of Nature (IUCN), globally about one third of all known species are threatened with extinction. Even it is estimated that 25% of all mammals will be extinct within 20 years.

The whole system's balance is threatened

Fresh water ecosystems are nowadays the most threatened ecosystems. Invasive species refer to those that would normally remain constrained from an ecosystem because of the presence of natural barriers. Since these barriers are no longer existing, invasive species invade the ecosystem, destroying native species. Human activities have been the major cause for encouraging invasive species.

Effects on species

Species can also be threatened by genetic pollution- uncontrolled hybridization and gene swamping. For instance, abundant species can interbreed with rare species thus causing swamping of the gene pool. Over exploitation is caused by activities such as over fishing, over hunting, excessive logging and illegal trade of wildlife. Over 25% of global fisheries are being overfished at unsustainable levels.

Global warming

Global warming is also becoming a major cause for loss of biodiversity. For example if the present rate of global warming continues, coral reefs which are biodiversity hotspots will disappear in 20-40 years. 10% of all species might become extinct by 2015, if global warming continues.

Point to ponder

biodiversity which is crucial for the wellbeing of life on earth, is coming under the threat of many factors related to human activities. There is an urgent need to take action to protect the magnificent biodiversity of our planet. We must create economic policies in order to maintain the Earth's biodiversity and take appropriate measures to protect habitats and species

34 Plant conservation

Consequences of deforestation

The consequences of deforestation are

- Increase in the temperature and pollution level on the earth.
- Increase in the level of carbon dioxide in the atmosphere leading to global warming.

- Lowering of ground water level.
- Disturbs the balance in nature.
- Decrease in rainfall leading to draught.
- Soil erosion and decrease in soil fertility leading to desertification.
- Decrease in the water holding capacity of soil leading to floods

Conservation of forest and wildlife

- Forest and wildlife can be conserved by setting up areas like Biosphere reserves Wildlife sanctuaries, National parks, etc.

Biosphere reserves: - are large areas of protected land for conservation of biodiversity and the traditional life of the tribals living there.

National parks: - are areas reserved for wildlife where they can freely use the habitats and natural resources.

Wildlife sanctuaries: - are areas where animals are protected from any disturbance to them or their habitat.

- **Biosphere Reserve**

Biosphere reserves are large areas of protected land for conservation of biodiversity and the traditional life of the tribes living there.

Biodiversity is the variety of plants, animals and microorganisms found in the area.

- **Flora and fauna**
- **Flora** are the plants found in a particular area.
- **Fauna** are the animals found in a particular area.

Endemic species are those species of plants and animals found only in a particular area and not found anywhere else.

• National parks

National parks are areas reserved for wildlife where they can freely use the habitats and natural resources. Eg Ayubia National Park is the first Reserve Forest in Pakistan.

Reforestation

Reforestation is the restocking of destroyed forests by planting new trees. We should plant at least as many trees as we cut. We have already caused a lot of damage to our forests. If we have to regain our green wealth, reforestation is the only option.

35 Plant breeding and Improvement

- Plant breeding is the art and science of changing the traits of plants in order to produce desired characteristics. Plant breeding can be accomplished through many different techniques ranging from simply selecting plants with desirable characteristics for propagation, to methods that make use of knowledge of genetics and chromosomes, to more complex molecular techniques.
- Plant breeding has been practiced for thousands of years, since near the beginning of human civilization. It is practiced worldwide by individuals such as gardeners and farmers, or by professional plant breeders employed by organizations such as government institutions, universities, crop-specific industry associations or research centres.
- International development nation agencies believe that breeding new crops is important for ensuring food security by developing new varieties that are higheryielding, disease resistant, drought-resistant or regionally adapted to different environments and growing conditions

History of plant breeding

- Plant breeding started with sedentary agriculture and particularly the domestication of the first agricultural plants, a practice which is estimated to date back 9,000 to 11,000 years. Initially early farmers simply selected food plants with particular desirable characteristics, and employed these as progenitors for subsequent generations, resulting in an accumulation of valuable traits over time. Modern bread wheat is a mixture of recombined genes from three different wild species.

- Gregor Mendel's experiments with plant hybridization led to his establishing laws of inheritance. Once this work became well known, it formed the basis of the new science of genetics, which stimulated research by many plant scientists dedicated to improving crop production through plant breeding
- Modern plant breeding is applied genetics, but its scientific basis is broader, covering molecular biology, cytology, systematics, physiology, pathology, entomology, chemistry, and statistics (biometrics). It has also developed its own technology.

Classical plant breeding

- One major technique of plant breeding is selection, the process of selectively propagating plants with desirable characteristics and eliminating or "culling" those with less desirable characteristics.
- Deliberate interbreeding (crossing) of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. Plants are crossbred to introduce traits/genes from one variety or line into a new genetic background. For example, a mildew-resistant pea may be crossed with a high-yielding but susceptible pea, the goal of the cross being to introduce mildew resistance without losing the high-yield characteristics
- Classical breeding relies largely on homologous recombination between chromosomes to generate genetic diversity. The classical plant breeder may also make use of a number of in vitro techniques such as protoplast fusion, embryo rescue or mutagenesis (see below) to generate diversity and produce hybrid plants that would not exist in nature.

Traits that breeders have tried to incorporate into crop plants include:

- Improved quality, such as increased nutrition, improved flavor, or greater beauty
- Increased yield of the crop
- Increased tolerance of environmental pressures (salinity, extreme temperature, drought)
- Resistance to viruses, fungi and bacteria
- Increased tolerance to insect pests
- Increased tolerance of herbicides
- Longer storage period for the harvested crop

36 Genetic Diversity in Ecosystem Management

What is genetic diversity?

- Genetic diversity is the variation at the level of
  - individual genes,
  - In a population,

Genetic diversity, means that the population contains most of the possible alleles for each particular gene locus. Provides a mechanism for populations to adapt to their changing environment. The more variation, the better the chance that at least some of the individuals will have an allelic variant that is suited for the new environment, and will produce offspring with the variant that will in turn reproduce and continue the population into subsequent generations.

Why study genetics in Ecosystem Management

- Loss of genetic diversity can imply lack of evolution and premature extinction.
- Fitness decreases with reduced genetic variation.
- Populations of endangered species are small and tend to lose genetic diversity.
- When genetic variation disappears the basis for life on earth becomes impoverished

Some useful definitions

- Locus: physical location of a gene.
- Allele: one of the genes at a particular locus.
- Homozygous: two of the same alleles at a given locus.
- Heterozygous: two different alleles at a given locus.

- Fitness: contribution of an individual's genotype to the next generation

Levels of genetic diversity

- **Within individuals,**
- **Among individuals within the same population, Among populations**
- **Amog Population**

Within individuals,

Every diploid organism has duplicated genetic information (from its mother and father, It is the same type of information (locus) but the specific forms may differ (alleles)

Among individuals within a population,

Different individuals carry different genetic information, The sum of the variation of an interbreeding population is called **Gene pool**

Among populations,

- Different gene pools among populations.

Isolation is and important factor responsible for among population genetic diversity (natural or man made barriers).

Can lead to

- local adaptation,
- Natural local adaptation: Example of mistletoe species in Argentina and Chile,
- Ultimate effect of among population variability: Speciation

Heterozygosity

- In an individual organism, is the state of possessing different alleles at a given locus in regard to a given character,
- At the population level: "The fraction of individuals in a population that are heterozygous for a specific locus",
    - Often positively correlated with fitness,
    - Often positively correlated with population size (declines in small populations),
- When an organism is referred to as a heterozygote, or being heterozygous for a specific gene, it means that the organism carries two different versions of that gene on the two corresponding chromosomes.
- Heterozygosity refers to both the state of being a heterozygote, but more commonly in population genetics to the fraction of individuals in a population that are heterozygous for that locus.

Loss of genetic diversity

Two ways of losing it

Loss of genetic diversity in small populations,

- Changes in the natural distribution of genetic diversity among populations (artificial isolation and mixing)
- Population size critical factor,
- Census population size (Nc) vs. Effective population size (Ne), Usually Ne is much smaller that Nc (10 to 30%)

Four factors responsible for genetic diversity loss in small populations :

- Genetic drift,
- Founder effect,
- Demographic bottleneck,
- Inbreeding

– Genetic drift

- " Random change in gene frequency within a population" (Meffe et al.),

- Not necessarily adaptive, Stronger in small populations

– Founder effect,

"The establishment of a new population by a few original founders which carry only a small fraction of the total genetic variation of the parental population." (Ernst Mayr), Alleles may be lost, Differentiation from the parental population, Example: Irish Potato Famine

– Demographic bottleneck,

Population suffers reduction in size and then recovers, Random losses of genetic diversity, Usually associated with catastrophic events or diseases, Genetic variation doesn't rebound from a decrease as quickly as population size.

– Inbreeding

Inbreeding is breeding between close relatives. Leads to a reduction in genetic diversity (inbreeding depression: reduced health and fitness). The primary problem with inbreeding is that two closely related individuals are likely to have very similar genomes, and if one individual has a gene for a given negative trait, then the other is likely to have it as well., Inbreeding increases homozygosity (therefore decreases heterozygosity)

The other way to loss genetic diversity

- Changes in the natural distribution of genetic diversity among populations
- Related with the geographical distribution of the species and therefore with landscape management issues
- Artificial isolation
- Avoids genetic flux among populations due to barriers such as highways, dams, etc
- Artificial mixing Enhances genetic flux among populations where that flux was not possible due to natural barriers (examples: bridges, tunnels)

Allelic richness

- Allelic richness Is the number of alleles in a sample (population),
- Rare alleles are important during extreme environmental events,
- Loss of allelic richness is perhaps more serious than loss of quantitative variation because alleles are lots forever while quantitative variation can be recovered,
- Rare alleles are more important that their frequency in the population
- Example: Peppered moth and pollution in Manchester, Small sized populations are more prone to lose allelic richness

Usefulness of Ecosystem Management and Genetics in Conservation

Ecosystem Management and Genetics in Conservation Useful in

- Endangered small populations,
- Captive breeding,
- Translocation of individuals,
- Determining dispersal patterns,
- Recognize limitations and scale of application, I

t's easy to lose the sight of the larger picture and try to apply a genetics approach when it is not appropriate to do so.

Conclusion

Ecosystem Management and Genetics in Conservation is Very powerful tool usually useful to solve specific problems. Rarely useful if it is not combined with other type of approaches

37 in situ and ex situ conservation

- **In situ**

Conservation of species in their natural habitat E.g. natural parks, nature reserves

- **Ex situ:**

Conserving species in isolation of their natural habitat E.g. zoos, botanical gardens, seed banks

- **In situ conservation**

Setting up wild life reserves is not just a matter of building a fence around an area and letting it grow “wild”

Nature reserves and national parks

- First the area that is suitable for the creation of a reserve has to be identified and delimited. This requires surveys to collect data on key species. Property may have to be expropriated.
- A legal framework may need to be set up to control human activities in the area and in it’s immediate surroundings
- Policing the area may also be necessary o If part of the area has been degraded due to bad land use it may need restoring o Alien species that have penetrated the area may need excluding or eliminating o Constant management will be needed to maintain the habitat of the species being conserved o This may mean arresting natural succession

The advantages of in situ conservation

- The species will have all the resources that it is adapted too
- The species will continue to evolve in their environment
- The species have more space
- Bigger breeding populations can be kept
- It is cheaper to keep an organism in its natural habitat

However there are problems

- It is difficult to control illegal exploitation (e.g. poaching)
- The environment may need restoring and alien species are difficult to control

Ex situ conservation Captive breeding

- The Hawaiian goose was practically extinct in the wild
- 12 birds were taken into captivity
- A population of 9000 was released back into the wild
- The experiment failed because the original cause rats had not been eliminated.
- The rats eat the eggs and the nestlings of the geese

Pere David’s deer success or failure?

- Pere David’s deer was a native species of China
- In 1865 18 were taken into zoological collections
- Meanwhile it became extinct in the wild
- By 1981 there were 994 individuals scattered through zoological collections

Ex situ conservation

- Captive breeding of endangered species is a last resort
- These species have already reached the point where their populations would not recover in the wild
- It works well for species that are easily bred in captivity but more specialised animals are difficult to keep (aye aye)
- Isolated in captivity they do not evolve with their environment

Zoos: The land of the living dead?

- They have a very small gene pool in which to mix their genes
- Inbreeding is a serious problem

- Zoos and parks try to solve this by exchanging specimens or by artificial insemination where it is possible
- In vitro fertilisation and fostering by a closely related species has even been tried (Indian Guar – large species of cattle - cloned)
- Even if it is possible to restore a population in captivity the natural habitat may have disappeared in the wild
- Species that rely on this much help are often considered to be "the living dead"

Botanical gardens

- Botanical gardens show the same problems as captive breeding of animals
- Originally the role of botanical gardens was economic, pharmaceutical and aesthetic
- There range of species collected was limited
- The distribution of botanical gardens reflects the distribution of colonial powers
- Most are found in Europe and North America
- But plant diversity is greatest in the tropics
- Botanical gardens show the same problems as captive breeding of animals

Seed banks

- Seeds can be maintained for decades or even centuries if the conditions are controlled • <5% humidity and –20°C
- Not all species are suited to this treatment
- Seeds need to be regularly germinated to renew stock or the seeds will eventually loose their viability
- Seed banks are at risk from power failure, natural disasters and war
- Duplicate stocks can be maintained
- Seeds kept in seed banks do not evolve with changes in the environment

International agencies

CITES (The Convention in International Trade in Endangered Species). Set up in 1988 to control and encourage the sustainable exploitation of species. The CITES conferences determine the status of a species and whether or not its exploitation requires regulation Species are placed into different appendices depending on their status

CITES Appendices

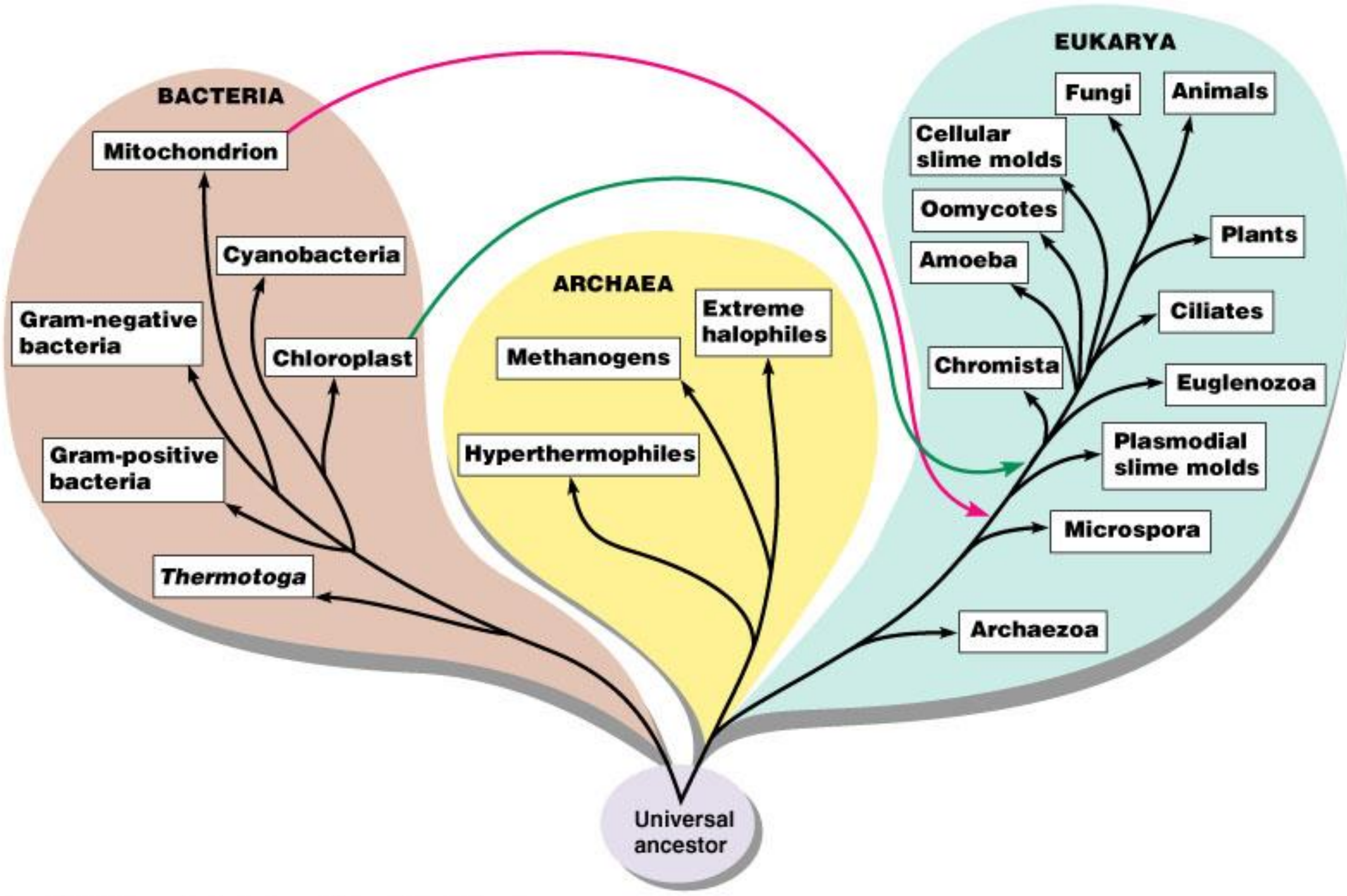
- Appendix 1: Total ban on exploitation
- Appendix 2: Limited exploitation subject to quotas
- Appendix 3: Species requiring protection in certain states only
- Species are reassessed every 2 years

WWF (World Wide Fund for Nature formerly World Wildlife Fund)

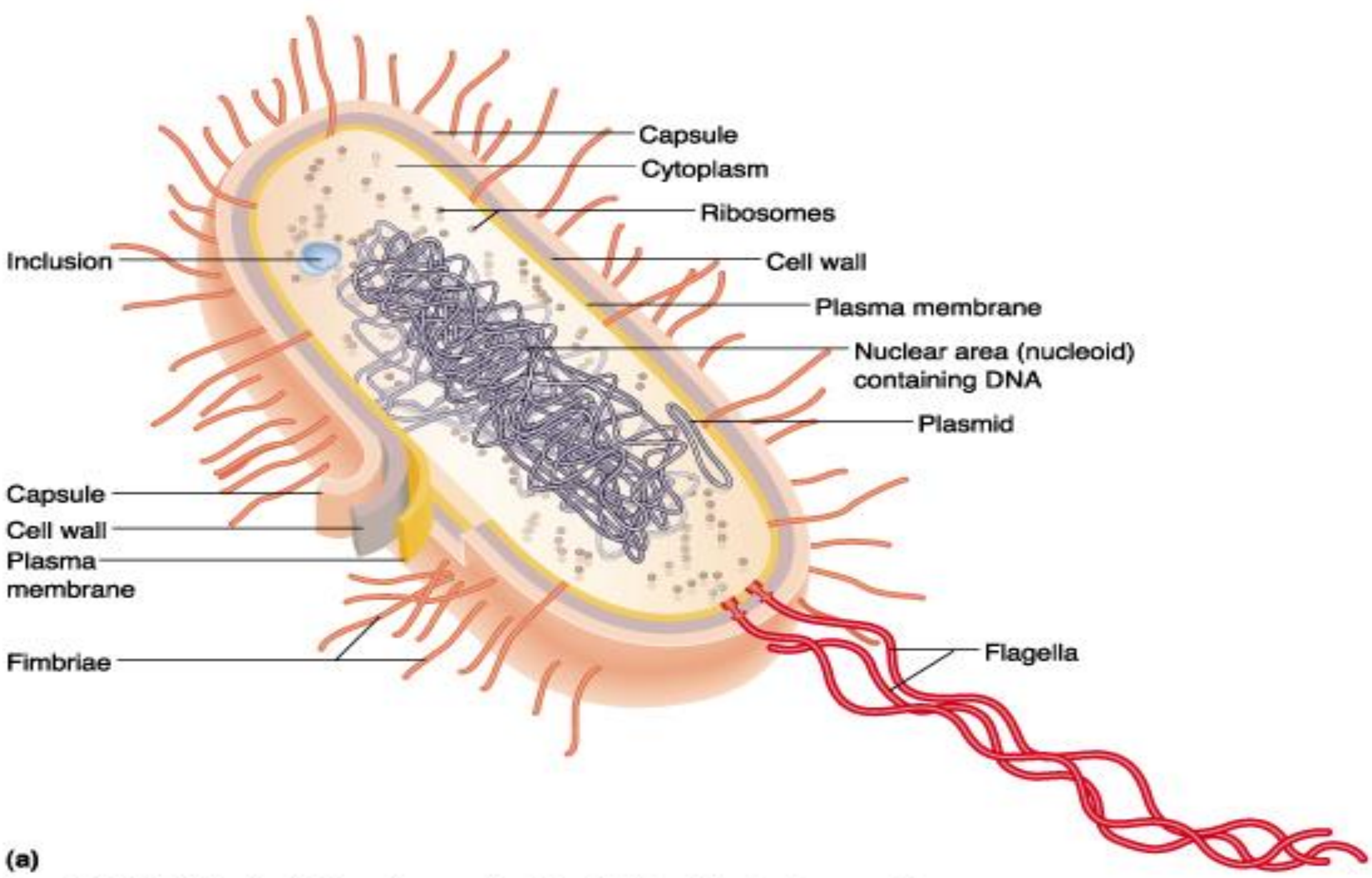
- Set up in 1961 as a non-governmental organisation
- Raises funds for conservation
- Lobbies parliaments for conservation
- Runs education programmes
- Provides advice to government conservation agencies
  - Raises awareness on conservation issues

38 Physiology of Microbial life

Phylogenetic Tree of Life (3 Domains)

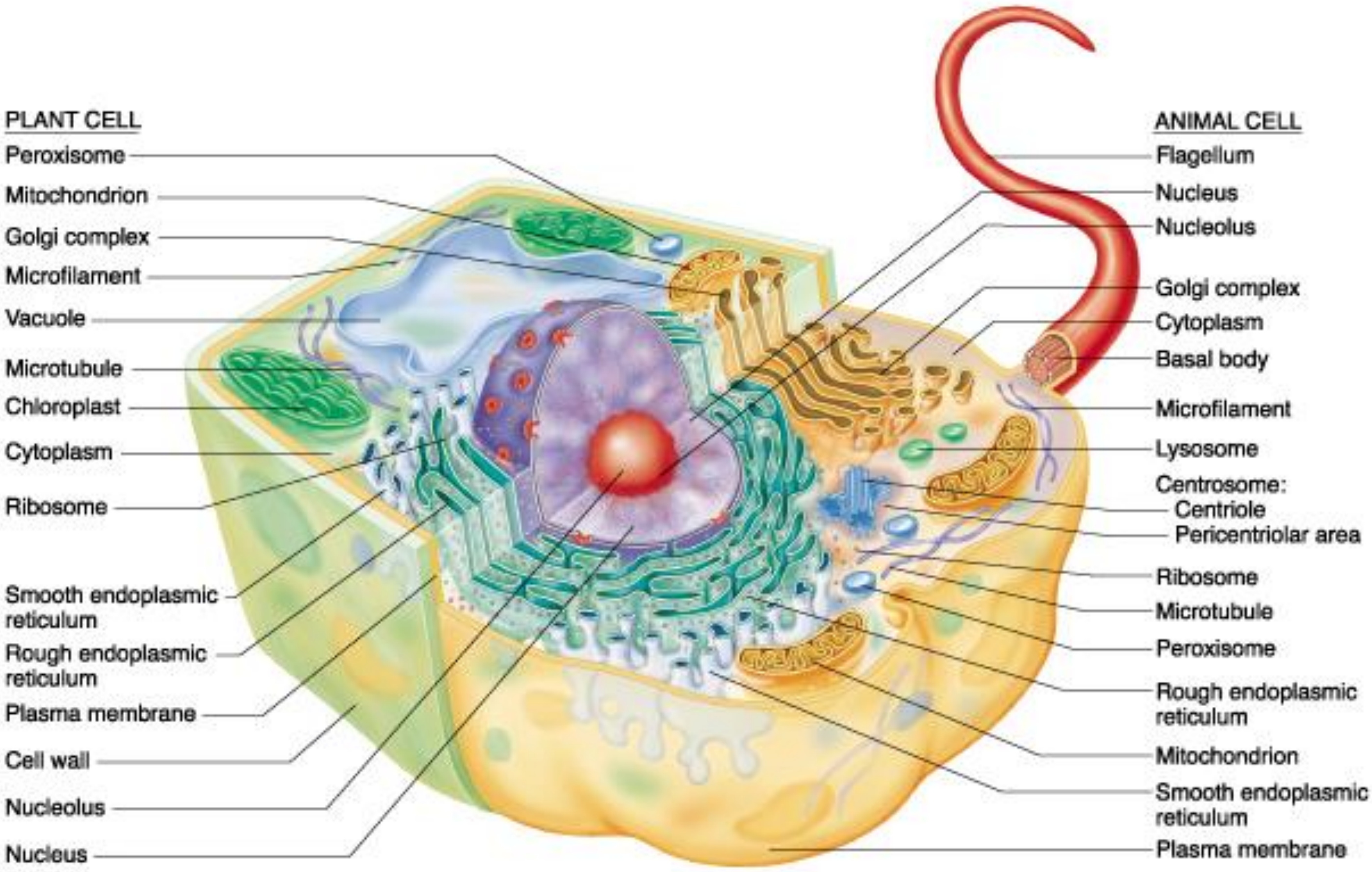


Prokaryote "Anatomy" Overview



Cell envelope: Collectively all the structures outside from the plasma membrane.

Eukaryote Cell "Anatomy"



(a) Highly schematic diagram of a composite eukaryotic cell, half plant and half animal

Peroxisome: Oxidizes amino acids, fatty acids and alcohol; self replicating.

Vacuole: membrane bound; liquid filled; storage of reserves and/or wastes.

Cell Wall: cellulose and lignin in plants; chitin in fungi; no peptidoglycan

TABLE 10.1 Some Characteristics of Archaea, Bacteria, and Eukarya

Methanosarcina

E. coli

Amoeba

	Archaea	Bacteria	Eukarya
Cell Type	Prokaryotic	Prokaryotic	Eukaryotic
Cell Wall	Varies in composition; contains no peptidoglycan	Contains peptidoglycan	Varies in composition; contains carbohydrates
Membrane Lipids	Composed of branched carbon chains attached to glycerol by ether linkage	Composed of straight carbon chains attached to glycerol by ester linkage	Composed of straight carbon chains attached to glycerol by ester linkage
First Amino Acid in Protein Synthesis	Methionine	Formylmethionine	Methionine
Antibiotic Sensitivity	No	Yes	No
rRNA Loop*	Lacking	Present	Lacking
Common Arm of tRNA†	Lacking	Present	Present

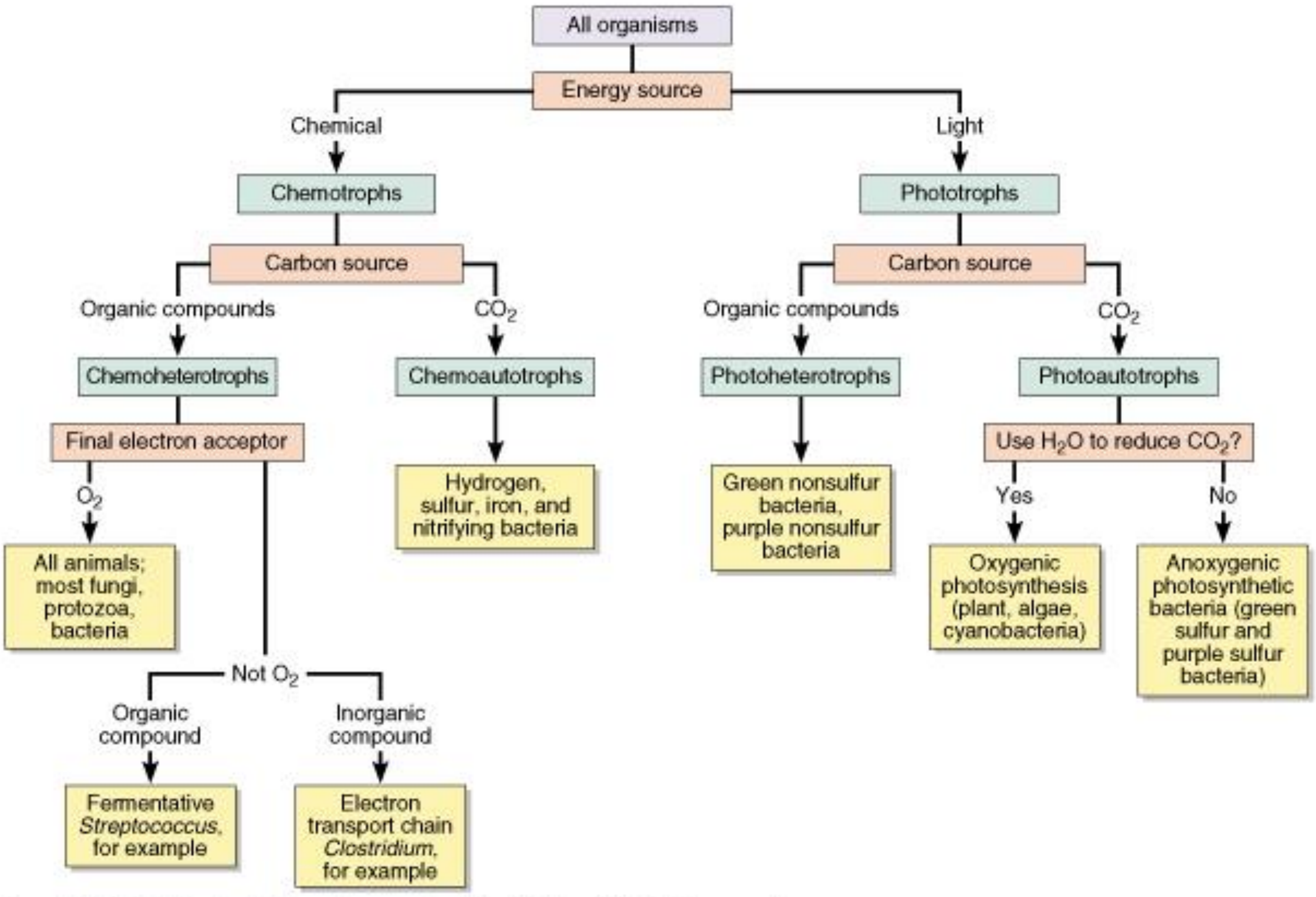
*Binds to ribosomal protein; found in all bacteria.
†A sequence of bases in tRNA found in all eukaryotes and bacteria: guanine-thymine-pseudouridine-cytosine-guanine.

Table 5.1 Sources of Carbon, Energy, and Electrons

Carbon Sources	
Autotrophs	CO_2 sole or principal biosynthetic carbon source (*pp. 207–8*)[a]
Heterotrophs	Reduced, preformed, organic molecules from other organisms (*chapters 9 and 10*)
Energy Sources	
Phototrophs	Light (*pp. 195–201*)
Chemotrophs	Oxidation of organic or inorganic compounds (*chapter 9*)
Electron Sources	
Lithotrophs	Reduced inorganic molecules (*pp. 193–94*)
Organotrophs	Organic molecules (*chapter 9*)

[a]For each category, the location of material describing the participating metabolic pathways is given within the parentheses.

Nutritional Types



What Lives Where and Why?

"Everything is everywhere, the environment selects"

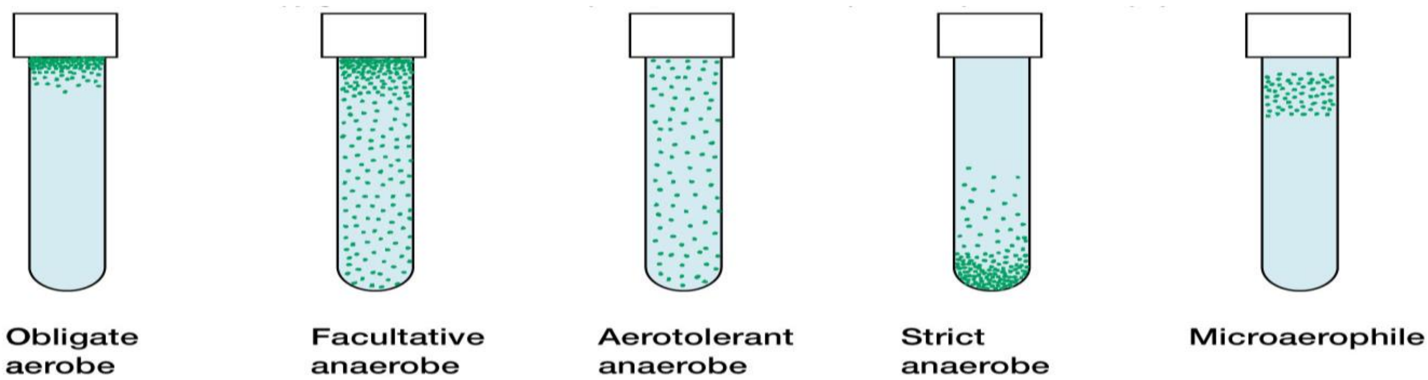
Martinus Beijerinck (ca. 1890)

- Tolerance to All Environmental Factors (Shelford's Law of Tolerance)
- Growth Limiting Resource (Liebig's Law of the Minimum)

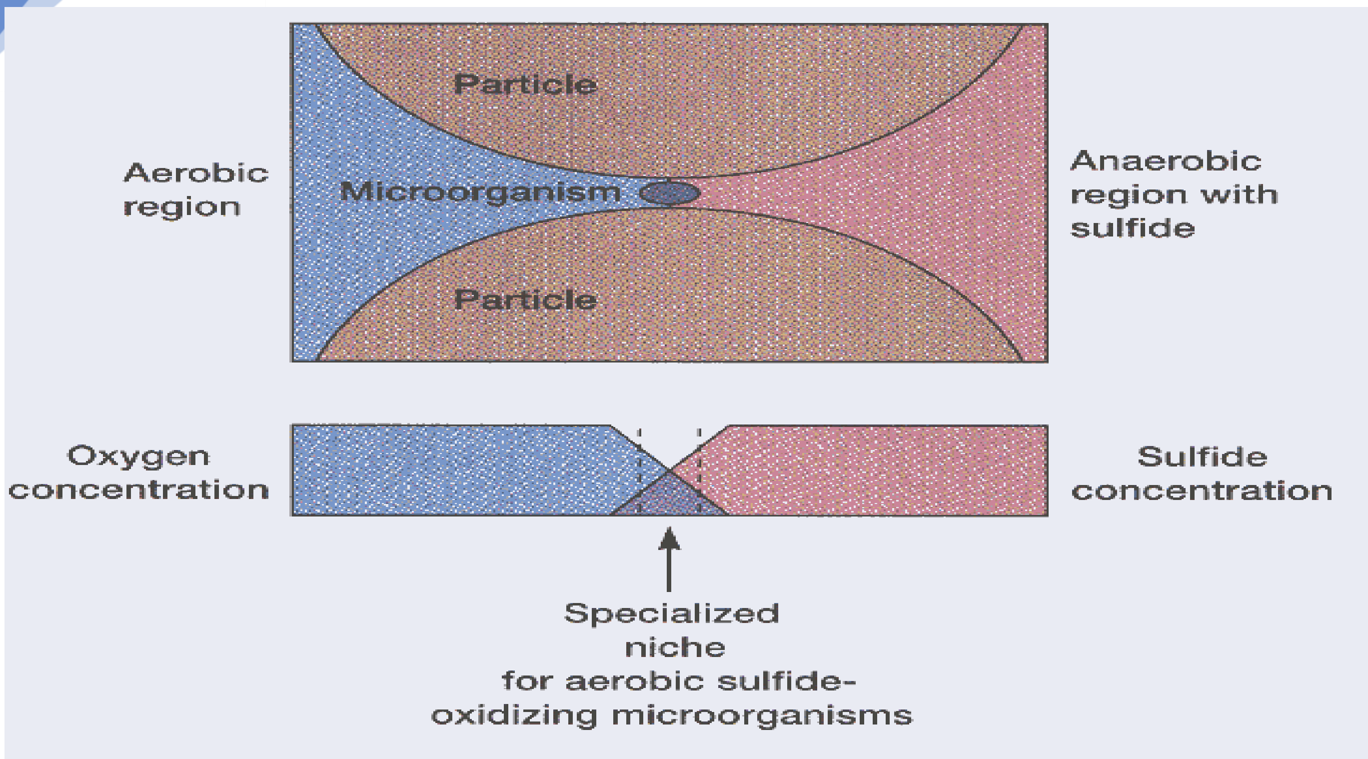
Environmental Factors

- Nutrients (org/inorg; macro/micro/trace)
- Temperature
- Solute Concentration and Water Activity
- pH (acidity versus alkalinity)
- Oxygen Concentration
- Barometric Pressure
- Electromagnetic Radiation

Oxygen Requirement Types



“Microbial Lasagna”



Microbial interactions control populations, too

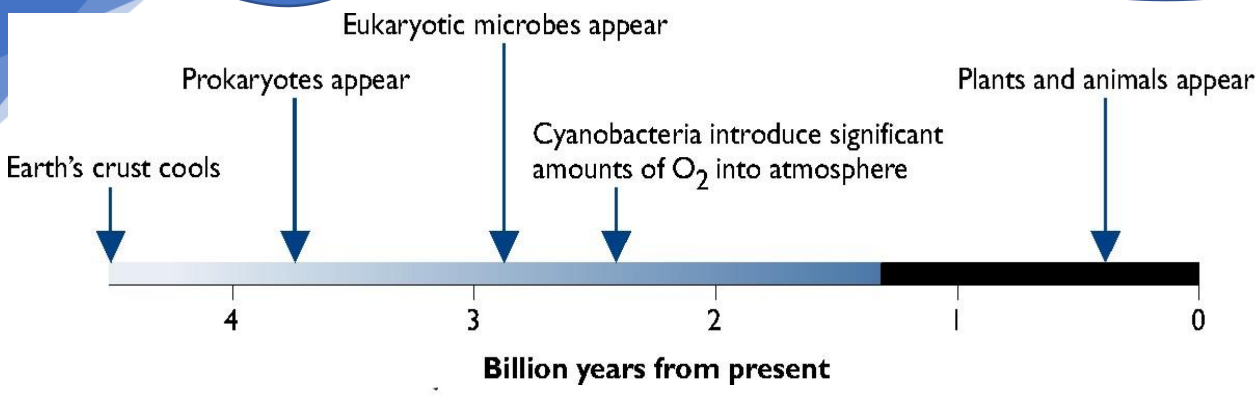
- **Positive interactions:**
  - Commensalism
  - Protocooperation
  - Mutualism
- **Negative Interactions:**
  - Amensalism:
  - Competition:
    - Intraspecific
    - Interspecific
  - Predation (e.g. *Bdellovibrio)*
  - Parasitism

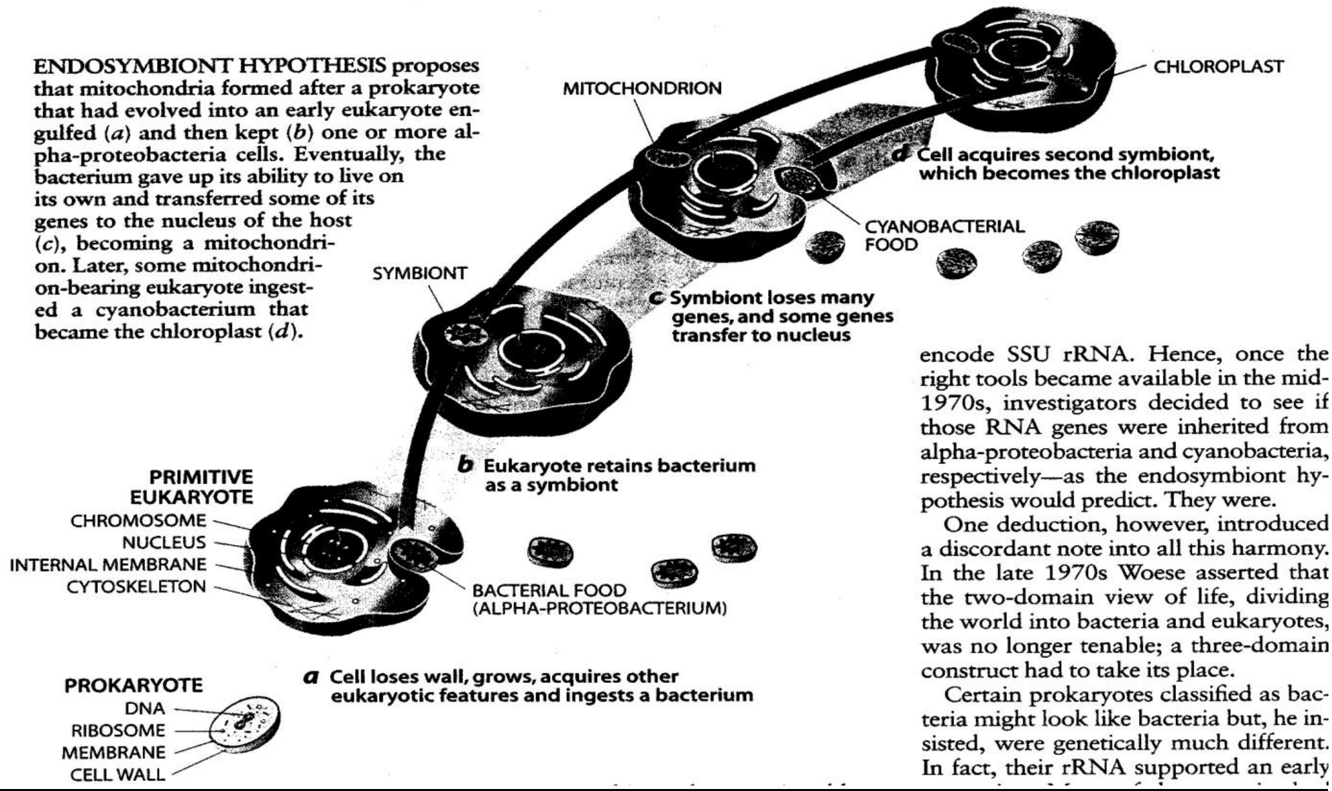
Predation and Disease (Parasitism) Control Populations Too!

- Protozoa and other “grazers”
  - May be selective.
- Viral Lysis
  - Highly selective.

39 Evolution of Microbial Life

Over 3.5 billion years of “microbes”
Micro-fossils of “cyanobacteria” and contemporary stromatolites.





ENDOSYMBIONT HYPOTHESIS proposes that mitochondria formed after a prokaryote that had evolved into an early eukaryote engulfed (*a*) and then kept (*b*) one or more alpha-proteobacteria cells. Eventually, the bacterium gave up its ability to live on its own and transferred some of its genes to the nucleus of the host (*c*), becoming a mitochondrion. Later, some mitochondrion-bearing eukaryote ingested a cyanobacterium that became the chloroplast (*d*).

encode SSU rRNA. Hence, once the right tools became available in the mid-1970s, investigators decided to see if those RNA genes were inherited from alpha-proteobacteria and cyanobacteria, respectively—as the endosymbiont hypothesis would predict. They were.

One deduction, however, introduced a discordant note into all this harmony. In the late 1970s Woese asserted that the two-domain view of life, dividing the world into bacteria and eukaryotes, was no longer tenable; a three-domain construct had to take its place.

Certain prokaryotes classified as bacteria might look like bacteria but, he insisted, were genetically much different. In fact, their rRNA supported an early

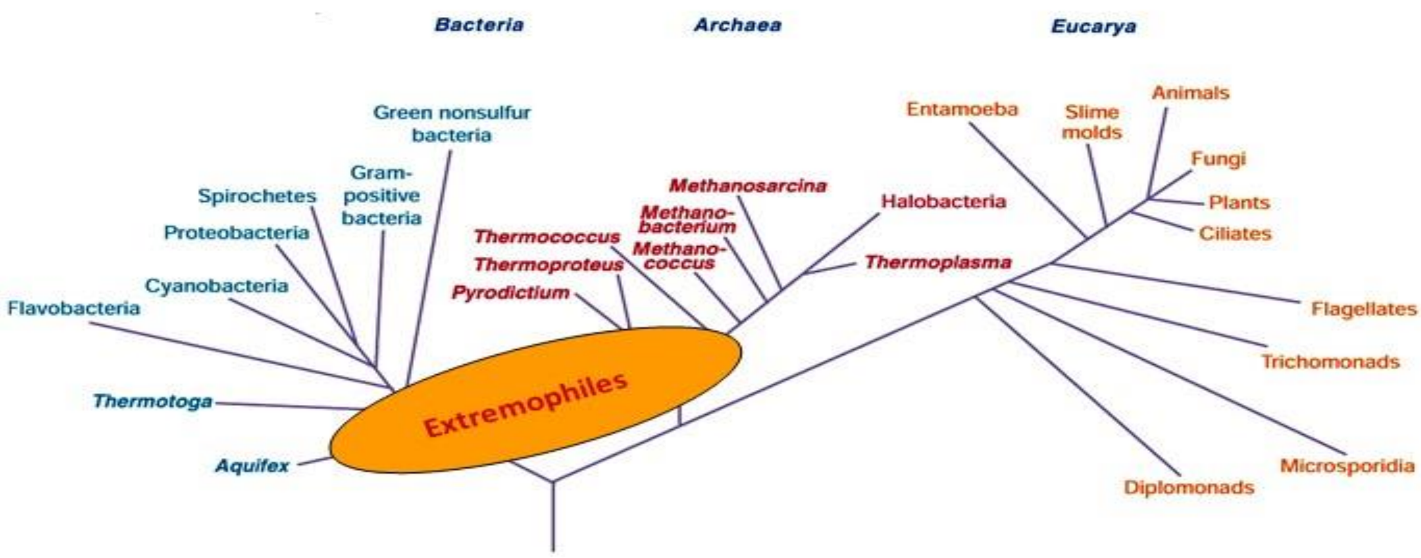
Acquisition of aerobic respiration from alpha-proteobacterium.
Acquisition of photosynthesis and Calvin Cycle from cyanobacterium.

• **Happened more than once?**

Major challenges for endosymbiotic theory

1. Most extant prokaryotes have rigid cell walls and don't do phagocytosis.
2. Hard to explain the nucleus (!) and flagella. (Eukaryotic flagella have a 9+2 arrangement of protein strands, vs. single strand for prokaryotic flagella.)

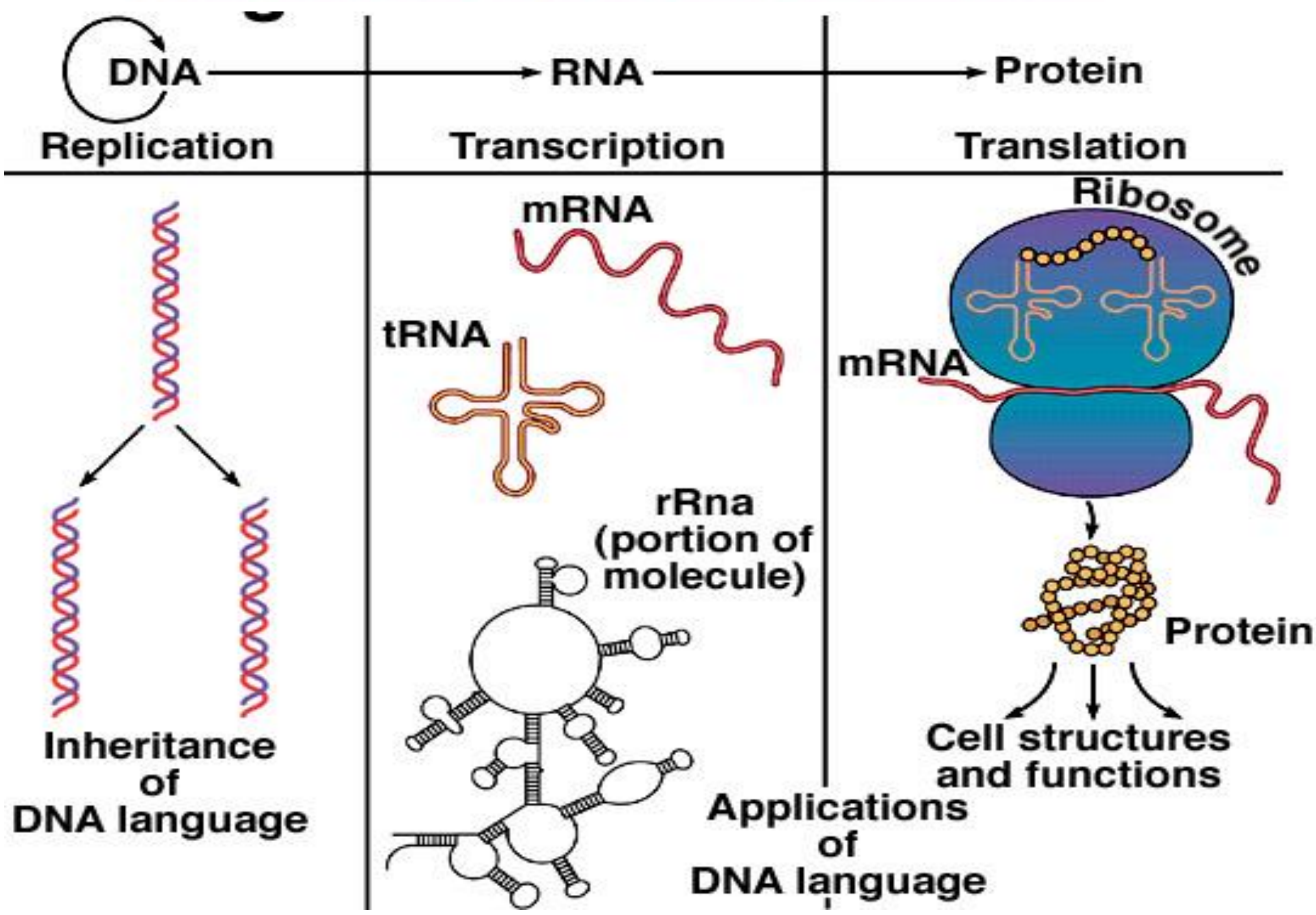
Phylogenetic Tree of Life:



Rooted Tree based on 16SrRNA and 18SrRNA sequence data.

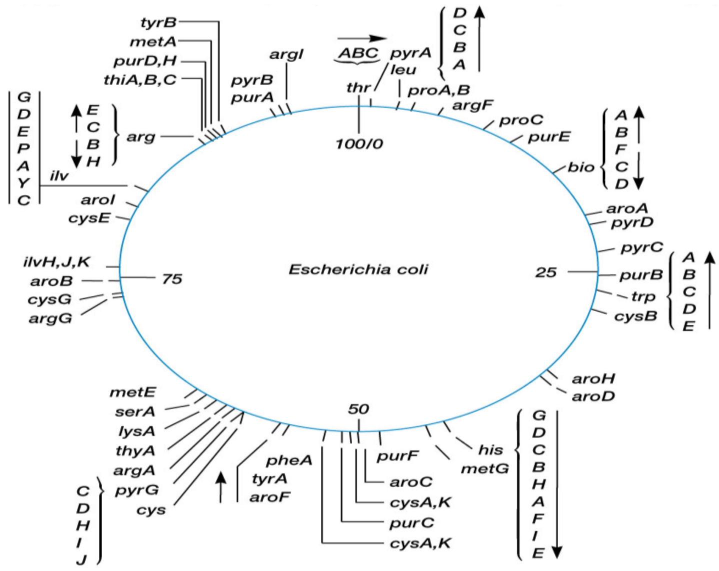
All extant life has evolved; evidence lost by extinction.

How does evolution work? We need to consider the molecule processes!



Bacterial Genomes

Chromosomal Map



- Only structural genes versus splash map
- Mostly single chromosome
- Size: 1-5 Mbp
- Many complete sequences (TIGR)!

Plasmids:

- Size: 2-200 bp
- Conjugative or not
- Copy number varies
- Gene functions vary

Scope of Mutation:

- A mutation is any change in the proper nucleic acid sequence of a specific gene in a cell's genome. It may result from a single base pair mismatch during DNA replication.
- Mutation can create genetic diversity within a population; either beneficial, neutral, bad, or lethal.
- Mutation could result in a new phenotype that is advantageous to successful reproduction of the mutated individual; this depends on particular environmental conditions, called selective pressures.
- Such beneficial mutations stay within a population from generation to generation, and drive the evolution of that species.
- Bad or lethal mutations are often lost from a population over subsequent generations.

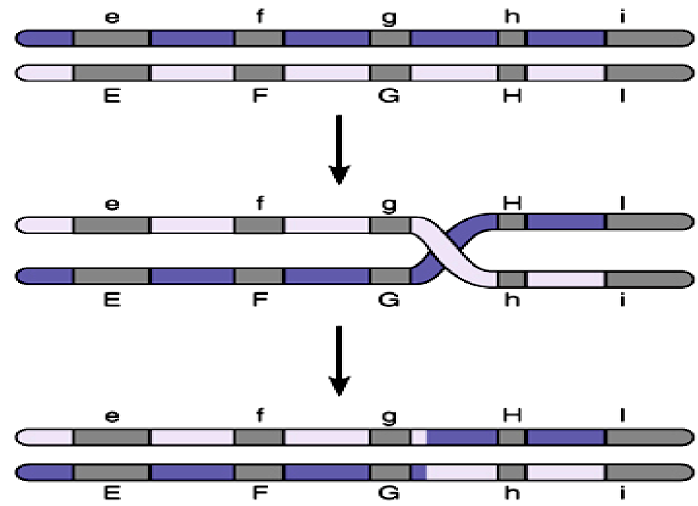
Mutation types:

- Macrolesions (large sequence sections)
  - Deleted *a-b-c-d-e-f-g-h → a-b-c-g-h*
  - Inserted *a-b-c-d-e-f-g-h → a-b-c-d-x-y-z-e-f-g-h*
  - Inverted *a-b-c-d-e-f-g-h → a-b-c-f-e-d-g-h*
  - Duplicated *a-b-c-d-e-f-g-h → a-b-c-d-e-f-d-e-f-g-h*
- Microlesions (1 or 2 bp alteration)
  - Point Mutations (Base Substitutions) *ACTG → ATTG*
  - Frameshifts (Insertions or Deletions)

    see the cat eat the rat → see thc ate att her at
- Mechanisms of microlesion mutation types
  - Spontaneous (1 per million; most corrected; 1 per billion remain)
  - Chemical mutagens
  - Radiation as mutagens

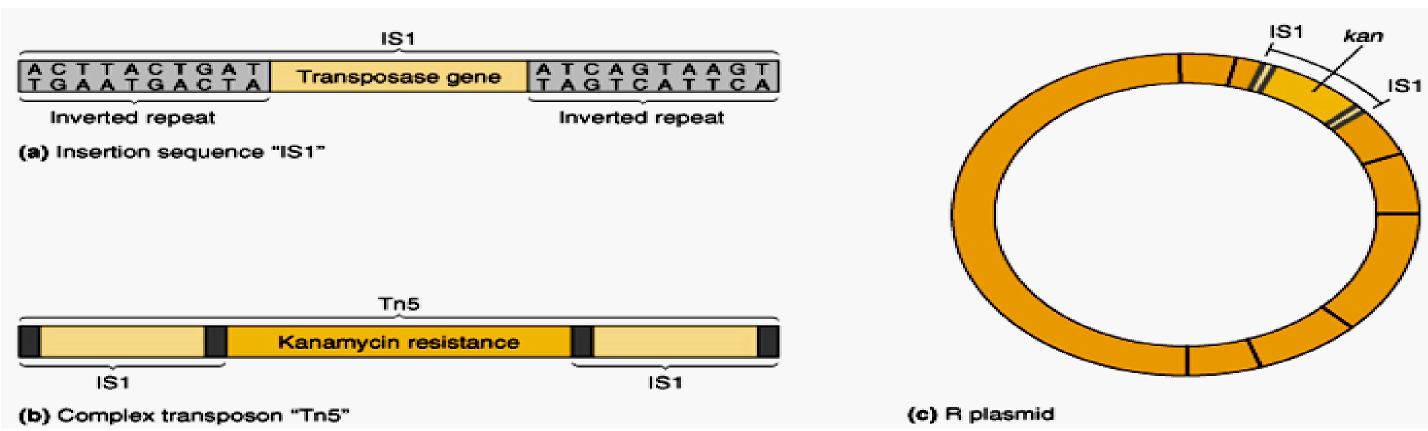
Genetic Recombination

- Two DNA molecules may recombine segments of their molecule in a process called crossing over.
- This is a relatively common event between chromosome copies in eukaryotes during meiosis. (Note the example here.)
- Prokaryote chromosomes, viral DNA, and smaller fragments of "foreign" DNA may recombine, adding new genes (or different alleles) to an individual cell.
- Bacteria can receive a foreign source of DNA for recombination through one of three different mechanisms of Genetic Exchange.



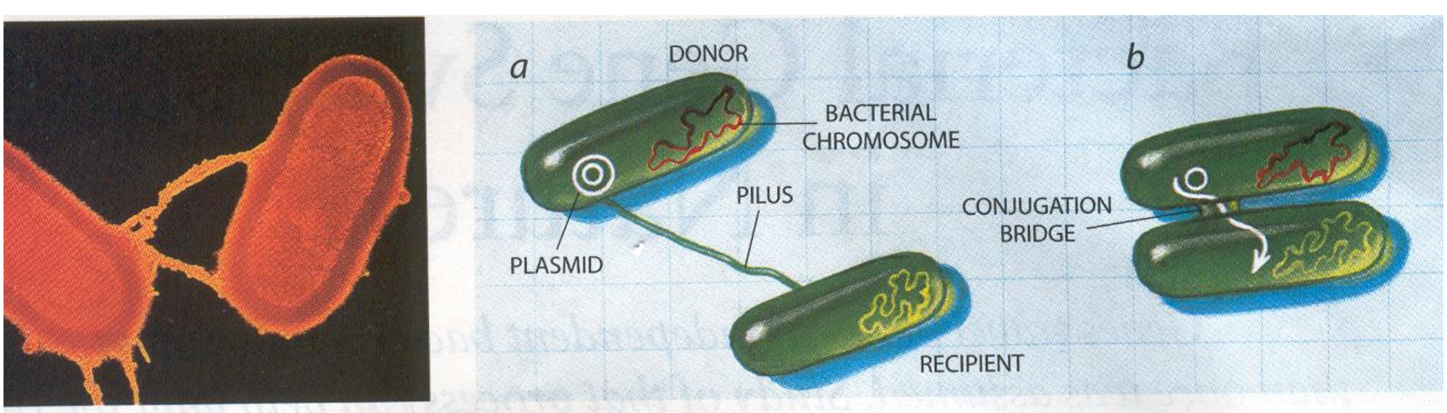
Transposable Elements: "Jumping Genes"

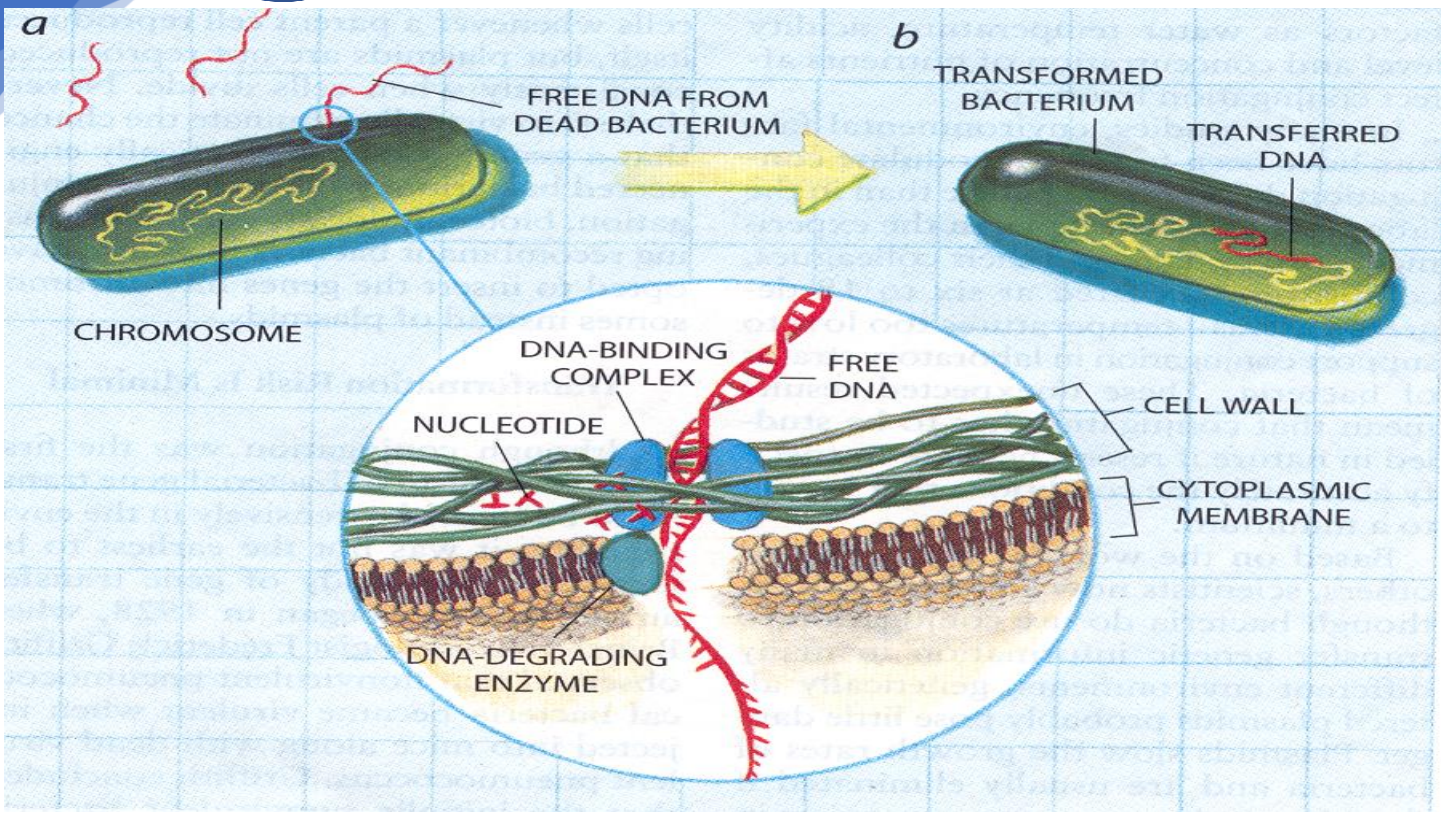
- Transposable elements (insertion sequences and transposons) can tranfer copies of themselves to other DNA molecules (chromosome, plasmid, or viral DNA).
- Antibiotic resistance genes rapidly spread within and between bacterial populations by transposons carried on F factors called R plasmids.

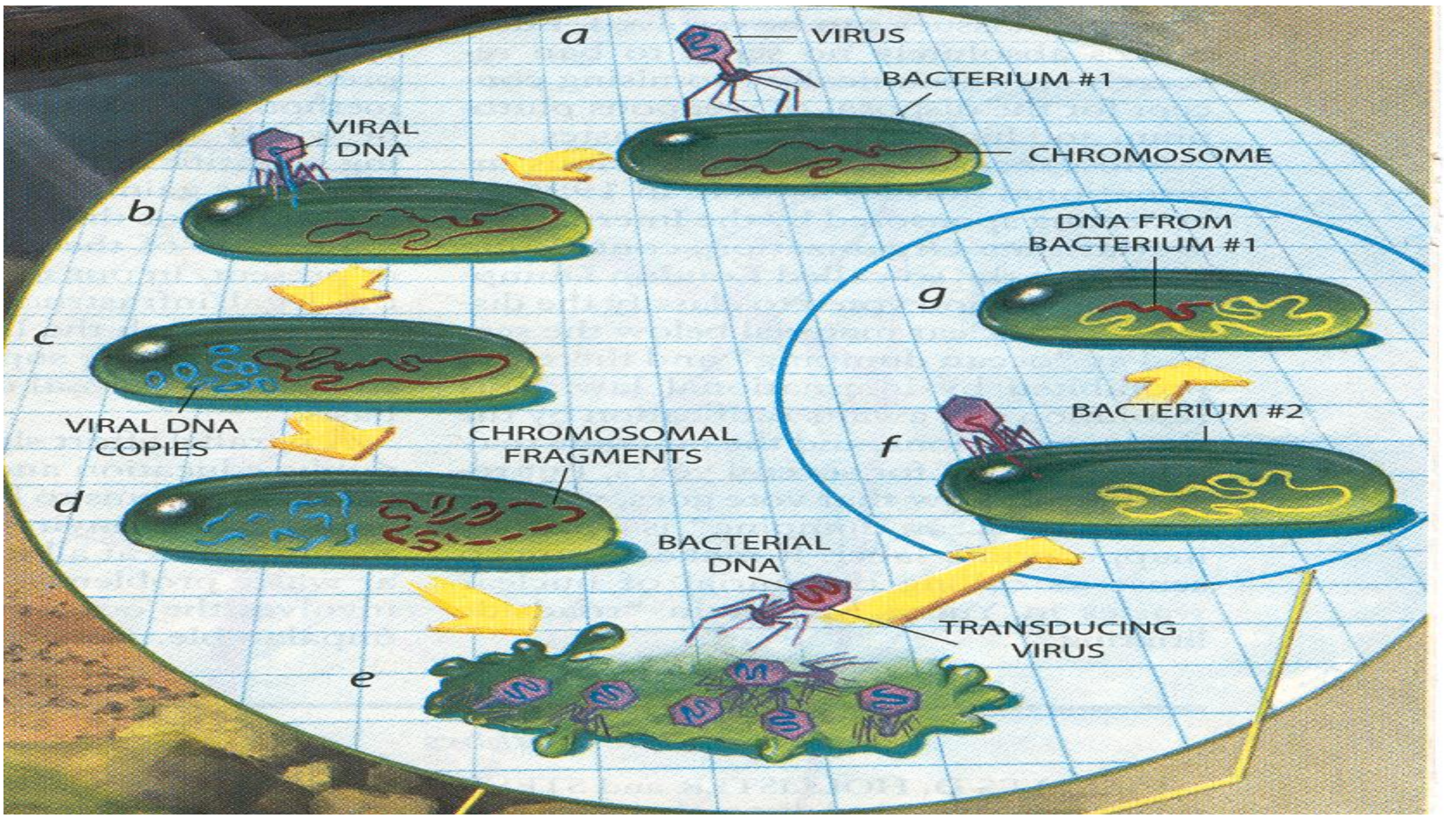


Horizontal Gene Transfer (= lateral gene exchange)

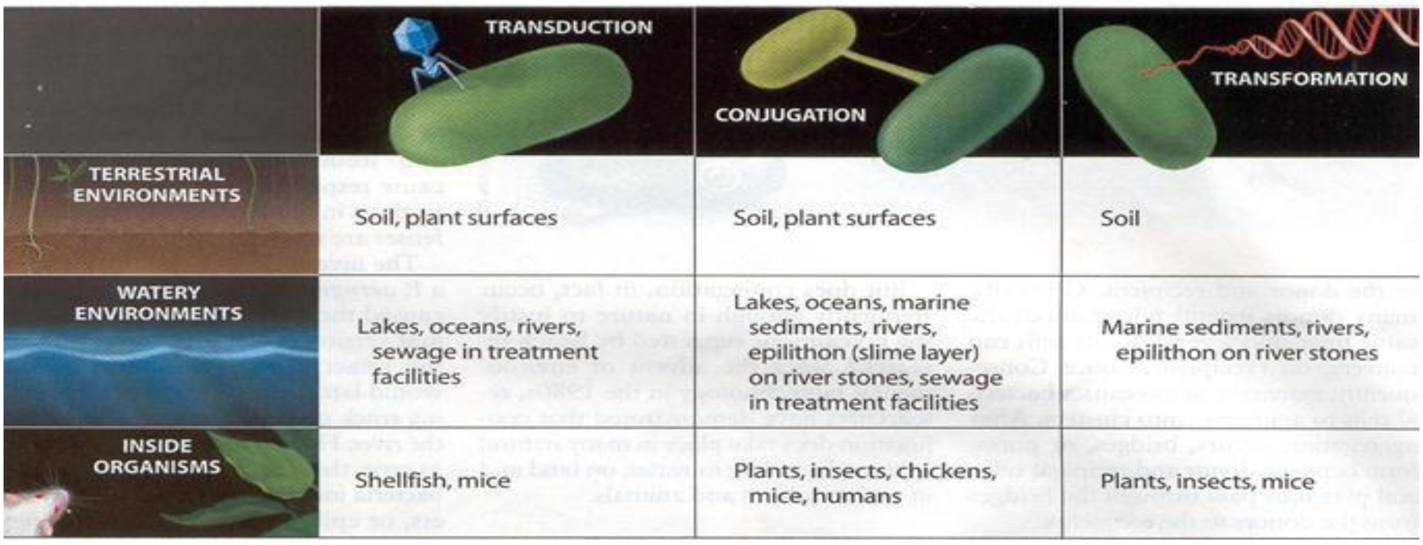
- Conjugation
- Tranformation
- Transduction




a
FREE DNA FROM
DEAD BACTERIUM
CHROMOSOME
b
TRANSFORMED
BACTERIUM
TRANSFERRED
DNA
DNA-BINDING
COMPLEX
FREE
DNA
NUCLEOTIDE
CELL WALL
CYTOPLASMIC
MEMBRANE
DNA-DEGRADING
ENZYME


a
VIRUS
BACTERIUM #1
CHROMOSOME
VIRAL
DNA
b
c
VIRAL DNA
COPIES
CHROMOSOMAL
FRAGMENTS
d
DNA FROM
BACTERIUM #1
g
BACTERIUM #2
f
BACTERIAL
DNA
TRANSDUCING
VIRUS
e

Where in Nature?



	TRANSDUCTION	CONJUGATION	TRANSFORMATION
TERRESTRIAL ENVIRONMENTS	Soil, plant surfaces	Soil, plant surfaces	Soil
WATERY ENVIRONMENTS	Lakes, oceans, rivers, sewage in treatment facilities	Lakes, oceans, marine sediments, rivers, epilithon (slime layer) on river stones, sewage in treatment facilities	Marine sediments, rivers, epilithon on river stones
INSIDE ORGANISMS	Shellfish, mice	Plants, insects, chickens, mice, humans	Plants, insects, mice

Summary of Prokaryote Evolution Mechanisms

- Mutation (micro or macro) changes genotype and possibly phenotype.
- Mobile genetic elements (insertions sequences and transposons) may rearrange genes between and within DNA molecules and this may cause mutations.
- Horizontal gene transfer (conjugation, transformation, transduction) may result in recombination of completely new genes.
- Selective pressures in the environment determine if a new phenotype becomes dominant in a population.
- Many changes in genotype are neutral or benign to phenotype and survival; these "cryptic" changes over time may result in genetic drift, i.e. a harmless variation of a gene randomly becomes dominant.

40 Origin of life

Life appeared after a period of chemical reactions According to physical and chemical laws.

Prebiotic Earth

- Conditions on the primitive Earth were not the same as those present today
- No spontaneous generation of life today (Pasteur)…
- because the necessary conditions no longer exist
- Abiogenesis

Oparin (1924): "Primeval soup" theory

Haldane (1929): "Hot, dilute soup" theory.

Conditions on early Earth

- Reducing atmosphere on the primitive Earth. No free oxygen (O_2)
- Free hydrogen (H_2) and saturated hydrides (CH_4, NH_3 and H_2O)
- Energy for chemical reactions between these gases could come from electric discharge in storms or solar energy (no ozone layer)
- The Earth's surface temperature probably hotter than today.

The formation of monomers

Miller and Urey recreate these conditions in vitro. The water is heated and the mixture circulates for many days.

Results

- After a week 15 amino acids in the mixture
- Other biologically important molecules had been formed including ethanoic acid, lactic acid and urea
- Later similar experiments were done using CO_2 that produced nucleotides

- Additonal organic material may have been delivered by comets.

Conclusion

- These experiments cannot reproduce the exact conditions on the primitive Earth
- We shall never know exactly what happened
- BUT basic building blocks for the large macromolecules can be synthesised in vitro from inorganic compounds.

From monomers to polymers

- Amino acids polypeptides, could have occurred when dry or highly concentrated monomers are heated
- Condensation reactions take place forming:
  peptide bonds between amino acids or phosphodiester bonds form between nucleotides.

Early catalysts

- As molecules adsorb to the clay mineral particles they become concentrated (stick to the surface particles)
- Clay particles (coacervates) may have been essential catalysts in the formation of polymers.

The first polynucleotides

- Polynucleotides show a tendency to copy themselves using complementary base pairing This was probably catalysed by the presence of clay particles and metal ions These single stranded polynucleotides would have been the equivalent of RNA.

The first hereditary information

- RNA was probably the first hereditary molecule having the ability to copy itself
- RNA shows enzymic (catalytic) properties – called ribozymes
- Polynucleotides are very good molecules at storing and transmitting information but they lack the versatility for all the chemical functions of a cell.

A great partnership

- Polypeptides can form complex 3-dimensional structures (proteins),
  Polypeptides much better at complex cell functions
- A partnership must have formed between the polynucleotides and the polypeptides
- The polynucleotides directed the synthesis of the polypeptides
- Today it is clear that information only flows from polynucleotides to polypeptides. Translation had started.

The origin of DNA

- Hereditary information was probably stored in the form of DNA later
  DNA is more stable than RNA
- The passage of information from RNA to DNA is possible in nature
- The reverse transcriptase enzyme of the retro viruses shows this.

The first membranes, the first cells

- If a piece of RNA codes for a particularly good protein then there is nothing to stop that protein being used by other RNA molecules
- If, however, the RNA is enclosed in a membrane then it can keep its protein to itself and it gains a selective advantage
- So membranes probably pushed evolution by natural selection forwards.

Membranes defined the first cell

- The phospholipids form lipid bilayers when they are surrounded by water
- All the components of a simple prokaryotic cell were now assembled
- They diversified in their metabolism
  - By 2 billion years ago free oxygen was appearing in the atmosphere due to the activity of photosynthetic bacteria.

41 Phylogeny and the Tree of Life

Investigating the Tree of Life

- **Phylogeny** is the evolutionary history of a species or group of related species
- The discipline of **systematics** classifies organisms and determines their evolutionary relationships
- Systematists use fossil, molecular, and genetic data to infer evolutionary relationships

Phylogenies show evolutionary relationships

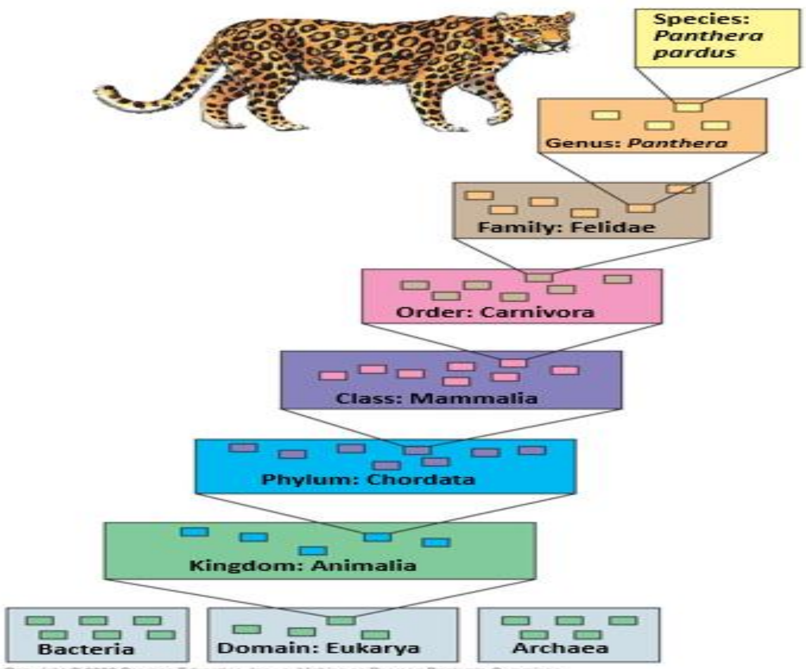
Taxonomy is the ordered division and naming of organisms

Binomial Nomenclature

In the 18th century, Carolus Linnaeus published a system of taxonomy based on resemblances. Two key features of his system remain useful today: two-part names for species and hierarchical classification. The two-part scientific name of a species is called a binomial. The first part of the name is the genus. The second part, called the specific epithet, is unique for each species within the genus. The first letter of the genus is capitalized, and the entire species name is italicized or underlined. Both parts together name the species

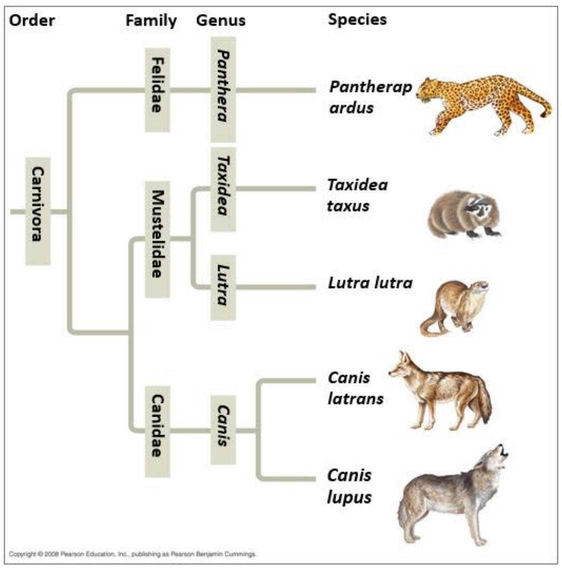
Hierarchical Classification

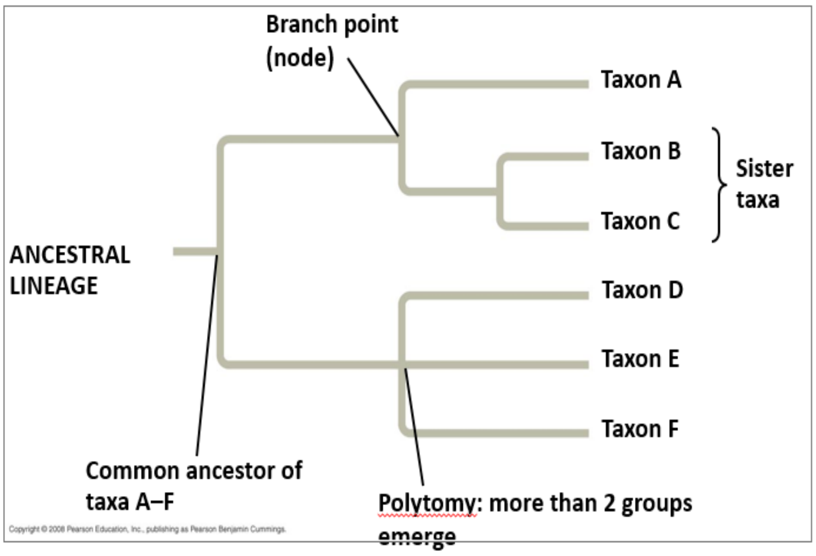
- Linnaeus introduced a system for grouping species in increasingly broad categories
- The taxonomic groups from broad to narrow are **domain**, **kingdom**, **phylum**, **class**, **order**, **family**, **genus**, and **species**
- A taxonomic unit at any level of hierarchy is called a **taxon**



Linking Classification and Phylogeny

- Systematists depict evolutionary relationships in branching **phylogenetic trees**
- Linnaean classification and phylogeny can differ from each other
- Systematists have proposed the PhyloCode, which recognizes only groups that include a common ancestor and all its descendents





Things to Learn from Phylogenetic Trees

- Phylogenetic trees do show patterns of descent
- Phylogenetic trees do not indicate when species evolved or how much genetic change occurred in a lineage
- It shouldn’t be assumed that a taxon evolved from the taxon next to it
- Applications: whale meat sold illegaly in Japa

Phylogenies are inferred from morphological and molecular data

- To infer phylogenies, systematists gather information about morphologies, genes, and biochemistry of living organisms
- Organisms with similar morphologies or DNA sequences are likely to be more closely related than organisms with different structures or sequences

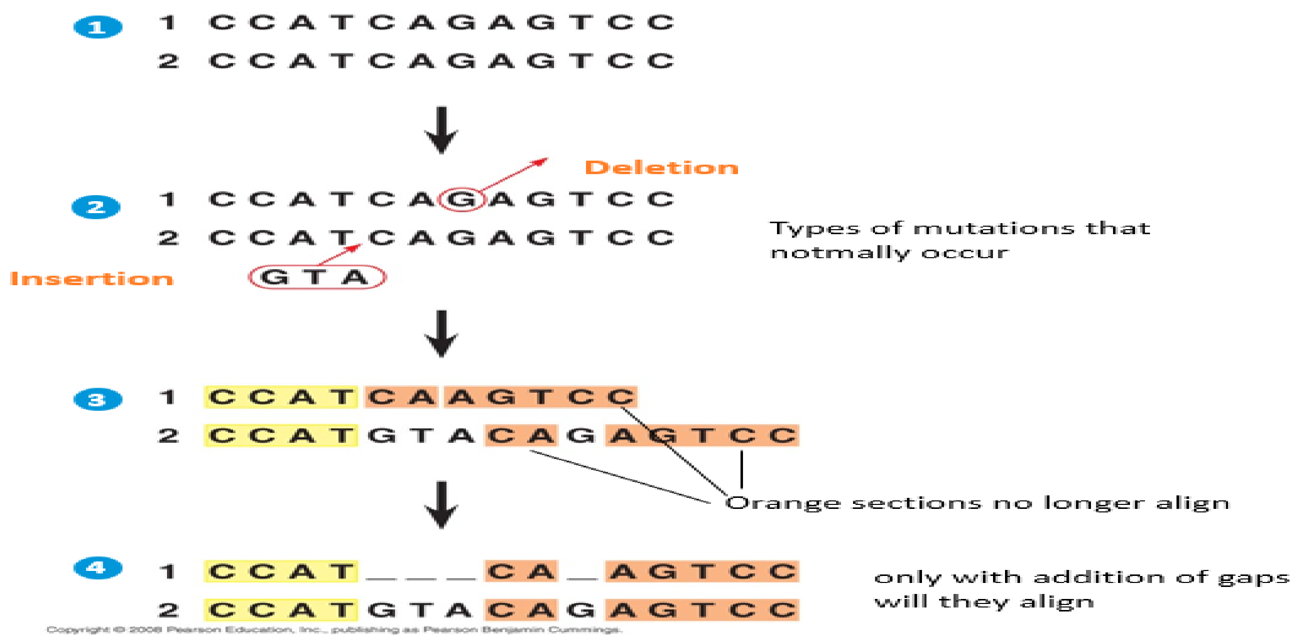
Sorting Homology from Analogy

- Homology is similarity due to shared ancestry like between a wolf and a coyote
- Analogy is similarity due to convergent evolution, similar conditions/adaptations
- E.g austrlian mole and NorthAmerican mole lokks alike but but evolved independantly from each other
- Analogies are also known as **homoplasies** ("to mold the same way")
- Homology can be distinguished from analogy by comparing fossil evidence and the degree of complexity
  - The more complex two similar structures are, the more likely it is that they are homologous

42 Evaluating Molecular Homologies

Evaluating Molecular Homologies

- Systematists use computer programs and mathematical tools when analyzing comparable DNA segments from different organisms



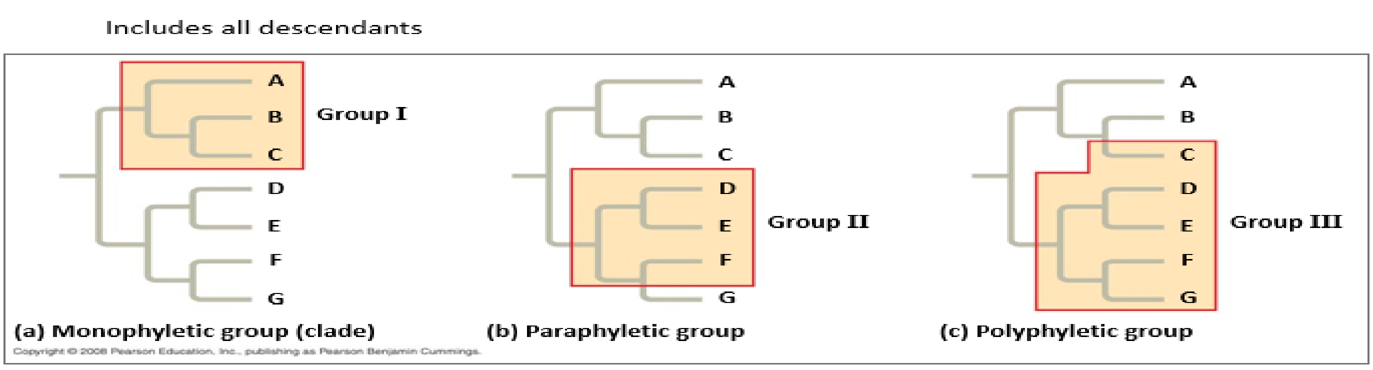
It is also important to distinguish homology from analogy in molecular similarities

Mathematical tools help to identify molecular homoplasies, or coincidences

- **Molecular systematics** uses DNA and other molecular data to determine evolutionary relationships

Shared characters are used to construct phylogenetic trees

- **Cladistics** groups organisms by common descent
- A **clade** is a group of species that includes an ancestral species and all its descendants
- A valid clade is **monophyletic**, signifying that it consists of the ancestor species and all its descendants
- A **paraphyletic** grouping consists of an ancestral species and some, but not all, of the descendants
- A **polyphyletic** grouping consists of various species that lack a common ancestor



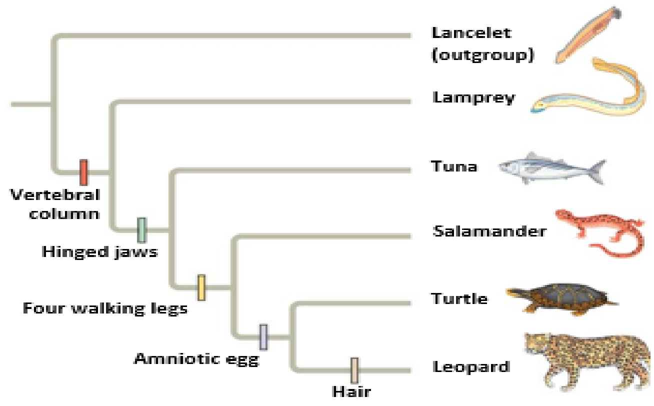
Shared Ancestral and Shared Derived Characters

- In comparison with its ancestor, an organism has both shared and different characteristics
- A shared ancestral character is a character that originated in an ancestor of the taxon
- A shared derived character is an evolutionary novelty unique to a particular clade
- A character can be both ancestral and derived, depending on the context, it is useful to know in which clade a shared derived character first appeared
- An outgroup is a species or group of species that is closely related to the ingroup, the various species being studied
- Systematists compare each ingroup species with the outgroup to differentiate between shared derived and shared ancestral characteristics
- Homologies shared by the outgroup and ingroup are ancestral characters that predate the divergence of both groups from a common ancestor

TAXA

CHARACTERS	Lancelet (outgroup)	Lamprey	Tuna	Salamander	Turtle	Leopard
Vertebral column (backbone)	0	1	1	1	1	1
Hinged jaws	0	0	1	1	1	1
Four walking legs	0	0	0	1	1	1
Amniotic (shelled) egg	0	0	0	0	1	1
Hair	0	0	0	0	0	1

(a) Character table



(b) Phylogenetic tree

Phylogenetic Trees with Proportional Branch Lengths

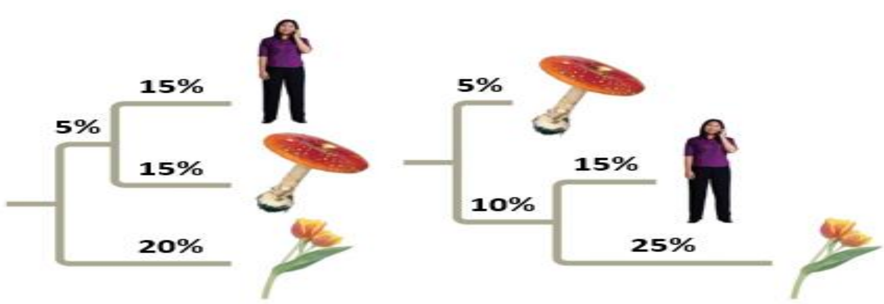
- In some trees, the length of a branch can reflect the number of genetic changes that have taken place in a particular DNA sequence in that lineage
- In other trees, branch length can represent chronological time, and branching points can be determined from the fossil record

Maximum Parsimony and Maximum Likelihood

- Systematists can never be sure of finding the best tree in a large data set
- They narrow possibilities by applying the principles of maximum parsimony and maximum likelihood
- **Maximum parsimony** assumes that the tree that requires the fewest evolutionary events (appearances of shared derived characters) is the most likely
- The principle of **maximum likelihood** states that, given certain rules about how DNA changes over time, a tree can be found that reflects the most likely sequence of evolutionary events

	Human	Mushroom	Tulip
Human	0	30%	40%
Mushroom		0	40%
Tulip			0

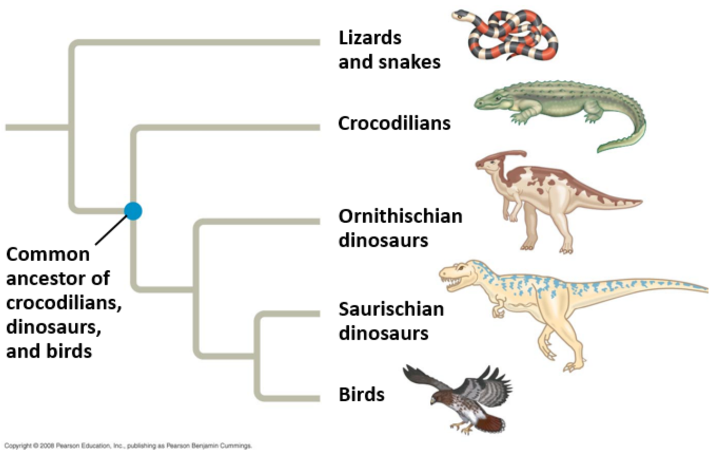
(a) Percentage differences between sequences

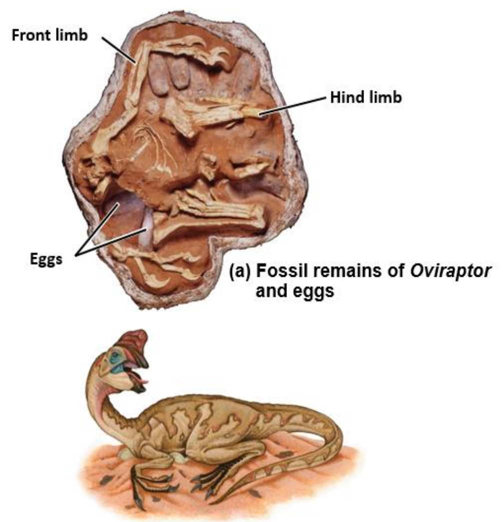


(b) Comparison of possible trees

43 Phylogenetic Trees as Hypotheses

- The best hypotheses for phylogenetic trees fit the most data: morphological, molecular, and fossil
- **Phylogenetic bracketing** allows us to predict features of an ancestor from features of its descendents
- This has been applied to infer features of dinosaurs from their descendents: birds and crocodiles





(a) Fossil remains of *Oviraptor* and eggs

(b) Artist's reconstruction of the dinosaur's posture

An organism's evolutionary history is documented in its genome

- Comparing nucleic acids or other molecules to infer relatedness is a valuable tool for tracing organisms' evolutionary history
- DNA that codes for rRNA changes relatively slowly and is useful for investigating branching points hundreds of millions of years ago
- mtDNA evolves rapidly and can be used to explore recent evolutionary events

Gene Duplications and Gene Families

Gene duplication increases the number of genes in the genome, providing more opportunities for evolutionary changes. Like homologous genes, duplicated genes can be traced to a common ancestor. **Orthologous genes** are found in a single copy in the genome and are homologous between species. They can diverge only after speciation occurs. **Paralogous genes** result from gene duplication, so are found in more than one copy in the genome. They can diverge within the clade that carries them and often evolve new functions

Genome Evolution

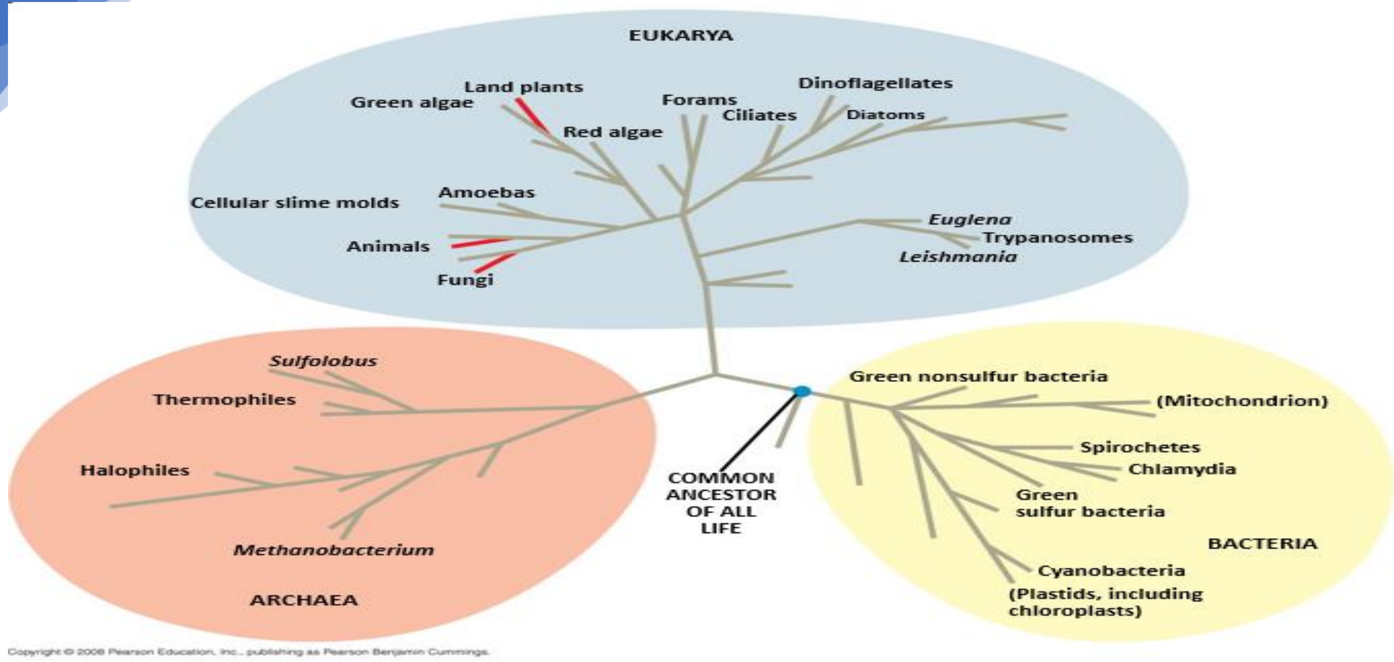
- Orthologous genes are widespread and extend across many widely varied species
- Gene number and the complexity of an organism are not strongly linked
- Genes in complex organisms appear to be very versatile and each gene can perform many functions

New information continues to revise our understanding of the tree of life

Recently, we have gained insight into the very deepest branches of the tree of life through molecular systematics

From Two Kingdoms to Three Domains

- Early taxonomists classified all species as either plants or animals
- Later, five kingdoms were recognized: Monera (prokaryotes), Protista, Plantae, Fungi, and Animalia
- More recently, the three-domain system has been adopted: Bacteria, Archaea, and Eukarya
- The three-domain system is supported by data from many sequenced genomes

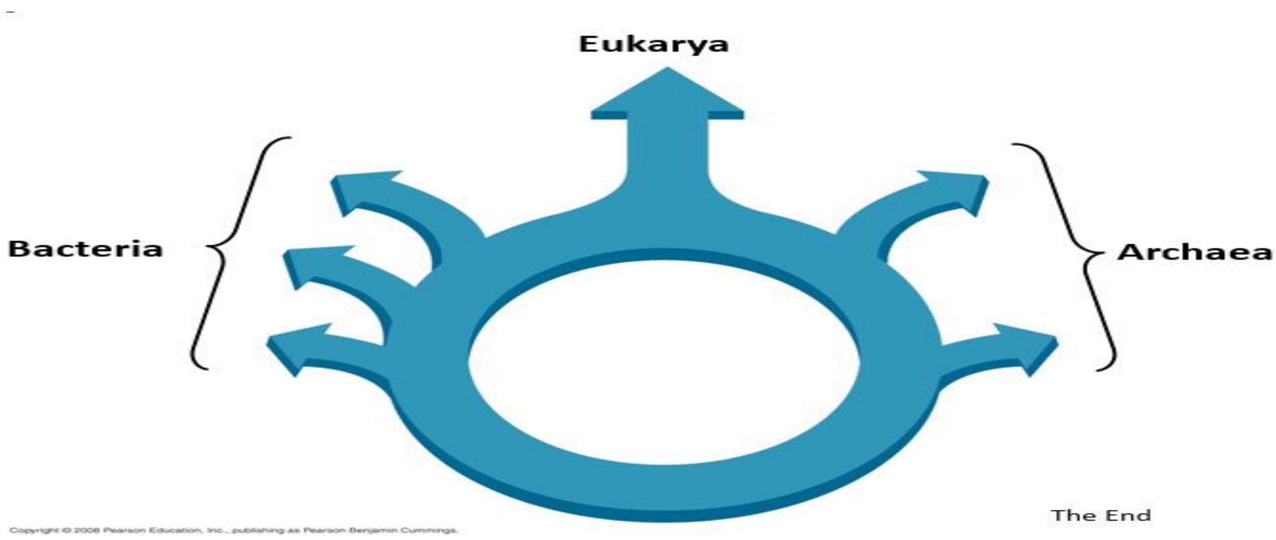


A Simple Tree of All Life

- The tree of life suggests that eukaryotes and archaea are more closely related to each other than to bacteria
- The tree of life is based largely on rRNA genes, as these have evolved slowly

Is the Tree of Life Really a Ring?

- Some researchers suggest that eukaryotes arose as an endosymbiosis between a bacterium and archaean
- If so, early evolutionary relationships might be better depicted by a ring of life instead of a tree of life



44 Natural Selection

Geographic ecology focuses on large-scale patterns of distribution and diversity of organisms, such as island biogeography, latitudinal patterns of species diversity, and the influences of large-scale regional and historical processes on biological diversity.

Isolation

On islands and habitat patches on continents, species richness increases with area and decreases with isolation.

- Larger oceanic islands support more species of most groups of organisms than small islands. Isolated oceanic islands generally contain fewer species than islands near mainland areas.
  - Many habitats on continents are so isolated that they can be considered as islands.

Species richness on habitat islands

- Species richness on habitat islands, such as mountain islands in the American Southwest, increases with area and decreases with isolation.
- Lakes can also be considered as habitat islands. They are aquatic environments isolated from other aquatic environments by land. Fish species richness generally increases with lake area.

Species richness and island isolation

Species richness is usually negatively correlated with island isolation. However, because organisms differ substantially in dispersal rates, an island that is very isolated for one group of organisms may be completely accessible to another group.

Models of Species richness on islands

Species richness on islands can be modelled as a dynamic balance between immigration and extinction of species. The equilibrium model of island biogeography proposes that the difference between rates of immigration and extinction determines the species richness on islands.

The equilibrium model of island biogeography

The equilibrium model of island biogeography assumes that rates of species immigration to islands are mainly determined by distance from sources of immigrants. The model assumes that rates of extinction on islands are determined mainly by island size.

Species richness and latitude

Species richness generally increases from middle and high latitudes to the equator. Most groups of organisms are more species-rich in the tropics.

Many factors may contribute to higher tropical species richness, including

- time since perturbation,
- productivity,
- environmental heterogeneity,
- favorableness,
- niche breadths and interspecific interactions, and
- differences in speciation and extinction rates. Several lines of evidence support the hypothesis that differences in surface area play a primary role in determining latitudinal gradients in species richness.

Structure of biotas and ecosystems

Long-term historical and regional processes significantly influence the structure of biotas and ecosystems. Much geographic variation in species richness can be explained by historical and regional processes.

Exceptional situations

Some exceptional situations that seem to have resulted from unique historical and regional processes include the exceptional species richness of the Cape floristic region of South Africa, the high species richness of temperate trees in east Asia, and the low bird diversity in beech forests of South America.

A word of advise

The ecologist interested in understanding large-scale patterns of species richness must consider processes occurring over similarly large scales and over long periods of time.

Global positioning systems

- Global positioning systems, remote sensing, and geographic information systems are important tools for effective geographic ecology.
- A global positioning system determines locations on the earth's surface, including latitude, longitude, and altitude, using satellites as reference points.

Remote sensing satellites

- Remote sensing satellites are generally fitted with electro-optical sensors that scan several bands of the electromagnetic spectrum.

- These sensors convert electromagnetic radiation into electrical signals that are in turn converted to digital values by a computer. These digital values can be used to construct an image.

Geographic information systems

Geographic information systems are computer-based systems that store, analyze, and display geographic information. Global positioning systems, remote sensing, and geographic information systems are increasingly valuable parts of the ecologist's tool kit.

Future avenues

Ecologists are using these new tools to study large-scale, dynamic ecological phenomena such as interannual variation in regional terrestrial primary production, dynamics of marine primary production, and potential population responses to climate change.

45 Evidence for evolution

Darwin’s Theory of Evolution by Natural Selection

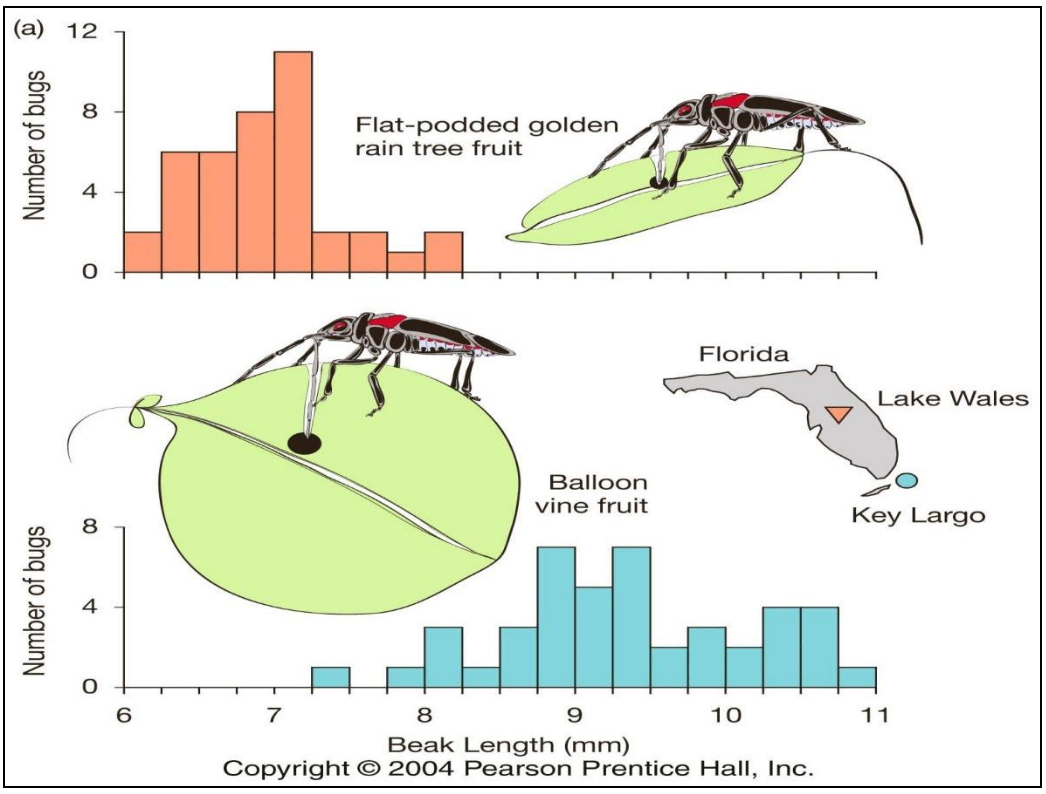
- Species have changed through time and are related by descent from a common ancestor
- The primary mechanism of Evolutionary Change is Natural Selection

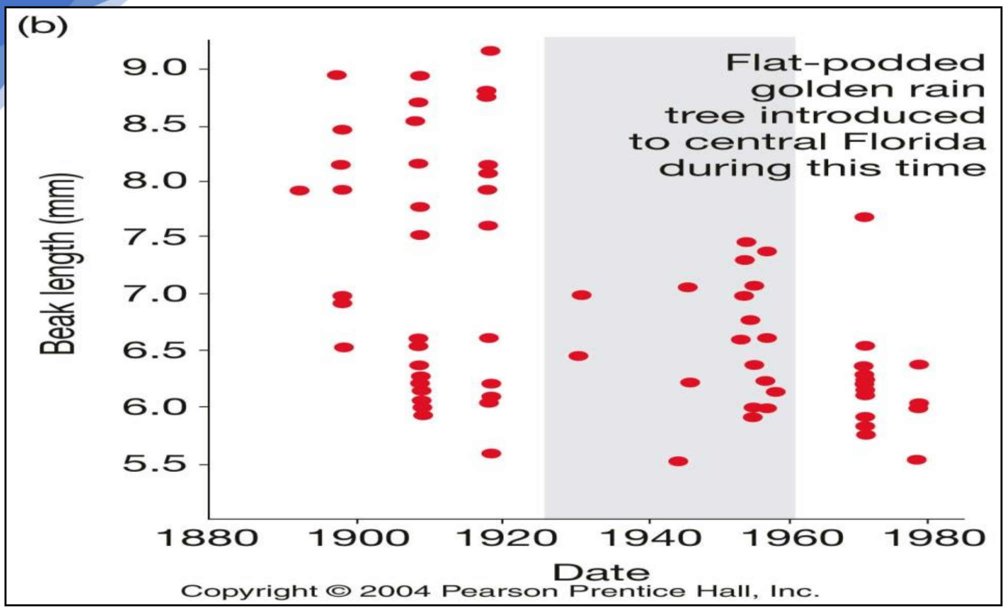
Evidence that Species have Changed Through Time?

- **Hypothesis**: Species have changed through time
- **Prediction**: we should be able to find signs of evolutionary history

- direct observation
- fossil record
- vestigial structures

Direct observation of Evolution





Fossil Record

The fossil record is the history of life recorded by remains from the past. Most fossils are at least 10,000 years old.

1. Body Fossil
2. Trace Fossil

What is found?

- Fossils exist and fossil forms are unlike species living today

1. Fossil Sequence?

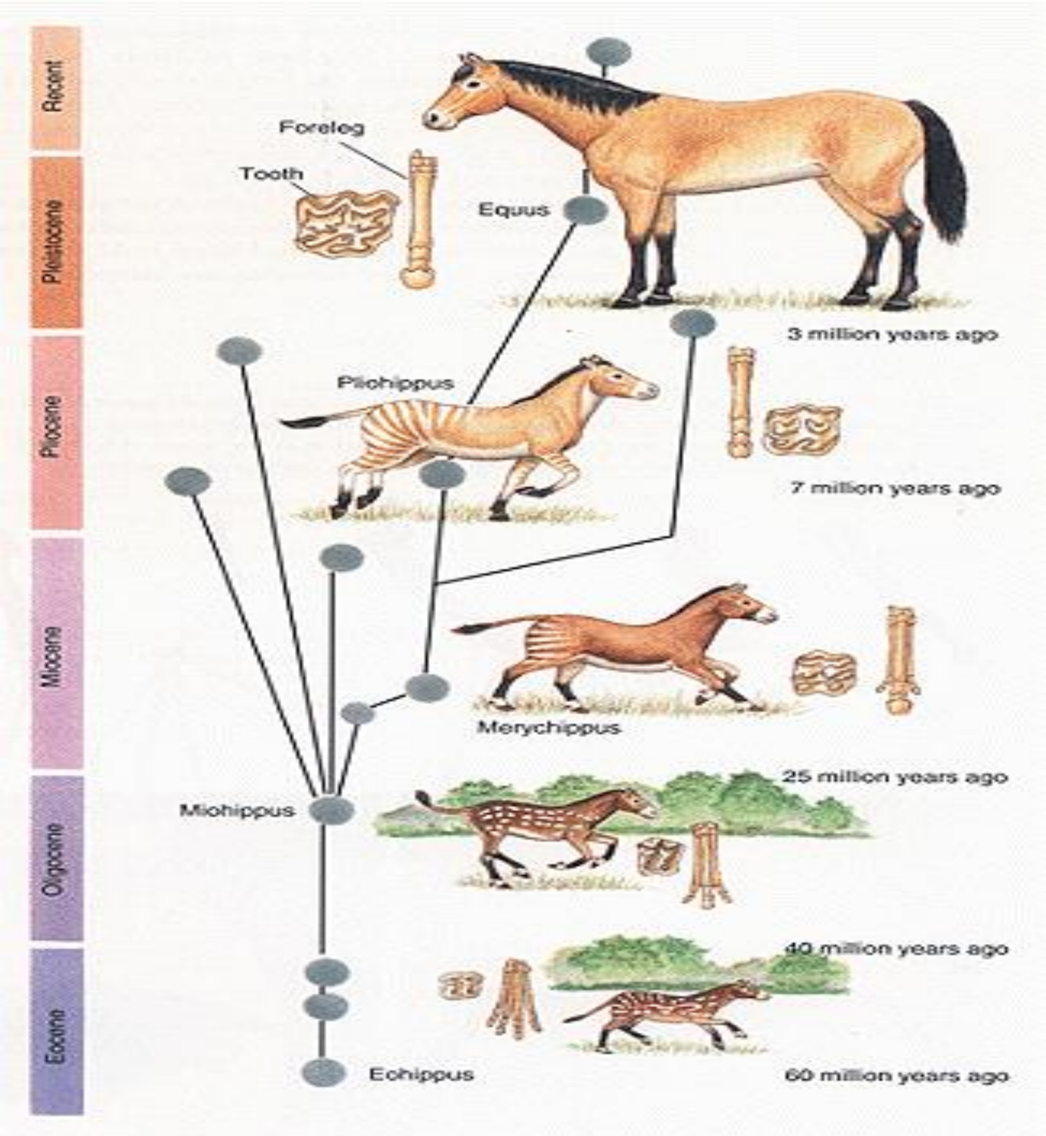
When fossils are arranged according to their age, they show successive evolutionary change

2. Fossil Intermediates?

Transitional fossils have been found between: Amphibians & reptiles, reptiles & birds, reptiles & mammals, apes and humans

The Evolution of Horses

A particularly well-documented case of evolution within a group



The fossil Record is Incomplete

At the time of Darwin, the fossil record was VERY scanty. A great deal of progress has been made since, but it is far from finished.

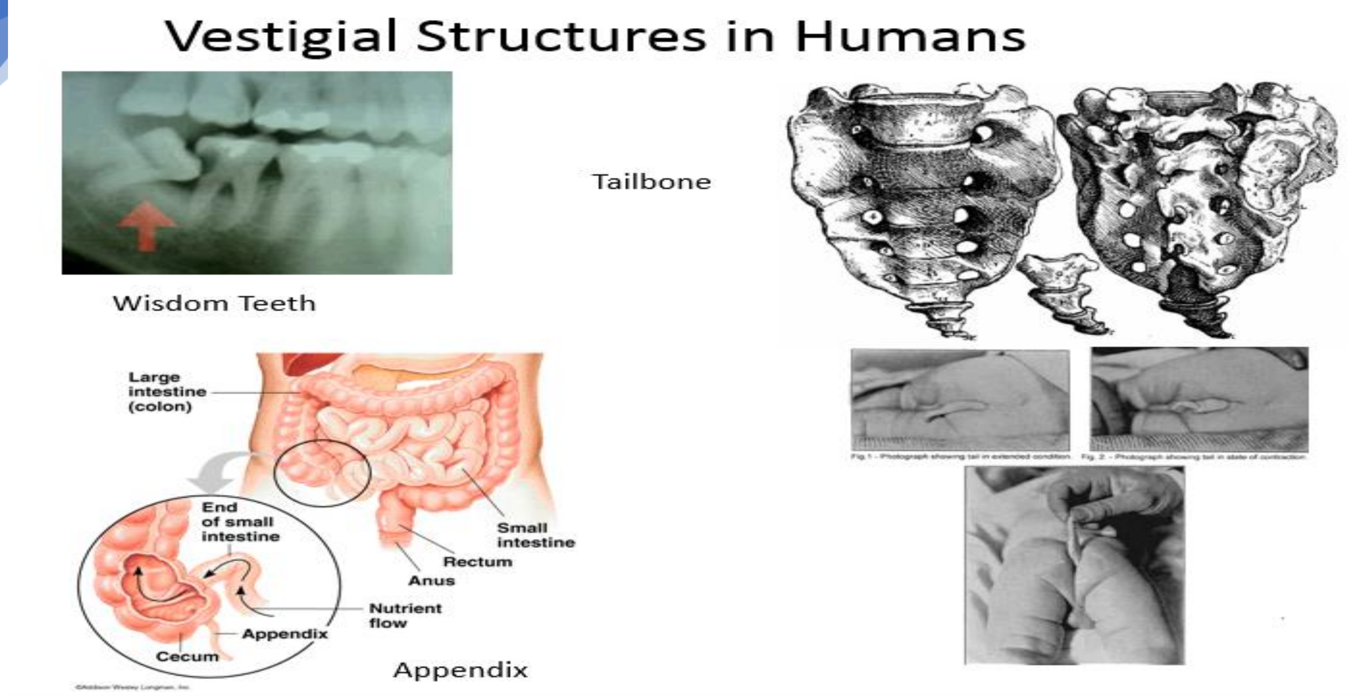
The fossil record is relatively incomplete for several reasons:

1. Soft tissues are rarely preserved
2. Movement of the earth's crust has obliterated and/or covered many fossils
3. Fossilization takes place only in certain types of habitats and favorable environments
4. Paleontologists have not dug up every place on earth

Even if there were no fossil record, the evidence from living organisms would be more than sufficient to demonstrate the historical reality of evolution

Vestigial Structures

- Features that have no apparent function
- Typically have an important function in related spp.
- Ex: Hindlimb joints in whales and snakes
- In humans Wisdom teeth, Tail bone, Appendix are vestigial structures.



Evidence for the Relatedness of Life Forms?

- Hypothesis: all living organisms have descended from a common ancestor
- Prediction: we should also be able to see evidence of relatedness of species
  - -Homology
  - -Geographic distribution

Homology:

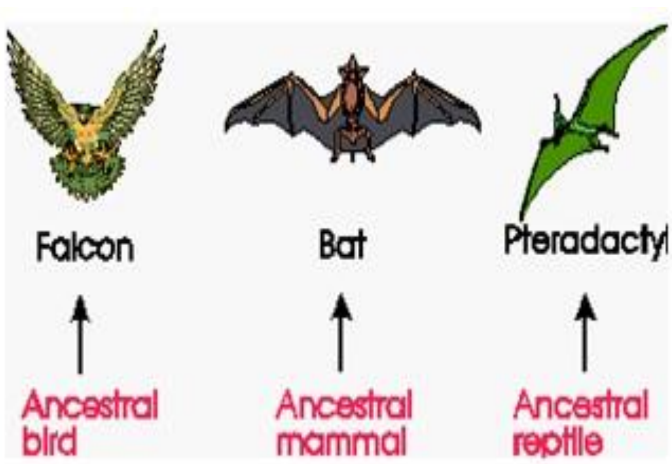
- Homology: a similarity between species that is the result from the inheritance of traits from a common ancestor
- The features of every creature reflect history as well as adaptation

3 types of homologies

- structural
- developmental
- genetic

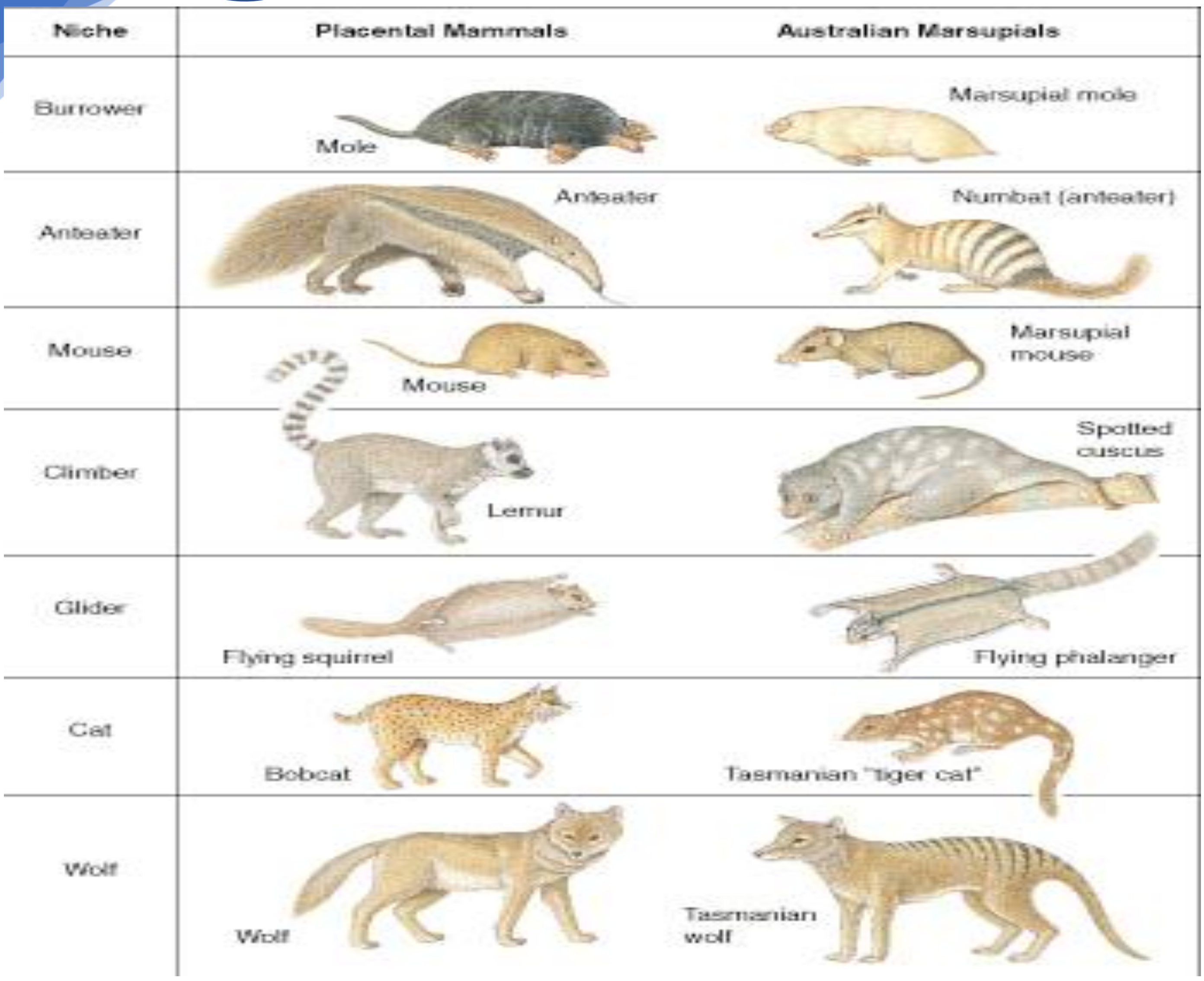
Homology vs. Analogy:

Natural selection appears to have favored similar adaptations in unrelated organisms in similar environments--> these structures are **analogous**

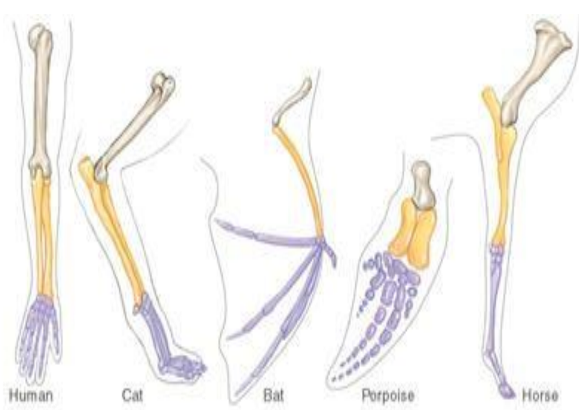


Whereas homologous structures share structural similarity, but not function, analogous structures share function but not structural similarity since they evolved independently

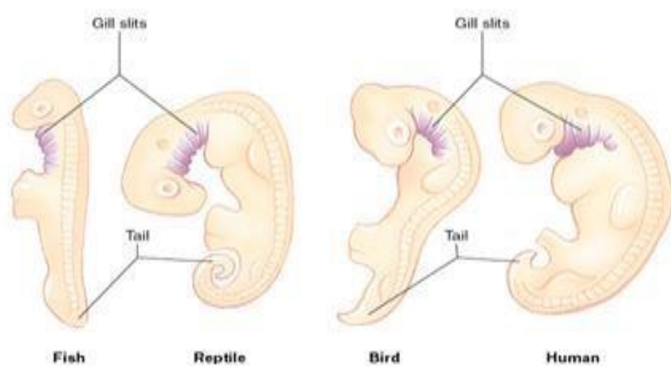
Convergent Evolution



Homologous structures: bones of the forelimb:



The underlying design of each structure is similar despite their functional differences



Homologous structures in adults develop from homologous groups of cells in embryos --> they share developmental pathways

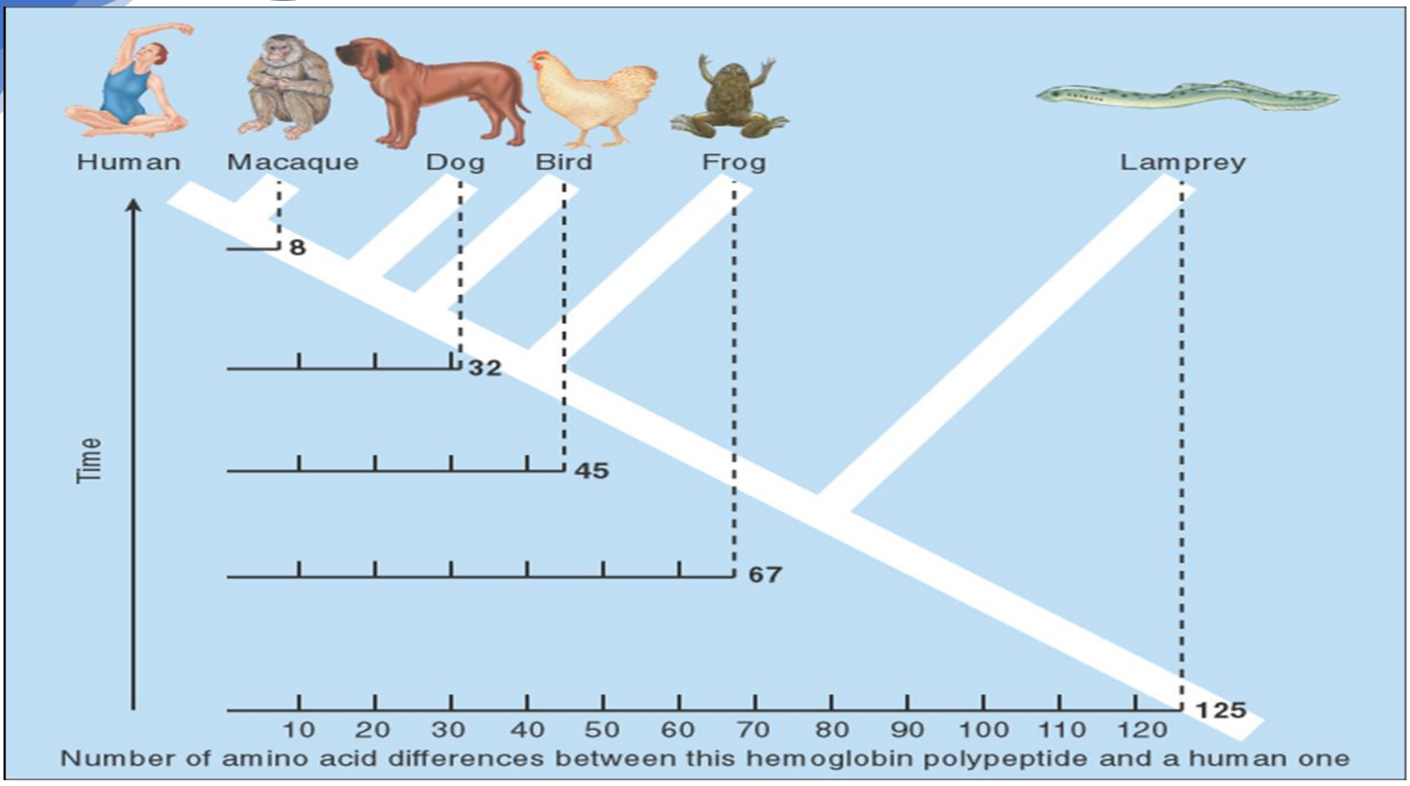
Convergent Evolution:

Convergent evolution is the process by which unrelated or distantly related organisms **evolve**similar body forms, coloration, organs, and adaptations. Natural selection can result in**evolutionary convergence** under several different circumstances.

Genetic Homologies

All living organisms share the same genetic code. Chromosome and gene similarities between species match evolutionary similarities. This is true for both coding regions and “junk DNA”

Molecules reflect evolutionary divergence



Geographic Distributions

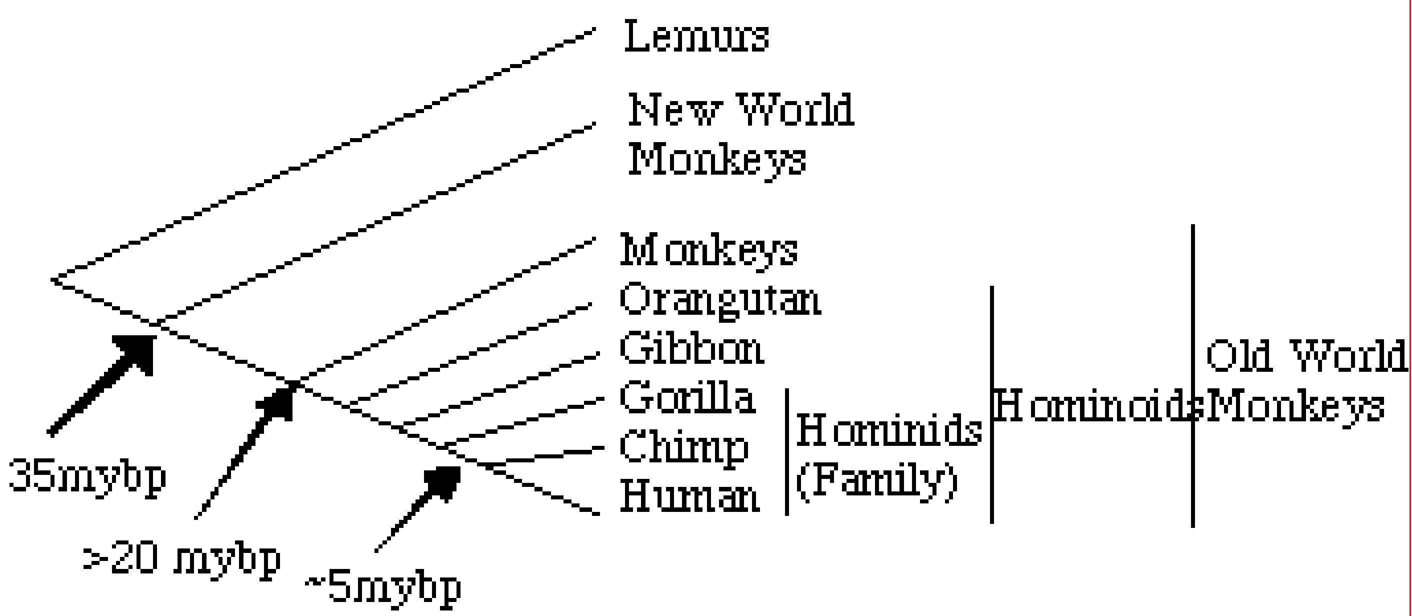
- Species that are extremely similar to one another tend to be clustered geographically (Ex.: Darwin's finches).
- Living species are more similar to fossil species in the same area than they are to living species in other areas

The law of succession

- General correspondence between fossil and living forms in same geographical area
- Darwin used this observation to predict that fossils of ancient humans should be found in Africa

46 Human Evolution

- Humans are too complex to be "understood" by any one field. Thus we will look at a few major steps in evolution and some of the things affecting human evolution.
- Humans are members of the order Primates which consists of about 180 species (there are 17 different orders of mammals which diverged 80-65 million years ago). Primates are a relatively old order of mammals. Most of the synapomorphies of this order are associated with an arboreal way of life: flexible digits, forward facing eyes, vision as a primary sense.
- These traits may have played a role in the evolution of brain size in the lineage leading to humans. Humans are a member of the family Hominidae which is believed to have diverged about 5 million years before the present (mybp) from the other members of the Old world monkeys. At least 20 mybp the Hominoids split off from the other old world monkeys. The dates are rough and get changed now and then.



Relationship of humans to African apes

Relationship of humans to African apes (chimps, gorillas) and orangutan DNA hybridization indicates that apes are our closest relatives. Human/chimp/gorilla relationships not proven but chimps are most likely our closest relatives. The molecular clock says ~ 5 million years ago the human-chimp line split.

While Chimp and gorilla have knuckle walking , the humans posses many traits associated with bipedality: vertebral column, shape of pelvis, angle of femur, foramen magnum at base of skull. Bipedality seems to be a major "innovation" which allowed humans to enter a new "adaptive zone". The first human (*Australopithecus afarensis*) seems to have an angle between the femur and tibia (Upper and lower leg) that is intermediate to that of humans and gorillas.

The evolution of modern humans from our hominid ancestor is commonly considered as having involved four major steps:

- evolving terrestriality,
- bipedalism,
- a large brain (encephalization)
- civilization.

There are (and have been) several competing hypotheses that have acknowledged these four steps, but put them in a different sequence during human evolution.

Origin of Homo sapiens: *Australopithecus afarensis* = first bipedal hominid, found in east Africa about 3.0-3.2 MYBP. Later forms became more slender (= "gracile"). Homo habilis and H. erectus (~1.5mybp) came later. The evolution of bipedalism may have freed the hands for us in other functions: carrying, tool use. The trends in the evolution of tool use (more types, more specific tasks, different types of materials, more efficient use of materials) seems to follow (lead??) the evolution of increase cranial capacity. These both seem to increase noticeably about 2 mybp.

Bipedalism and Brain development

- One theme that involves each of the different sequences of evolution is that there was some feedback that lead to the increase in cranial capacity, e.g., becoming bipedal creates selection pressure for a more elaborate brain to control motor function and to process incoming sensory information. This in turn would allow for more successful bipedalism, etc.

- The same argument could be leveled about culture leading to an increase in brain size, and vice versa, so the sequence cannot be resolved just on the logic of feedback loops alone.

Human Origins

- Origin of "modern humans": Two alternative scenarios for origins:
  - humans originated in more than one site ("Multiregional" model). Evidence supporting this are modern Homo sapiens samples found in Asia and Africa

- a single origin ("Noah's Ark" model: one origin and dispersal out from site of origin). Homo sapiens are believed to have originated ~100,000 - 200,000 years ago.

- Paleontological evidence suggests a single origin in Africa. Molecular data shows low genetic diversity worldwide with the highest diversity in Africa, aslo suggsting an African origin. Recent re-analyses shown that the cladograms of mtDNA cannot support an African origin on statistical grounds.

Humans, out of Africa

The spread of Homo out of Africa is presumed to have taken place about 1.5 MYBP by Homo erectus. This species seems to be on a trajectory of brain size and body size that looks anagenetic, whereas one lineage that lead to Australopithecus robustus seems to be on another line. In a broad sweep of time, the notion of the chimp leading to the Australopithecine, to Homo, to the Neanderthal to the modern American family standing in their driveway is a myth. There were lineages that diverged in a branching cladogram, some of which did not make it to the present. Evidence for this is provided by more than one distinct morphological type of early humans present at the same time (see below). As time gets closer to modern humans, however (Homo erectus on up), a phyletic gradualist anagenesis is more easy to accept.

Brain and human evolution

- Once a big brain is achieved and this provides the intellect for an organism to anticipate its environment, the notion that an organism evolves in response to changes of the environment becomes too simplistic..
  • Humans evolved the power to alter their environment so as to protect themselves from its abiotic pressures. This means that they are altering their own selective pressures and a dialectic emerges between the organism and the environment such that these cannot be separated. Other organisms do this (beaver dams, deciduous trees), but in humans this cycle is accelerating

47 Proterozoic Eon

The Length of the Proterozoic

The Proterozoic Eon alone, at 1.955 billion years long, accounts for 42.5% of all geologic time.

Phanerozoic
Yet the Phanerozoic, consisting of

- Paleozoic,
- Mesozoic,
- Cenozoic eras,

lasted a comparatively brief 545 million years.

Gunflint Microfossils
Even in well-known Early Proterozoic fossils assemblages, only fossils of bacteria are recognized. Photomicrograph of spheroidal and filamentous microfossils from the Gunflint Chert of Ontario Canada

Prokaryote and Eukaryotes
An organism made up of prokaryotic cells is called a prokaryote, whereas those composed of eukaryotic cells are eukaryotes is the basis for the most profound distinction between all living things

Lack of Organic Diversity
Prokaryotic cells reproduce asexually. Most variation in sexually reproducing populations comes from the shuffling of genes, and their alleles, from generation to generation. Mutations introduce new variation into a population, but their effects are limited in prokaryotes

Sexual Reproduction Increased the Pace of Evolution
Prior to the appearance of cells capable of sexual reproduction, evolution was a comparatively slow process, thus accounting for the low organic diversity. This situation did not persist. Sexually reproducing cells probably evolved by Early Proterozoic time, and the tempo of evolution increased

Eukaryotic Cells Evolve
The appearance of eukaryotic cells marks a milestone in evolution comparable to the development of complex metabolic mechanisms such as photosynthesis during the Archean. How do they differ from their predecessors, the prokaryotic cells? All prokaryotes are single-celled, but most eukaryotes are multicelled.

Eukaryotes
Most eukaryotes reproduce sexually, in marked contrast to prokaryotes, and nearly all are aerobic, that is, they depend on free oxygen to carry out their metabolic processes. Accordingly, they could not have evolved before at least some free oxygen was present in the atmosphere

Prokaryotic Cell

Prokaryotic Cellare smaller and not nearly as complex as eukaryotic cells

Eukaryotic Cell
Eukaryotic cells have a cell nucleus containing such as mitochondria and plastids, as well as chloroplasts in plant cells

Eukaryotic Fossil Cells
The Negaunee Iron Formation in Michigan 2.1 billion years old . Fossils are oldest known eukaryotic cells Bitter Springs Formation of Australia –1 billion yrs old, fossils of single-celled eukaryotes, evidence of meiosis and mitosis, processes carried out only by eukaryotic cells

Evidence for Eukaryotes
Prokaryotic cells are mostly rather simple spherical or platelike structures. Eukaryotic cells are large much more complex have a well-defined, membrane-bounded cell nucleus, which is lacking in prokaryotes have several internal structures called organelles such as plastids and mitochondria their organizational complexity is much greater than it is for prokaryotes

Acritarc
These common Late Proterozoic microfossils are probably from eukaryotic organisms. Acritarchs are very likely the cysts of algae

Late Proterozoic Microfossil
Numerous microfossils of organisms with vase-shaped skeletons have been found in Late Proterozoic rocks, in the Grand Canyon. These too have tentatively been identified as cysts of some kind of algae

48 evolutionary biodiversity in Proterozoic Eon

Evolutionary Biodiversity in Proterozoic Eon

Endosymbiosis and the Origin of Eukaryotic Cells
Formed from several prokaryotic cells . In a symbiotic relationship Symbiosis involving a prolonged association of two or more dissimilar organisms, is quite common today. In many cases both symbionts benefit from the association as occurs in lichens, once thought to be plants but actually symbiotic fungi and algae

Evidence for Endosymbiosis
Supporting evidence for endosymbiosis comes from studies of living eukaryotic cells containing internal structures called organelles, such as mitochondria and plastics which contain their own genetic material. In addition, prokaryotic cells synthesize proteins as a single system, whereas eukaryotic cells are a combination of protein-synthesizing systems.

Organelles Capable of Protein Synthesis
That is, some of the organelles within eukaryotic cells are capable of protein synthesis. These organelles with their own genetic material and protein-synthesizing capabilities are thought to have been free-living bacteria that entered into a symbiotic relationship, eventually giving rise to eukaryotic cells

Multicelled Organisms
Obviously multicelled organisms are made up of many cells, perhaps billions as opposed to a single cell as in prokaryotes. In addition, multicelled organisms have cells specialized to perform specific functions such as respiration, food gathering and reproduction

Dawn of Multicelled Organisms
We know from the fossil record that multicelled organisms were present during the Proterozoic but we do not know exactly when they appeared. What seem to be some kind of multicelled algae appear in the 2.1billion-year-old fossils from the Negaunee Iron Formation in Michiganas carbonaceous filaments from 1.8 billion-year-old rocks in China as somewhat younger carbonaceous impressions of filaments and spherical forms.

Multicelled Algae?

Carbonaceous impressions in Proterozoic rocks, Montana. These may be impressions of multicelled algae

The Multicelled Advantage?

Is there any particular advantage to being multicelled? For something on the order of 1.5 billion years all organisms were single-celled and life seems to have thrived. In fact, single-celled organisms are quite good at what they do but what they do is very limited. Single celled organisms can not grow very large, because as size increases proportionately less of a cell is exposed to the external environment in relation to its volume and the proportion of surface area decreases. Transferring materials from the exterior to the interior becomes less efficient. Multicelled organisms live longer, since cells can be replaced and more offspring can be produced. Cells have increased functional efficiency when they are specialized into organs with specific capabilities.

Other Proterozoic Animal Fossils

- Although scarce, a few animal fossils older than those of the Ediacaran fauna are known.
- A jellyfish-like impression is present in rocks 2000 m below the Ediacara Hills Pound Quartzite.
- Burrows in many areas presumably made by worms, occur in rocks at least 700 million years old.
- Wormlike and algae fossils come from 700 to 900 million-year-old rocks in China but the identity and age of these “fossils” has been questioned

Soft Bodies

All known Proterozoic animals were soft-bodied, but there is some evidence that the earliest stages in the origin of skeletons was underway. Even some Ediacaran animals may have had a chitinous carapace and others appear to have had areas of calcium carbonate. The odd creature known as Kimberella from the latest Proterozoic of Russia had a tough outer covering similar to that of some present-day marine invertebrates.

Latest Proterozoic Kimberella

Kimberella, an animal from latest Proterozoic rocks in Russia. Exactly what Kimberella was remains uncertain. Some think it was a sluglike creature whereas others think it was more like a mollusk

Durable Skeletons

Latest Proterozoic fossils of minute scraps of shell-like material and small tooth like denticles and spicules, presumably from sponges indicate that several animals with skeletons or at least partial skeletons existed. More durable skeletons of silica, calcium carbonate, and chitin (a complex organic substance) did not appear in abundance until the beginning of the Phanerozoic Eon 545 million years ago --- Cambrian age

49 Evolution of definition of Ecology

Evolution of Definitions of Ecology

- Ecology = from the Greek root OIKOS, “at home”, and OLOGY, “the study of” Haeckle (1870):
- “By ecology we mean the body of knowledge concerning the economy of Nature - the investigation of the total relations of the animal to its inorganic and organic environment.”
- Burdon-Sanderson (1890s): Elevated Ecology to one of the three natural divisions of Biology: Physiology - Morphology - Ecology
- Elton (1927): “Scientific natural history”

  Andrewartha (1961): “The scientific study of the distribution and abundance of organisms”
  Odum (1963): “The structure and function of Nature”

Our Definition

• “Ecology is the scientific study of the processes regulating the distribution and abundance of organisms and the interactions among them, and the study of how these organisms in turn mediate the transport and transformation of energy and matter in the biosphere (i.e., the study of the design of ecosystem structure and function).

• Beyond Fundamental Ecology Applied Ecology: Using ecological principles to maintain conditions necessary for the continuation of present day life on earth.

Industrial Ecology

The design of the industrial infrastructure such that it consists of a series of interlocking "technological ecosystems" interfacing with global natural ecosystems. Industrial ecology takes the pattern and processes of natural ecosystems as a design for sustainability. It represents a shift in paradigm from conquering nature to becoming nature.

Ecological Engineering

Unlike industrial ecology, the focus of Ecological Engineering is on the manipulation of natural ecosystems by humans for our purposes, using small amounts of supplemental energy to control systems in which the main energy drives are still coming from non-human sources. It is the design of new ecosystems for human purposes, using the self-organizing principles of natural ecosystems.

Ecological Economics

Integrating ecology and economics in such a way that economic and environmental policies are reinforcing rather than mutually destructive.

Urban ecology

For ecologists, urban ecology is the study of ecology in urban areas, specifically the relationships, interactions, types and numbers of species found in urban habitats. Also, the design of sustainable cities, urban design programs that incorporate political, infrastructure and economic considerations.

Conservation Biology

The application of diverse fields and disciplines to the conservation of biological diversity. Restoration Biology: Application of ecosystem ecology to the restoration of deteriorated landscapes in an attempt to bring it back to its original state as much as possible. Example, prarie grass.

Landscape Ecology

“Landscape ecology is concerned with spatial patterns in the landscape and how they develop, with an emphasis on the role of disturbance, including human impacts” (Smith and Smith). It is a relatively new branch of ecology, that employs Global Information Systems. The goal is to predict the responses of different organisms to changes in landscape, to ultimately facilitate ecosystem management

Organizing principles

All these disciplines require an understanding of the "organizing principles" of ecosystems, i.e., their ecology. This involves the detailed study of the structure and function of ecosystems in their undisturbed state, and using their designs to: determine the resilience of ecosystem functions to human activities. design ecosystems which function in the service of human beings with minimal fossil energy input (ideally none) and minimal waste. design the industrial infrastructure. integrate the value of "goods and services" of natural ecosystems into the global economic system.

What is "Sustainability"?

There are many definitions of this one, depending on your perspective. Here’s ours: Sustainability is a property of a human society in which ecosystems (including humans) are managed such that the conditions supporting present day life on Earth can continue.

50 Levels of studying ecology

Biosphere: The earth’s ecosystem interacting with the physical environment as a whole to maintain a steady state system intermediate in the flow of energy between the high energy input of the sun and the thermal sink of space (merges with atmosphere, lithosphere, hydrosphere…).

Biome: Large scale areas of similar vegetation and climatic characteristics.

Ecosystem: Set of organisms and abiotic components connected by the exchange of matter and energy (forest, lake, coastal ocean). Or, “the smallest units that can sustain life in isolation from all but atmospheric surroundings.”

Community: Interacting populations which significantly affect each other’s distributions and abundance (intertidal, hot spring, wetland).

Population: Group of interacting and interbreeding organisms

- Cell/Organism
- Organelle
- Molecule
- Atom

Oxidation/reduction reactions

The energy that drives all life processes is organized around oxidation/reduction reactions. Ultimately on Earth today, oxygenic photosynthesis, and energy from the sun, fuels the entire biosphere. Oxygenic photosynthesis produces (by the splitting of water as a reducing agent) one of the most powerful oxidants known – oxygen. The biosphere on the contemporary Earth runs largely on the carbon produced by CO2 fixation by oxygenic photosynthesis, and on the free energy difference between O2 and organic carbon, which heterotrophs use to fuel their metabolism.

Autotrophs

The autotrophs synthesize glucose using solar or chemical energy, which is broken down through respiration (either their own or that of the organisms that eat them) to provide the energy necessary for "biological work". Redox reactions are central to all of these energy transformations, and the resulting flows of electrons manifest themselves, collectively, in the form of global biogeochemical cycles.

Role of bacteria

The activities of bacteria keep these cycles moving. For example, the chemosynthetic bacteria oxidize many essential elements in the process of getting the energy required to reduce CO2. Certain anaerobic bacteria in turn reduce these compounds in the process of anaerobic respiration i.e., they use them as an electron acceptor in the absence of oxygen. This keeps the element cycles cycling maintaining balanced amounts of oxidants and reductants necessary for diverse metabolic processes. This keeps the system from "running down" energetically. Stay tuned for section on Biogeochemical Cycles.

51 Natural history

Lamarck

Began as a botanist; became the professor responsible for 'insects, worms and microscopic animals' at the museum of natural history in Paris. Introduced the vertebrate/invertebrate distinction.Distinguished insects, crustaceans and arachnids. Proposed the first really good system of invertebrates (1801). In that book, he proposed an evolutionary view of life. Proposed 'biology' as the title of the science of life.

Interpreted the ladder or chain of being as a real historical series, depicting the evolution of life.

The chain?

Lamarck realized life couldn't all be ordered in a single chain; we can only do this within each main group. But evolution works exactly that way for him– it 'pushes' living things towards higher and higher positions on the chain. So he needed something other than 'progressive evolution' to explain the variety of life– why it seems to have separate branches.

Branching

The branches arise from adaptation to local conditions. Local conditions alter what the animal does/ how it lives (habits, efforts, activity). This in turn lead it to acquire traits which can be passed on to offspring (when both parents possess them). Nothing new here– but as part of a theory of progressive evolution– that was new.

Needs

On Lamarck's account, it's the animal's felt needs that produce these changes. So evolution arises from an interaction between organism and environment. This gives us some notion of how adaptation can be explained in a natural way. (Reverses the argument from design: instead of the final causation story, 'Animals have trait x because x will serve their needs in that environment,' he says 'Because x will serve their needs, animals change and acquire x.' The environment causes the change– no need for design)

Extinction

For Lamarck, evolution was an alternative to extinction– instead of dying out (in most cases, anyway) ancient animals and plants evolved into different forms that continue today. Lamarck opposed Cuvier's catastrophism. But Cuvier could cite so many examples of extinction, and Lamarck couldn't say much about (for instance) which animals today were the descendents of trilobites, etc. Besides, Lamarck's evolutionary theory was not easy to understand or all that clear: 'sentiment interieure' seemed pretty mysterious...

Cuvier's advantage

Cuvier's anatomical and classificational work was impeccable. He identified four basic body plans for animals– vertebrates, molluscs, arthropods, and radiata (jellyfish & others). With these groups clearly distinguished, the chain of being was no longer part of biology. But links between distinct groups were still striking– Lamarck cited teeth in fetal baleen whales, for instance, which St. Hilaire took as an instance of 'unity of plan'. A broader sort of unity could restore the chain to some respectability

Unity of plan

St. Hilaire explored the unity of parts and their patterns of development– skeletons in different vertebrates, etc. Established a strong unity of structure for the vertebrates that seemed to go far beyond the demands of Cuvier's correlation of parts. St. Hilaire tried to expand his unity to animals of different embranchements: vertebrates and mollusks. Cuvier was having none of it– his anatomical knowledge won the day for him again.

Von Baer

Development proceeds up the tree of life. All animals begin as eggs. They develop by multiplying, folding in various ways (patterns preserved throughout large groups of animals) to produce the organs, with details being gradually laid down as development continues. Development thus begins in the same way for each embranchement and only later identifies the particular class, family, genus & species of an organism (in that order).

Paleontology

Meanwhile, Smith, Buckland and Cuvier himself (along with Brongniart) were developing paleontology. The order and regular association of particular species of fossil plants and animals with particular formations was becoming well known. Older species differ substantially from known forms. More familiar forms arise gradually as we examine more recent fossils. The transitions were widely regarded as catastrophic (de Beaumont, for example). But Lyell turned the tide on this, showing that the claims of undeniable catastrophes in the record were much exaggerated.

Lyell's mistake

As a part of his general resistance to direction/ substantial change in geology, Lyell maintained there was no real direction of change in the fossil record either. This was greeted with pretty general astonishment, but Lyell claimed the apparent changes were just due to our having bad (misleading) samples…more mammals would soon appear in older formations, etc., as we extend our fossil collections. Within ten years (1840) it was clear that this was completely untenable.

Gradualism and species

Since the environment is steadily changing for Lyell, some plants and animals will become extinct because they're no longer adapted to the environment they're in (and cannot migrate, for some reason). Where do new species come from? This was a much harder question to answer– though Lyell thought it too would be piecemeal and gradual.

But adaptation?

Aside from Lamarck's somewhat vague and hard-to-test story of habits, effort and interior sentiment, we have no account here of how living things became adapted to so many different ways of life. Even Lamarck's account involves effort and needs, so it uses a sort of local final causation to explain how richer, more detailed final causes are worked out. The argument from design remains central here— although it doesn't explain the tree business (recall the whale's tooth).

52 Life in Water

Humans everywhere hold a land-centered perspective of the planet. Consequently, aquatic life is often most profuse where conditions appear most hostile to people, for example, along cold, wave-swept seacoasts, in torrential mountain streams, and in the murky waters where rivers meet the sea.

The hydrologic cycle exchanges water among reservoirs

Of the water in the biosphere, the oceans contain 97% and the polar ice caps and glaciers an additional 2%, leaving less than 1% as freshwater. The turnover of water in the various reservoirs of the hydrologic cycle ranges from only 9 days for the atmosphere to 3,100 years for the oceans.

Biology of aquatic environments

The biology of aquatic environments corresponds broadly to variations in physical factors such as light, temperature, and water movements and to chemical factors such as salinity and oxygen.

The oceans

The oceans form the largest continuous environment on earth. An ocean is generally divided vertically into several depth zones, each with a distinctive assemblage of marine organisms. Limited light penetration restricts photosynthetic organisms to the euphotic, or epipelagic, zone and leads to thermal stratification.

Oceanic temperatures are much more stable than terrestrial temperatures. Tropical seas are more stable physically and chemically; temperate and high-latitude seas are more productive. Highest productivity occurs along coastlines. The open ocean supports large numbers of species and is important to global carbon and oxygen budgets.

Kelp forests

Kelp forests are found mainly at temperate latitudes. Coral reefs are limited to the tropics and subtropics to latitudes between 30° N and S latitudes. Coral reefs are generally one of three types: fringing reefs, barrier reefs, and atolls. Kelp beds share several structural features with terrestrial forests. Both seaweeds and reef-building corals grow only in surface waters, where there is sufficient light to support photosynthesis. Kelp forests are generally limited to areas where temperature ranges from about 10°to 20℃, while reef-building corals are limited to areas with temperatures of about 18° to 29℃. The diversity and productivity of coral reefs rival that of tropical rain forests.

The intertidal zone

The intertidal zone lines the coastlines of the world. It can be divided into several vertical zones: the supratidal, high intertidal, middle intertidal, and low intertidal. The magnitude and timing of the tides is determined by the interaction of the gravitational effects of the sun and moon with the configuration of coastlines and basins. Tidal fluctuation produces steep gradients of physical and chemical conditions within the intertidal zone. Exposure to waves, bottom type, height in the intertidal zone, and biological interactions determine the distribution of most organisms within this zone. Salt marshes, mangrove forests, and estuaries occur at the transitions between freshwater and marine environments and between marine and terrestrial environments. Salt marshes, which are dominated by herbaceous vegetation, are found mainly at temperate and high latitudes. Mangrove forests grow in the tropics and subtropics. Estuaries are extremely dynamic physically, chemically, and biologically. The diversity of species is not as high in estuaries, salt marshes, and mangrove forests as in some other aquatic environments but productivity is exceptional.

Rivers and streams

Rivers and streams drain most of the land area of the earth and reflect the land use in their basins. Rivers and streams are very dynamic systems and can be divided into several distinctive environments: longitudinally, laterally, and vertically. The temperature of rivers follows variation in air temperature but does not reach the extremes occurring in terrestrial habitats. The flow and chemical characteristics of rivers change with climatic regime. Current speed, distance from headwaters, and the nature of bottom sediments are principal determinants of the distributions of stream organisms.

Lakes

Lakes are much like small seas. Most are found in regions worked over by tectonics, volcanism

and glacial activity, the geological forces that produce lake basins. A few lakes contain most of the freshwater in the biosphere. Lake structure parallels that of the oceans but on a much smaller scale. The salinity of lakes, which ranges from very dilute waters to over 200‰, is much more variable than that of the oceans. Lake stratification and mixing vary with latitude. Lake flora and fauna largely reflect geographic location and nutrient content

Potential threats to aquatic systems

Potential threats to all these aquatic systems include over-exploitation of populations and waste dumping. Freshwater environments are particularly vulnerable to the introduction of exotic species. The nature of fish assemblages is being used to assess the "biological integrity" of freshwater communities. The application of this Index of Biological Integrity depends on detailed knowledge of the natural history of regional fish faunas

53 temperature relations

Microclimates

Macroclimate interacts with the local landscape to produce microclimates .The sun's uneven heating of the earth's surface and earth's permanent tilt on its axis produce macroclimate. Macroclimate interacts with the local landscape--mainly altitude, aspect, vegetation, color of the ground, and small-scale structural features such as boulders and burrows--to produce microclimates. For the individual organism, macroclimate may be less significant than microclimate. The physical nature of water limits temperature variation in aquatic environments.

Temperature Ranges

Most species perform best in a fairly narrow range of temperatures. The influence of temperature on the performance of organisms begins at the molecular level, where extreme temperatures impair the functioning of enzymes. Rates of photosynthesis and bacterial activity generally peak in a narrow range of temperatures and are much lower outside of this optimal temperature range. How temperature affects the performance of organisms often corresponds to the current distributions of species and their evolutionary histories.

Regulation of body temperature

Many organisms have evolved ways to compensate for variations in environmental temperature by regulating body temperature. Temperature regulation balances heat gain against heat loss. Plants and ectothermicanimals use morphology and behavior to modify rates of heat exchange with the environment. Birds and mammals rely heavily on metabolic energy to regulate body temperature. The physical nature of the aquatic environment reduces the possibilities for temperature regulation by aquatic organisms. Most endothermic aquatic species are air breathers. Some organisms, mainly flying insects and some large marine fish, improve performance by selectively heating parts of their anatomy. The energetic requirements of thermoregulation may influence the geographic distribution of species.

Survival in extreme temperatures

Many organisms survive extreme temperatures by entering a resting stage. This stage may be as simple as resting in a sheltered spot during the heat of the day or may involve elaborate physiological adjustments. Hummingbirds may enter a state of torpor, a state of low metabolic rate and lowered body temperature, when food is scarce and night temperatures cold. Other animals can go into a state of reduced metabolism that may last several months. If this state occurs mainly in winter, it is called hibernation. If it occurs in summer, it is called estivation. Such reductions in metabolic rate allow these animals to survive extreme environmental conditions during which they must rely entirely on stored energy reserves.

Effects of habitat destruction and climatic warming

Long-term studies of populations of land snails around Basel, Switzerland, have documented local extinctions of these land snails. These extinctions are attributable to habitat destruction and climatic warming. The results of these studies suggest that climatic warming can lead to the local extinction of species. As we face the prospect of climatic warming at a global scale, studies of temperature relations will assume greater importance.

54 Water Relations

Water Availability

The movement of water down concentration gradients in terrestrial and aquatic environments determines the availability of water to organisms. The most familiar relative measure of the water content of air is relative humidity, defined as water vapor density divided by saturation water vapor density multiplied by l00. On land, the tendency of water to move from organisms to the atmosphere can be approximated by the vapor pressure deficit of the air. Vapor pressure deficit is calculated as the difference between the actual water vapor pressure and the saturation water vapor pressure.

Movement of water

In the aquatic environment, water moves down its concentration gradient, from solutions of higher water concentration and lower salt content (hypoosmotic) to solutions of lower water concentration and higher salt content (hyperosmotic). This movement of water creates osmotic pressure. Larger osmotic differences, between organism and environment, generate higher osmotic pressures. In the soil-plant system water flows from areas of higher water potential to areas of lower water potential. The water potential of pure water, which by convention is set at zero, is reduced by adding solute and by matric forces, the tendency of water to cling to soil particles and to plant cell walls. Typically, the water potential of plant fluids is determined by a combination of solute concentrations and matric forces, while the water potential of soils is determined mainly by matric forces. In saline soils, solutes may also influence soil water potential. Water potential, osmotic pressure, and vapor pressure deficit can all be measured in pascals (newtons/m2), a common currency for considering the water relations of diverse organisms in very different environments.

Regulation of internal water on terrain

- **Terrestrial plants and animals regulate their internal water by balancing water acquisition against water loss.** Water regulation by terrestrial animals is summarized by

$$W_{ia} = W_d + W_f + W_a - W_e - W_s,$$

where W_d = drinking, W_f = taken in with food, W_a = absorption from the air, W_e = evaporation and W_s = secretions and excretions. Water regulation by terrestrial plants is summarized by W_{ip} = Wr + Wa - Wt - Ws, where Wr = uptake by roots, Wa = absorption from the air, Wt = transpiration, and Ws = secretions and reproductive structures.

Survival in arid climates

Some very different terrestrial plants and animals, such as the camel and saguaro cactus, use similar mechanisms to survive in arid climates. Some organisms, such as scorpions and cicadas, use radically different mechanisms. Comparisons such as these suggest that natural selection is opportunistic

Regulation of internal water in marine environment

Marine and freshwater organisms use complementary mechanisms for water and salt regulation. Marine and freshwater organisms face exactly opposite osmotic challenges. Water regulation in aquatic environments is summarized by**:**

Wi = Wd - Ws + Wo,

where **Wd = drinking**, **Ws = secretions and excretions**, **Wo = osmosis.**

Survival in marine environment

An aquatic organism may either gain or lose water through osmosis, depending on the organism and the environment. Many marine invertebrates reduce their water regulation problems by being isosmotic with seawater. Some freshwater invertebrates also reduce the osmotic gradient between themselves and their environment. Sharks, skates, and rays elevate the urea and TMAO content of their body fluids to the point where they are slightly hyperosmotic to seawater Marine bony fish and saltwater mosquito larvae are hypoosmotic relative to their environments, while freshwater bony fish and freshwater mosquito larvae are hyperosmotic. While the strength of environmental challenge varies from one environment to another, and the details of water regulation vary from one organism to another, all organisms in all environments expend energy to maintain their internal pool of water and dissolved substances.

Influence of global-climate change

Scientists who are addressing the question of how global-climate change will influence the distribution of terrestrial vegetation have built a computerized model to predict change in terrestrial biomes across North America. Their model uses what we know about the physiology of major plant growth forms to predict the response of whole biomes. According to the model, climate, the combination of temperature and water availability, determines the distribution of vegetation at large scales, while topography, soils, and fires have local influences. The model gives ecologists a means to explore how various changes in climate may affect the future distributions of biomes.

55 Energy and Nutrient Relations

Three main sources of energy

Organisms use one of three main sources of energy:

- light,
- inorganic molecules, or
- organic molecules.

Photosynthetic plants and algae CO_2 as a source of carbon and light, of wavelengths between 400 and 700 nm, as a source of energy. Light within this band, which is called photosynthetically active radiation, or PAR, accounts for about 45% of the total energy content of the solar spectrum at sea level.

PAR quantification

PAR can be quantified as photosynthetic photon flux density, generally reported as μmol per square meter per second. Among plants, there are three major alternative photosynthetic pathways, C_3, C_4, and CAM. C_4 and CAM plants are more efficient in their use of water than are C_3plants.

Heterotrophs

Heterotrophs use organic molecules both as a source of carbon and as a source of energy. Herbivores, caunivores, and detritivores face fundamentally different trophic problems. Herbivores feed on plant tissues. which often contain a great deal of carbon but little nitrogen. Herbivores must also overcome the physical and chemical defenses of plants.

Detritivores

Detritivores feed on dead plant material, which is even lower in nitrogen than living plant tissues. Carnivores consume prey that are nutritionally rich but very well defended. Chemosynthetic autotrophs, which consist of a highly diverse group of chemosynthetic bacteria, use inorganic molecules as a source of energy. Bacteria are the most trophically diverse organisms in the biosphere.

Rate of uptake of energy

The rate at which organisms can take in energy is limited, either by external or internal constraints. The relationship between photon flux density and plant photosynthetic rate is called photosynthetic response. Herbs and short-lived perennial shrubs from sunny habitats have high maximum photosynthetic rates that level on at high light intensities. The lowest maximum rates of photosynthesis occur among plants from shady environments. The relationship between food density and animal feeding rate is called the functional response. The shape of the functional response is generally one of three types. The forms of photosynthetic response curves and type 2 animal functional responses are remarkably similar. Energy limitation is a fundamental assumption of optimal foraging theory.

Optimal foraging theory

Optimal foraging theory attempts to model how organisms feed as an optimizin process.

Evolutionary ecologists predict that if organisms have limited access to energy, natural selection is likely to favor individuals that are more effective at acquiring energy and nutrients. Many animals select food in a way that appears to maximize the rate at which they capture energy.

Plants appear to allocate energy to roots versus shoots in a way that increases their rate of intake of the resources that limit their growth. Plants in environments with abundant nutrients but little light tend to invest more energy in the growth of stems and leaves and less in roots. In environments rich in light but poor in nutrients, plants tend to invest more energy in the growth of roots.

Trophic diversity of bacteria

The trophic diversity of bacteria, which is critical to the health of the biosphere, can also be used as a tool to address some of our most challenging waste disposal problems. Bacteria can be used to eliminate the huge quantities of sewage produced by human populations, clean up soils and aquifers polluted by petroleum products such as benzene, and eliminate the pollution caused by some kinds of mine waste.

Role of bacteria

The success of these projects requires that ecologists under- stand the energy and nutrient relations of bacteria. Bacteria will likely continue to play a great role as we address some of our most vexing environmental problems.

56 Social Relation

Social relations are important since they often directly and obviously impact the reproductive contribution of individuals to future generations, a key component of evolutionary fitness, the number of offspring, or genes, contributed by an individual to future generations. One of the most fundamental social interactions between individuals takes place during sexual reproduction.

Mate choice

Mate choice by one sex and/or competition for mates among individuals of the same sex can result in selection for particular traits in individuals, a process called sexual selection. Sexual selection results from differences in reproductive rates among individuals as a result of differences in their mating success. Sexual selection is thought to work either through intrasexual selection, where individuals of one sex compete with each other for mates, or intersexual selection, when members of one sex consistently choose mates from among members of the opposite sex on the basis of some particular trait.

The case of male guppies

Experimental evidence supports the hypothesis that the coloration of male guppies in local populations is determined by a dynamic interplay between natural selection exerted by predators, under which lesscolorful males have higher survival, and by female mate choice, which results in higher mating success by more-colorful males.

Scorpionflies

Among scorpionflies, larger males are more likely to successfully defend available arthropod offerings due to their advantages in aggressive encounters and consequently mate mom frequently than smaller males without arthropod offerings. Studies of mating in the wild radish, Raphanus sativus, in greenhouse and field experiments indicate nonrandom mating and suggest interference competition among pollen from different pollen donors.

Evolution of sociality

The evolution of sociality is generally accompanied by cooperative feeding, defense of the social group, and restricted reproductive opportunities. The degree of sociality in a social species ranges from acts as simple as mutual grooming or group protection of young to highly complex, stratified societies such as those found in colonies of ants or termites.

Eusociality

This more complex level of social behavior, which is considered to be the pinnacle of social evolution, is called eusociality. Eusociality is generally thought to include three major characteristics:

(1) individuals of more than one generation living together,
(2) cooperative care of young, and
(3) division of individuals into sterile, or nonreproductive, and reproductive castes.

Examples

Cooperation among green woodhoopoes and African lions appears to be a response to environmental conditions that require cooperation for success. For green woodhoopoes, the scarcity of high quality territories and intense competition between flocks for those territories create conditions that favor staying in the natal territory and helping raise related young and perhaps inheriting the territory at a later date.

African lions

To survive, reproduce, and successfully raise offspring to maturity, African lions must work in cooperative groups of females, which are called prides, and of males, which are called coalitions.

The comparative method for examining eusociality

One of the most valuable tools available to evolutionary biologists is the comparative method. The comparative method examines the characteristics of different species or populations of organisms in a way that attempts to isolate a particular variable or characteristic of interest, such as sociality, while randomizing the influence of confounding, or confusing, variables on the variable of interest. The comparative method has been used to study the evolution of eusociality among a wide variety of animal species including leafcutter ants and naked mole rats, both of which live in social groups in which individuals are divided among castes that engage in very different activities. Compared to other ant species, leafcutter ant colonies have a larger number of castes that engage in a wider variety of behaviors. In contrast to leafcutter ant colonies, where all workers are females, both males and females work in naked mole rat colonies. However, as in leafcutter ant colonies, work in naked mole rat colonies is divided among members according to their size. Many factors have likely contributed to the evolution of eusociality in leafcutter ants and naked mole rats, including kin selection and ecological constraints.

57 Population Genetics and Natural Selection

The rise of modem evolutionary ecology

Darwin and Mendel complemented each other well and their twin visions of the natural world revolutionized biology. The synthesis of the theory of natural selection and genetics gave rise to modem evolutionary ecology. Here we examine four major concepts within the area of population genetics and natural selection.

Genetic and phenotypic variation

Populations include genetic and phenotypic variation among individuals, which are significant aspects of population structure. The first biologists to conduct thorough studies of phenotypic and genotypic variation and to incorporate experiments in their studies, focused on plants. By using plants cloned from the same parent**, Bonnier** was able to control for the effects of genotype on plant form and observe the effects of climate.

The work of different Scientists

- **Kerner** showed that the differences in growth form observed by him and Bonnier were the result of temporary adjustments to environmental variation and not hereditary changes in the experimental plants.
- **Turesson's** studies provided evidence for genetic differences among populations.
- **Clausen, Keck, and Hiesey** explored the extent and sources of morphological variation in plant populations, including both the influences of environment and genetics.
- **Case** determined that the best predictor of chuckwalla, Sauromalus, body length was average winter rainfall.
- **Tracy's** laboratory growth experiments indicated that variation in body size among chuckwalla populations is at least partly determined by genetic differences among populations.

Hardy-Weinberg equilibrium model

The Hardy-Weinberg equilibrium model helps identify evolutionary forces that can change gene frequencies in populations. Because evolution involves changes in gene frequencies in a population, a thorough understanding of evolution must include the area of genetics known as population genetics.

Hardy-Weinberg principle

One of the most fundamental concepts in population genetics, the Hardy-Weinberg principle, states that “in a population mating at random in the absence of evolutionary forces, allele frequencies will remain constant.”

For a population in Hardy-Weinberg equilibrium in a situation where there are only two alleles at a particular locus, **$p + q = 1.0$.** The frequency of genotypes in a population in Hardy-Weinberg equilibrium can be calculated as **$(p + q)^2 = (p + q) \times (p + q) = p^2 + 2pq + q^2 = 1.0$.**

The conditions necessary to maintain constent allele frequencies in a population are:

(1) random mating,
(2) no mutations,
(3) large population size,
(4) no immigration, and
(5) equal survival and reproductive rates for all genotypes.

When a population is not in Hardy-Weinberg equilibrium, the Hardy-Weinberg principle helps us to identify the evolutionary forces that may be in play.

Genetic drift

Random processes such as genetic drift can change gene frequencies in populations, especially in small populations. Genetic drift is theoretically most effective at changing gene frequencies in small populations such as those that inhabit islands

Fragmentation of natural ecosystems

One of the greatest concerns associated with fragmentation of natural ecosystems due to human land use is that reducing habitat availability will decrease the size of animal and plant populations to the point where genetic drift will reduce the genetic diversity within natural populations.

The work of different Scientists

Ledig and his colleagues found a significant positive correlation between populafion size and genetic diversity in populations of Chihuahua spruce, a naturally fragmented population of trees living on mountain islands.

Frankham showed that compared to mainland populations, island populations generally include less genetic variation.

Saccheri and his colleagues found that higher heterozygosity (genetic diversity) was associated with lower rates of population extinction through the effects of heterozygosity on larval survival, adult longevity, and egg hatching in populations of the Glanville fritillary butterfly, Melitaea cinxia.

Natural selection

Natural selection, which changes genetic and phenotypic frequencies in populations, can result in adaptation to the environment. The most general postulate of the theory of natural selection is that the environment determines the evolution of the anatomy, physiology, and behaviour of organisms. Some of the clearest demonstrations of natural selection have resulted from studies of populations of Galfapagos finches. Losos, Warhelt, and Schoenerused replicated field experiments to study natural selection for changes in morphology in Anolis lizard populations.

The work of different Scientists

Their results indicate that colonizing populations can adapt rapidly to new environmental conditions.

Studies by Carroll and several colleagues show that soapberry bug populations living on native and introduced host plants have undergone natural selection for traits that favor their survival and reproduction on particular host plant species.

Natural selection

Hundreds of other examples of natural selection have been brought to light during the nearly one and a half century since Darwin published his theory. Still, evolutionary ecology remains a vigorous field of inquiry with plenty of debate, self criticism, and significant work yet to be done.

The earlier research on adaptation of populations to local environmental conditions used transplant experiments to detect genetic differences among populations. More recent research on genetic variation within and among populations has applied techniques developed in molecular biology. Ecologists now have many powerful tools, ranging from classical techniques to modem technologically sophisticated approaches, for assessing the extent of genetic variation within and among populations and meeting the challenge of documenting and conserving biodiversity.

58 Population Distribution and Abundance

Population

Ecologists define a population as a group of individuals of a single species inhabiting an area delimited by natural or human-imposed boundaries. Population studies hold the key to solving practical problems such as saving endangered species, controlling pest populations, or managing fish and game populations. All populations share a number of characteristics including Distribution and abundance.

Physical environment limits the geographic distribution of species

While there are few environments on earth without life, no single species can tolerate the full range of earth's environments. Because all species find some environments too warm, too cold, too saline, and so forth,

the physical environment limits the geographic distribution of species. For instance, there is a close relationship between climate and the distributions of the three largest kangaroos in Australia.

Examples

The tiger beetle Cicindela longilabris is limited to cool boreal and mountain environments. Large- and small-scale variation in temperature and moisture limits the distributions of certain desert plants, such as shrubs in the genus Encelia. However, differences in the physical environment only partially explain the distributions of barnacles within the marine intertidal zone, a reminder that biological factors constitute an important part of an organism's environment.

Distribution patterns of individuals

On small scales, individuals within populations are distributed in patterns that may be random, regular, or clumped. Patterns of distribution can be produced by the social interactions within populations, by the structure of the physical environment, or by a combination of the two. Social organisms tend to be clumped; territorial organisms tend to be regularly spaced.

Clumped distribution

An environment in which resources are patchy also fosters clumped distributions. Aggressive species of stingless bees live in regularly distributed colonies, while the colonies of nonaggressive species are randomly distributed. The distribution of creosote bushes changes as they grow.

On larger scales, individuals within a population are clumped. In North America, populations of both wintering and breeding birds are concentrated in a few hot spots of high population density. Clumped distributions are also shown by plant populations living along steep environmental gradients on mountainsides.

Population density vs increasing organism size

Population density declines with increasing organism size. In general, animal population density declines with increasing body size. This negative relationship holds for animals as varied as terrestrial invertebrates, aquatic invertebrates, birds, poikilothermic vertebrates, and herbivorous mammals. Plant population density also decreases with increasing plant size. However, the biological details underlying the size--density relationship shown by plants are quite different from those underlying the size--density patterns shown by animals. A single species of tree can span a very large range of sizes and densities during its life cycle. The largest trees start life as small seedlings that can live at very high population densities. As trees grow, their population density declines progressively until the mature trees live at low densities.

Influences on the Rarity

Rarity is influenced by geographic range, habitat tolerance, and population size. Rarity of species can be expressed as a combination of extensive versus restricted geographic range, broad versus narrow habitat tolerance, and large versus small population size. The most abundant species and those least threatened by extinction combine large geographic ranges, wide habitat tolerance, and high local population density. All other combinations of geographic range, habitat tolerance, and population size include one or more attributes of rarity. Rare species are vulnerable to extinction. Populations that combine restricted geographic range with narrow habitat tolerance and small population size are the rarest of the rare and are usually the organisms most vulnerable to extinction.

Abundance of organisms

The abundance of organisms and how abundance changes in time and space are among the most fundamental concerns of ecology. To estimate the abundance of species the ecologist must contend with a variety of practical challenges and conceptual subtleties. Mark and recapture methods are useful in the study of populations of active, elusive, or secretive animals.

Mark and recapture techniques

Mark and recapture techniques, which use natural distinguishing marks, are making an important contribution to the study of populations of endangered whales. Ecologists studying organisms, such as corals, algae, and sponges or many types of terrestrial plants that differ a great deal in size and form often estimate abundance as coverage, the area covered by a species. Patterns of distribution and abundance are ultimately determined by underlying population dynamics.

59 Population Dynamics

Survivorship curve

A survivorship curve summarizes the pattern of survival in a population. Patterns of survival can be determined either by following a cohort of individuals of similar age to produce a cohort life table or by determining the age at death of a large number of individuals or the age distribution of a population to produce a static life table.

Life table

Life tables can be used to draw survivorship curves, which generally fall into one of three categories:

(1) type I survivorship, in which there is low mortality among the young but high mortality among older individuals:
(2) type II survivorship, in which there is a fairly constant probability of mortality throughout life; and
(3) type III survivorship, in which there is high mortality among the young and low mortality among older individuals.

Age distribution of a population

The age distribution of a population reflects its history of survival, reproduction, and potential for future growth. Age distributions indicate periods of successful reproduction, high and low survival, and whether the older individuals in a population are replacing themselves or if the population is declining.

Population age structure

Population age structure may be highly complicated in variable environments, such as that of the Galapagos Islands. Populations in highly variable environments may reproduce episodically.

Net reproductive rate (R_0)

A life table combined with a fecundity schedule can be used to estimate net reproductive rate (R_0), geometric rate of increase (λ), generation time (T), and per capita rate of increase (r). Because these population parameters form the core of population dynamics, it is important to understand their derivation as well as their biological meaning.

Net reproductive rate

Net reproductive rate, R0, the average number of off-spring left by an individual in a population, is calculated by multiplying age-specific survivorship rates, l_x, times age-specific birthrates, m_x, and summing the results: $\sum l_x m_x$

Geometric rate of increase

The geometric rate of increase, λ, is calculated as the ratio of population sizes at two successive points in time, Generation time is calculated as: $T = \sum x l_x m_x / R_0$

The per capita rate of increase

The per capita rate of increase, r, is related to generation time and net reproductive rate as: $r = \ln R_0 / T$

The per capita rate of increase may be positive, zero, or negative depending on whether a population is growing, stable. Or declining.

Dispersal

Dispersal can increase or decrease local population densities. The contribution of dispersal to

local population density and dynamics is demonstrated by studies of expanding populations of species such as Africanized bees in the Americas and collared doves in Europe.

Effect of climate change

Climate changes can induce massive changes in the ranges of species. As availability of prey changes, predators may disperse, which increases and decreases their local population densities. Stream organisms actively migrating upstream or drifting downstream increase densities of stationary and migrating populations by immigrating and decrease them by emigrating.

Effects of pollutants
Ecologists are using the effects of pollutants on population dynamics to predict the potential ecological impact of these pollutants on populations. Good candidates for indicators of pollution are those aspects of population dynamics that are sensitive to environmental variation

Impact of a wide range of potential pollutants
Based on its environmental sensitivity, per capita rate of increase, r, appears to be an excellent predictor of the impact of a wide range of potential pollutants. The results of this research suggest that population processes and the mechanisms underlying variation in those processes can be used as sensitive predictors of the ecological effects of environmental change.

60 Population Growth

In the presence of abundant resources, populations can grow at geometric or exponential rates, Population growth by organisms with nonoverlapping generations can be described by the geometric model of population growth, Population growth that occurs as a continuous process, as in human or bacterial populations, can be described by the exponential model of population growth.

Examples of exponential growth
Examples of exponential growth from natural populations suggest that this type of growth may be very important to populations during establishment in new environments, during recovery from some form of exploitation, or during exploitation of transient, favorable conditions.

Logistic population growth
As resources are depleted, population growth rate slows and eventually stops; this is known as logistic population growth. As population size increases, population growth eventually slows and then ceases, producing a sigmoidal, or S-shaped, population growth curve. Population growth stops when populations reach a maximum size called the carrying capacity, the number of individuals of a particular population that the environment can support.

Sigmoidal population growth
Sigmoidal population growth can be modelled by the logistic growth equation, a modification of the exponential growth equation that includes a term for environmental resistance. In the logistic model, the rate of population growth decreases as population density increases. Research on laboratory populations indicates that zero population growth at carrying capacity may be attained by many combinations of reduced birthrates and increased death rates.

Effects of environmental limits
The environment limits population growth by changing birth and death rates. The factors affecting population size and growth include biotic factors such as food, disease, and predators and abiotic factors such as rainfall, floods, and temperature. Because the effects of biotic factors, such as disease and predation, ale often influenced by population density, biotic factors are often referred to as density dependent factors. Meanwhile, abiotic factors such as floods and extreme temperature can exert their influences independently of population density and so are often called density-independent factors. As we have already seen, both abiotic and biotic forces have important influences on populations. The significant effects of biotic and abiotic factors on populations have been well demonstrated by studies of Galapagos finches and their major food sources.

The intrinsic rate of increase(rm)
On average, small organisms have higher rates of per capita increase, r, and more variable populations, while large organisms have lower rate a of per capita increase and less variable populations. The intrinsic rate of increase, r_m is the maximum rate of increase for a given species. This rate of increase would occur in the absence of negative environmental influences. The per capita rate of increase, r, which is the realized rate of increase, is generally less than r_m One of the best predictors of r_m is body size. In general, rm decreases with increasing body size, from over I00,000 times from viruses to large vertebrate animals. The present state of the human population can be examined using the conceptual tools of population biology discussed in chapters 9 and 10 and in this chapter. Though humans live on every continent, their population density differs by several orders of magnitude in different regions.

Global population
In 1997, 61.4% of the global population, or about 3.5 billion people, were concentrated in Asia. The remainder of the human population was spread across Africa (12.8%), Europe (11.8%), North America (7.9%), South America (5.7%), Australia (0.3%), and oceanic islands (0.1%).

Sustainable global human population

Population densities in different regions vary from less than 1 person per square kilometer to nearly 1,000 persons per square kilometer. While the populations of some countries are stable, and some are declining, the global population is expected to continue growing well past the year 2000. One of the greatest environmental challenges of the twenty-first century will be to establish a sustainable global human population.

61 Competition

Competition, interactions between individuals that reduce their fitness, is generally divided into intraspecific competition, competition between individuals of the same species, and interspecific competition, competition between individuals of different species.

Forms of Competition

Competition can take the form of interference competition, direct aggressive interactions, or resource competition in which individuals compete through their dependence on the same limiting resources.

Intraspecific competition

Studies of intraspecific competition provide evidence for resource limitation. Experiments with herbaceous plants show that soil nutrients may limit plant growth rates and plant weight and that competition for nutrients increases with plant population density. Plants reflect their competition for resources, including water, light, and nutrients, through the process of self-thinning. Resource competition among leafhoppers also varies with population density and is reflected in reduced survivorship, smaller size, and increased developmental time at higher population densities. Experiments with terrestrial isopods show that even where there is no food shortage, intraspecific competition through interference may be substantial.

Niche

The niche reflects the environmental requirements of species. The niche concept was developed early in the history of ecology and has had a prominent place in the study of interspecific competition because of the competitive exclusion principle:

Same Niche, two species

Two species with identical niches cannot coexist indefinitely. Hutchinson added the concepts of the fundamental niche, the physical conditions under which a species might live in the absence of other species, and the realized niche, the more restricted conditions under which a species actually lives as the result of interactions with other species.While a species' niche is theoretically defined by a very large number of biotic and abiotic factors, Hutchinson's n-dimensional hypervolume, the most important attributes of the niche of most species, can often be summarized by a few variables. For instance, the niches of Galapagos finches are largely determined by their feeding requirements, while the niche of a salt marsh grass can be defined by tidal levels.

Lotka and Volterra

Mathematical and laboratory models provide a theoretical foundation for studying competitive interactions in nature. Lotka and Volterra independently expanded the logistic model of population growth to represent interspecific competition.

Lotka-Volterra competition model

In the Lotka-Volterra competition model, the growth rate of a species depends both upon numbers of conspecifics and numbers of the competing species. In this model, the effect of one species upon another is summarized by competition coefficients. In general, the Lotka-Volterra competition model predicts coexistence of species when interspecific competition is less intense than intraspecific competition. Competitive exclusion in laboratory experiments suggests the potential for competitive exclusion in nature. Even in the laboratory, however, organisms yield results that are much less predictable than the predictions of the Lotka-Volterra competition equations.

Ecological and evolutionary influences on the niches

Competition can have significant ecological and evolutionary influences on the niches of species. Field experiments involving organisms from herbaceous plants to desert rodents have demonstrated that competition can restrict the niches of species to a narrower set of conditions than they would otherwise occupy in the absence of competition.

Natural selection and niches

Theoretically, natural selection may lead to divergence in the niches of competing species, a situation called character displacement. However, stringent requirements for a definitive demonstration have limited the number of documented cases of character displacement in nature. After many decades of theoretical and experimental work on competition, we can conclude that competition is a common and strong force operating in nature, but not always and not everywhere.

Field experiments

The field experiment is one of the most powerful and important tools at the disposal of the field ecologist.

However, the validity of field experiments depends upon several design features, including

1. a testable hypothesis,
2. knowledge of initial conditions,
3. controls, and
4. replication.

62 Exploitation

Predation, Herbivory, Parasitism, and Disease

Exploitation

The diversity of interactions between herbivores and plants, between predators and prey, and between parasites, parasitoids, pathogens, and hosts can be grouped under the heading of exploitation--interactions between species that enhance the fitness of one individual at the expense of another.

Exploitation weaves populations into a web of relationships that defy easy generalization.

The number of exploitative interactions between species far exceeds the number of species in the biosphere, and the nature of exploitation goes far beyond the typical consumption of one organism by another. For instance, many parasites and pathogens manipulate host behavior to enhance their own fitness at the expense of the host. Spiny-headed worms alter the behavior of a variety of crustacean hosts in a way that increases the probability that the one host species will be eaten by another. A pathogenic fungus manipulates the growth program of its host plant in a way to produce "pseudo flowers," structures aimed at promoting the reproduction of the pathogen. In the process the pathogen usually kills the host plant and always renders it sterile. Predation by one flour beetle species on another can be used as a potent means of interference competition except in the presence of a protozoan parasite, which seems to give a competitive advantage to less predaceous species.

Examples

Predators, parasites, and pathogens influence the distribution, abundance, and structure of prey and host populations. Herbivorous stream insects have been shown to control the density of their algal and bacterial food. The herbivorous moth larva *Cactoblastis cactorum* combined with pathogenic microbes reduced the coverage of prickly pear cactus in Australia from millions of hectares to a few thousand. A parasitic infestation reduced the red fox population in Sweden by 70%, which in turn led to increases in the abundance of several prey species eaten by foxes. This parasitic disease revealed the influence of a predator on its prey populations.

Relationships

Predator-prey, parasite-host, and pathogen-host relationships are dynamic. Populations of a wide variety of predators and prey show highly dynamic fluctuations in abundance ranging from days to decades. A particularly well-studied example of predator-prey cycles is that of snowshoe hares and their predators, which have been shown to result from the combined effects of the snowshoe hares on the quantity and quality of their food and of the predators on the snowshoe hare population.

Predator-prey interactions

Mathematical models of predator-prey interactions by Lotka and Volterra suggest that exploitative interactions themselves can produce population cycles without any influences from outside forces such as weather. Predator-prey cycles have also been observed in a few laboratory populations under restricted circumstances.

To persist in the face of exploitation, hosts and prey need refuges.

The refuges that promote the persistence of hosts and prey include secure places to which the exploiter has limited access. However, living in large groups can be considered as a kind of refuge since it reduces the probability that an individual host or prey will be attacked. It appears that predator satiation is a defensive tactic used by a wide variety of organisms from rain forest trees to temperate insects. Growing to large size can also represent a kind of refuge when the prey species is faced by size-selective predators, Size is used as a refuge by prey species ranging from stream insects and intertidal invertebrates to rhinoceros.

Population control
Predators and parasites have been used to control populations of insects that attack crops or to control invasive weeds. Recent research in Kenya has shown that a crayfish, Procambarus clarkii, controls the snails that act as intermediate hosts for Schistosoma. ahighly pathogenic human parasite. Preliminary results indicate that crayfish successfully control host snails in the artificial impoundments used for livestock watering and domestic water, important sources of infection by Schistosoma.

63 Mutualism

Mutualism
Mutualism, interactions between individuals that benefit both partners, is a common phenomenon in nature that has apparently made important contributions to the evolutionary history of life and continues to make key contributions to the ecological integrity of the biosphere.

Mutualisms types
Mutualisms can be divided into those that are facultative, where species can live without their mutualistic partners, and obligate, where species are so dependent on the mutualistic relationship that they cannot live without their mutualistic partners

Examples
Plants benefit from mutualistie partnerships with a wide variety of bacteria, fungi, and animals. Mutualism provides benefits to plants ranging from nitrogen fixation and enhanced nutrient and water uptake to pollination and seed dispersal.

Mycorrhiza
Ninety percent of terrestrial plants form mutualistic relationships with mycorrhizal fungi, which make substantial contributions to plant performance. Mycorrhizae, which are mostly either vesicular arbuscular mycorrhizae or ectomycorrhizae, are important in increasing plant access to water, nitrogen, phosphorus, and other nutrients. In return for these nutrients, mycorrhizae receive energy-rich root exudates. Experiments have shown that the mutualistic balance sheet between plants and mycorrhizal fungi can be altered by the availability of nutrients. Plant-ant protection mutualisms are found in both tropical and temperate environments.

Ants
In tropical environments, many plants provide ants with food and shelter in exchange for protection from a variety of natural enemies. In temperate environments, mutualistic plants provide ants with food but not shelter in trade for protection

Mutualistic algae
Mutualistic algae called zooxanthellae provide reef-building corals with their principal energy source; in exchange for this energy, corals provide zooxanthellae with nutrients, especially nitrogen, a scarce resource in tropical seas.

Mutualism between corals
Reef-building corals depend upon mutualistic relationships with algae and animals. The coral-centered mutualisms of tropical seas show striking parallels with terrestrial plant-centered mutualisms. The mutualism between corals and zooxanthellae appears to be largely under the control of the coral partner, which chemically solicits the release of organic compounds from zooxanthellae and controls zooxanthellae population growth. Crabs and shrimp protect some coral species from coral predators in exchange for food and shelter.

Evolution of Mutualism
Theory predicts that mutualism will evolve where the benefits of mutualism exceed the costs. **Keeler** built a cost-benefit model for the evolution and persistence of facultative plant-ant protection mutualisms in which the benefits of the mutualism to the plant are represented in terms of the proportion of the plant's energy budget that ants protect from damage by herbivores.

The model assesses the costs of the mutualism to the plant in terms of the proportion of the plant's energy budget invested in extrafloral nectaries and the water, carbohydrates, and amino acids contained in the nectar. The model predicts that the mutualism will be favored where there are high densities of ants and potential herbivores and where the effectiveness of alternative defenses are low.

Humans in Mutualism
Humans have developed a variety of mutualistic relationships with other species, but one of the most spectacular is that between the greater honeyguide and the traditional honey gatherers of Africa. In this apparently ancient mutualism, humans and honeyguides engage in elaborate communication and

cooperation with clear benefit to both partners. The mutualism offers the human side a higher rate of discovery of bees' nests, while the honeyguide gains access to nests that it could not raid without human help. Careful observations have documented that the honeyguide informs the honey gatherers of the direction and distance to bees' nests as well as of their arrival at the nest.

64 Specie Abundance and Diversity

Community

A community is an association of interacting species inhabiting some defined area. Examples of communities include the plant community on a mountainside, the insect community associated with a particular species of tree, or the fish community on a coral reef. Community ecologists often restrict their studies to groups of species that all make their living in a similar way. Animal ecologists call such groups guilds, while plant ecologists use the term life-form. The field of community ecology concerns how the environment influences community structure, including the relative abundance and diversity of species, the subjects of this chapter.

Abundance

Most species are moderately abundant; few are very abundant or extremely rare. Frank Preston (1948) graphed the abundance of species in collections as distributions of species abundance, with each abundance interval twice the preceding one. Preston's graphs were approximately "bell-shaped" curves and are called "lognormal" distributions.

Lognormal distributions

Lognormal distributions, which describe the relative abundance of organisms ranging from algae and terrestrial plants to birds, may result from many random environmental variables acting upon the populations of a large number of species or may be a consequence of how species subdivide resources. Regardless of the underlying mechanisms, the lognormal distribution is one of the best described patterns in community ecology.

Species diversity

A combination of the number of species and their relative abundance defines species diversity.

Two major factors define the diversity of a community:

(1) the number of species in the community, which ecologists usually call species richness, and
(2) the relative abundance of species, or species evenness.

Shannon-Wiener index

One of the most commonly applied indices of species diversity is the Shannon-Wiener index:

$$H' = -\sum_{i=1}^{s} p_i \log_e p_i$$

The relative abundance and diversity of species can also be portrayed using rank-abundance curves.

Species diversity in complex envirnments

Species diversity is higher in complex environments. Robert MacArthur (1958) discovered that five coexisting warbler species feed in different layers of forest vegetation and that the number of warbler species in North American forests increases with increasing forest stature. Various investigators have found that the diversity of forest birds increases with increased foliage height diversity. The niches of algae can be defined by their nutrient requirements.

Heterogeneity

Heterogeneity in physical and chemical conditions across aquatic and terrestrial environments can account for a significant portion of the diversity among planktonic algae and terrestrial plants. Soil characteristics and depth to groundwater strongly influence the nature of local plant communities in the Amazon River basin. Increased nutrient availability correlates with reduced algal and plant diversity.

Disturbance

Intermediate levels of disturbance promote higher diversity. Joseph Connell (1975, 1978) proposed that high diversity is a consequence of continually changing conditions, not of competitive accommodation at equilibrium. He predicted that intermediate levels of disturbance would foster higher levels of diversity. At intermediate levels of disturbance, a wide array of species can colonize open habitats, but there is not enough time for the most effective competitors to exclude the other species

Work of Sousa
Wayne Sousa (1979), who studied the effects of disturbance on the diversity of sessile marine algae and invertebrates growing on intertidal boulders, found support for the intermediate disturbance hypothesis. Diversity in prairie vegetation also appears to be higher in areas receiving intermediate levels of disturbance. The effect of disturbance on diversity appears to depend upon a trade-off between dispersal and competitive abilities.

Human disturbance
Human disturbance is an ancient feature of the biosphere. Human influences touch every portion of the biosphere and have done so for thousands of years. For instance, humans disturbed tropical rain forests in Central America beginning about 11,000 years ago.

Intermediate disturbance hypothesis
The effects of human disturbance fall within the framework of the intermediate disturbance hypothesis. Though intense human disturbance reduces species diversity, moderate levels of disturbance may increase the diversity of some communities such as the European chalk grasslands.

65 Food Webs

A food web summarizes the feeding relations in a community. The earliest work on food webs concentrated on simplified communities in areas such as the Arctic islands. However, researchers such as Charles Elton (1927) soon found that even these so-called simple communities included very complex feeding relations. The level of food web complexity increased substantially, however, as researchers began to study complex communities. Studies of the food webs of tropical freshwater fish communities revealed highly complex networks of trophic interaction that persisted even in the face of various simplifications. A focus on strong interactions can simplify food web structure and identify those interactions responsible for most of the energy flow in communities.

Food web and structure of communities
The feeding activities of a few keystone species may control the structure of communities. Robert Paine (1966) proposed that the feeding activities of a few species have inordinate influences on community structure. He predicted that some predators may increase species diversity by reducing the probability of competitive exclusion. Manipulative studies of predaceous species have identified many keystone species, including starfish and snails in the marine intertidal zone and fish in rivers. On land, birds exert substantial influences on communities of their arthropod prey.

Jane Lubchenko (1978)
Jane Lubchenko (1978) demonstrated that the influence of consumers on community structure depends upon their feeding preferences, their local population density, and the relative competitive abilities of prey species. Keystone species are those that, despite low biomass, exert strong effects on the structure of the communities they inhabit.

Exotic predators and the structure of food webs
Exotic predators can collapse and simplify the structure of food webs. Introduced fishes have devastated the native fishes of Lake Atitlan and Gatun Lake in Central America.

Examples
The influence of the Nile perch on the fish community of Lake Victoria is enmeshed with massive changes in the lake's ecosystem.Introduction of the Nile perch is rapidly reducing the species-rich fish fauna of Lake Victoria to a community dominated by a handful of species.

Humans
Humans have acted as keystone species in communities. People have long manipulated food webs both as a consequence of their own feeding activities and by introducing or deleting species from existing food webs. In addition, many of these manipulations have been focused on keystone species. Hunters in tropical rain forests have been responsible for removing keystone animal species from large areas of the rain forests of Central and South America. Chinese farmers have used ants as keystone predators to control pests in citrus orchards for over 1,700 years.

66 Primary Production and Energy Flow

Flow of energy
We can view a forest, a stream, or an ocean as a system that absorbs, transforms, and stores energy. In this view, physical, chemical, and biological structures and processes are inseparable. When we look at natural

systems in this way we view them as ecosystems. An ecosystem is a biological community plus all of the abiotic factors influencing that community.

Production

- **Primary production**, the fixation of energy by autotrophs, is one of the most important ecosystem processes.
- The **rate of primary production** is the amount of energy fixed over some interval of time.
- **Gross primary production** is the total amount of energy fixed by all the autotrophs in the ecosystem. Net primary production is the amount of energy left over after autotrophs have met their own energetic needs.

Terrestrial primary production

Terrestrial primary production is generally limited by temperature and moisture. The variables most highly correlated with variation in terrestrial primary production are temperature and moisture. Highest rates of terrestrial primary production occur under warm, moist conditions.

Annual Actual Evapo Transpiration (AET)

Temperature and moisture conditions can be combined in a single measure called annual actual evapotranspiration, or AET, which is the total amount of water that evaporates and transpires off a landscape during the course of a year. Annual AET is positively correlated with net primary production in terrestrial ecosystems. However, significant variation in terrestrial primary production results from differences in soil fertility.

Aquatic primary production

Aquatic primary production is generally limited by nutrient availability. One of the best documented patterns in the biosphere is the positive relationship between nutrient availability and rate of primary production in aquatic ecosystems.

Phosphorus concentration usually limits rates of primary production in freshwater ecosystems, while nitrogen concentration usually limits rates of marine primary production.

Exmaples

- Consumers can influence rates of primary production in aquatic and terrestrial ecosystems. Piscivorous fish can indirectly reduce rates of primary production in lakes by reducing the density of plankton-feeding fish..
- Reduced density of planktivorous fish can lead to increased density of herbivorous zooplankton, which can reduce the densities of phytoplankton and rates of primary production. Intense grazing by large mammalian herbivores on the Serengeti increases annual net primary production by inducing compensatory growth in grasses

Energy losses

Energy losses limit the number of trophic levels in ecosystems. Ecosystem ecologists have simplified the trophic structure of ecosystems by arranging species into trophic levels based upon the predominant source of their nutrition. A trophic level is determined by the number of transfers of energy from primary producers to that level.

Energy losses and trophic levels

As energy is transferred from one trophic level to another, energy is lost due to limited assimilation, respiration by consumers, and heat production. As a result of these losses, the quantity of energy in an ecosystem decreases with each successive trophic level, forming a pyramid-shaped distribution of energy among trophic levels. As losses between trophic levels accumulate, eventually there is insufficient energy to support a viable population at a higher trophic level.

Stable isotope analysis

Stable isotope analysis can be used to trace the flow of energy through ecosystems. The ratios of different stable isotopes of important elements such as nitrogen and carbon are generally different in different parts of ecosystems.

Use of Stable isotope analysis

As a consequence, ecologists can use isotopic ratios to study the trophic structure and energy flow through ecosystems. **Stable isotope analysis** has helped **quantify dietary composition of wild populations** and the major sources of energy used by prehistoric human populations.

67 Nutrient Cycling and Retention

Nutrient cycling
The elements organisms require for development, maintenance, and reproduction are called nutrients. Ecologists refer to the use, transformation, movement, and reuse of nutrients in ecosystems as nutrient cycling.

Nutrient cycling is one of the most ecologically significant processes studied by ecosystem ecologists. The carbon, nitrogen, and phosphorus cycles have played especially prominent roles in studies of nutrient cycling.

Decomposition rate
Decomposition rate is influenced by temperature, moisture, and chemical composition of litter and the environment. The rate of decomposition affects the rate at which nutrients, such as nitrogen and phosphorus, are made available to primary producers. Rates of decomposition in terrestrial ecosystems are higher under warm, moist conditions. The rate of decomposition in terrestrial ecosystems increases with nitrogen content and decreases with the lignin content of litter. The chemical composition of litter and the availability of nutrients in the surrounding environment also influence rates of decomposition in aquatic ecosystems.

Cycling of nutrients in ecosystems
- Plants and animals can modify the distribution and cycling of nutrients in ecosystems.
- The dynamics of nutrients in streams are best represented by a spiral rather than a cycle.
- The length of stream required for an atom of a nutrient to complete a cycle is called the spiraling length.
- Stream macroinvertebrates can substantially reduce spiralling length of nutrients in stream ecosystems.
- Animals can also alter the distribution and rate of nutrient cycling in terrestrial ecosystems. Nitrogen-fixing plants increase the quantity and rates of nitrogen cycling in terrestrial ecosystems.

Disturbance and nutrient loss from ecosystems
Disturbance increases nutrient loss from ecosystems. Vegetation exerts substantial control on nutrient retention by terrestrial ecosystems. Vegetative controls on nutrient loss from forest ecosystems appear to be most important in environments that are warm and moist during the growing season

Nutrient enrichment by humans
Vegetative controls appear to be less important in cold and/or dry environments. Nutrient loss by stream ecosystems is highly pulsed and associated with disturbance by flooding. Nutrient enrichment by humans is altering aquatic and terrestrial ecosystems. Nitrate concentration and export by the earth's major rivers correlate directly with human population density. Human disturbance also increases export of phosphorus from aquatic catchments. Nutrient enrichment appears to be reducing the diversity of plants and fungi in terrestrial ecosystems. Land managers around the world use nutrient loading models to predict and manage the impact of land use on aquatic ecosystems.

68 Succession and Stability

Primary succession
Succession is the gradual change in plant and animal communities in an area following disturbance

or the creation of new substrate. Primary succession occurs on newly exposed geological substrates not significantly modified by organisms.

Secondary succession
Secondary succession occurs in areas where disturbance destroys a community without destroying the soil. Succession generally ends with a climax community whose populations remain stable until disrupted by disturbance.

Community changes during succession
Community changes during succession include increases in species diversity and changes in species composition. Primary forest succession around Glacier Bay may require about 1,500 years, while secondary forest succession on the Piedmont Plateau takes about 150 years.

Succession duration
Meanwhile, succession in the intertidal zone requires 1 to 3 years and succession within a desert stream occurs in less than 2 months. Despite the great differences in the time required, all these Successional sequences show increased species diversity over time.

Ecosystem changes during succession

Ecosystem changes during succession include increases in biomass, primary production, respiration, and nutrient retention. Succession at Glacier Bay produces changes in several ecosystem properties, including increased soil depth, organic content, moisture, and nitrogen. Over the same successional sequence, several soil properties show decreases, including soil bulk density, pH, and phosphorus concentration. Succession at the Hubbard Brook Experimental Forest increased nutrient retention by the forest ecosystem.

Predictability of succession

Several ecosystem properties change predictably during succession in Sycamore Creek, Arizona, including biomass, primary production, respiration, and nitrogen retention.

Mechanisms of succession

Mechanisms that drive ecological succession include facilitation, tolerance, and inhibition.
Most studies of succession support the facilitation model, the inhibition model, or some combination of the two.
Both facilitation and inhibition occur during intertidal succession. Facilitation and inhibition also occur during secondary and primary forest succession.

Community stability

Community stability may be due to lack of disturbance or community resistance or resilience in the face of disturbance. Ecologists generally define stability as the persistence of a community or ecosystem in the face of disturbance. Resistance is the ability of a community or ecosystem to maintain structure and/or function in the face of potential disturbance.

Resilience

The ability to bounce back after disturbance is called resilience. A resilient community or ecosystem may be completely disrupted by disturbance but quickly return to its former state. Studies of the Park Grass Experiment suggest that our perception of stability is affected by the scale of measurement. Studies in Sycamore Creek indicate that resilience is sometimes influenced by resource availability and that resistance may result from landscape-level phenomena

Repeat photography

Repeat photography can be used to detect long-term ecological change. Most successional sequences and most community and ecosystem responses to climatic change take place over very long periods of time. Repeat photography has become a valuable tool to help ecologists study these long-term changes.

69 Landscape Ecology

Landscape:

A landscape is a heterogeneous area composed of several ecosystems. The ecosystems making up a landscape generally form a mosaic of visually distinctive patches. These patches are called landscape elements. Landscape ecology is the study of landscape structure and processes.

Landscape structure

Landscape structure includes the size, shape, composition, number, and position of different ecosystems within a landscape. Most questions in landscape ecology require that ecologists quantify landscape structure. Until recently, however, geometry, which means “earth measurement,” could offer only rough approximations of complex landscape structure.

Structure of complex natural shapes

Today, an area of mathematics called fractal geometry can be used to quantify the structure of complex natural shapes. One of the findings of fractal geometry is that the length of the perimeter of complex shapes depends upon the size of the device used to measure the perimeter. One implication of this result is that organisms of different sizes may use the environment in very different ways

Landscape structure influences Ecological processes

Landscape structure influences processes such as the flow of energy, materials, and species between the ecosystems within a landscape. Landscape ecologists have proposed that landscape structure, especially the size, number, and isolation of habitat patches, can influence the movement of organisms between potentially suitable habitats. The group of subpopulations living on such habitat patches make up a metapopulation.

Examples

- Studies of the movements of small mammals in a prairie landscape show that a smaller proportion of individuals moves in more fragmented landscape but that the individuals that do move will move farther. The local population density of the Glanville fritillary butterfly, ***Melitaea cinxia***, is lower on larger and on isolated habitat patches. Small populations of this butterfly and desert bighorn sheep are more vulnerable to local extinction.
- The source of water for lakes in a Wisconsin lake district is determined by their positions in the landscape, which in turn determine their hydrologic and chemical responses to drought.

Landscapes are structured and dynamic

Landscapes are structured and change in response to geological processes, climate, activities of organisms, and fire.

Geological features produced by processes such as volcanism, sedimentation, and erosion interact with climate to provide a primary source of landscape structure. In the Sonoran Desert, plant distributions map clearly onto soils of different ages and form a vegetative mosaic that closely matches soil mosaics. This mosaic will gradually shift as geological processes and climate gradually change the soil mosaic. While geological processes and climate set the basic template for landscape structure, the activities of organisms, from plants to elephants, can be an additional source of landscape structure and change.

Human activity changes the structure of landscapes

Economically motivated human activity changes the structure of landscapes all over the globe. Beavers can quickly change landscape structure and processes over large regions. Fire contributes to the structure of landscapes ranging from tropical savanna to boreal forest. However, fire plays a particularly prominent role in regions with a Mediterranean climate. Because human activity has often altered landscape structure and processes in undesirable ways, there is growing pressure and interest in landscape restoration. Some of the most ambitious current restoration efforts focus on the restoration of riverine landscapes. Rivers and their floodplains form a complex, highly dynamic landscape that includes river riparian forest, marsh, oxbow lake, and wet meadow' ecosystems.

Water management and landscapes

Over the past century, water management by building dams, channelizing rivers, constructing flood levees, and diverting water for irrigation has cut the historic connections between most rivers and their floodplains. The restoration of the Kissimmee River landscape is also one of the largest ecological experiments ever conducted and will be a significant test of the predictive ability of ecological theory.

70 Geographic Ecology

Geographic ecology focuses on large-scale patterns of distribution and diversity of organisms, such as island biogeography, latitudinal patterns of species diversity, and the influences of large-scale regional and historical processes on biological diversity.

Isolation

On islands and habitat patches on continents, species richness increases with area and decreases

with isolation. Larger oceanic islands support more species of most groups of organisms than small islands. Isolated oceanic islands generally contain fewer species than islands near mainland areas. Many habitats on continents are so isolated that they can be considered as islands.

Species richness on habitat islands

Species richness on habitat islands, such as mountain islands in the American Southwest, increases with area and decreases with isolation. Lakes can also be considered as habitat islands. They are aquatic environments isolated from other aquatic environments by land. Fish species richness generally increases with lake area. Species richness is usually negatively correlated with island isolation. However, because organisms differ substantially in dispersal rates, an island that is very isolated for one group of organisms may be completely accessible to another group.

Models of Species richness on islands

Species richness on islands can be modelled as a dynamic balance between immigration and extinction of species.

The equilibrium model of island biogeography proposes that the difference between rates of immigration and extinction determines the species richness on islands.

The equilibrium model of island biogeography

The equilibrium model of island biogeography assumes that rates of species immigration to islands are mainly determined by distance from sources of immigrants. The model assumes that rates of extinction on islands are determined mainly by island size.

Species richness and latitude

Species richness generally increases from middle and high latitudes to the equator. Most groups of organisms are more species-rich in the tropics.

Many factors may contribute to higher tropical species richness, including

(1) time since perturbation,
(2) productivity,
(3) environmental heterogeneity,
(4) favorableness,
(5) niche breadths and interspecific interactions, and
(6) differences in speciation and extinction rates. Several lines of evidence support the hypothesis that differences in surface area play a primary role in determining latitudinal gradients in species richness

Structure of biotas and ecosystems

Long-term historical and regional processes significantly influence the structure of biotas and ecosystems. Much geographic variation in species richness can be explained by historical and regional processes.

Exceptional situations

Some exceptional situations that seem to have resulted from unique historical and regional processes include the exceptional species richness of the Cape floristic region of South Africa, the high species richness of temperate trees in east Asia, and the low bird diversity in beech forests of South America.

A word of advise

The ecologist interested in understanding large-scale patterns of species richness must consider processes occurring over similarly large scales and over long periods of time.

Global positioning systems

Global positioning systems, remote sensing, and geographic information systems are important tools for effective geographic ecology. A global positioning system determines locations on the earth's surface, including latitude, longitude, and altitude, using satellites as reference points.

Remote sensing satellites

Remote sensing satellites are generally fitted with electro-optical sensors that scan several bands of the electromagnetic spectrum. These sensors convert electromagnetic radiation into electrical signals that are in turn converted to digital values by a computer. These digital values can be used to construct an image.

Geographic information systems

Geographic information systems are computer-based systems that store, analyze, and display geographic information. Global positioning systems, remote sensing, and geographic information systems are increasingly valuable parts of the ecologist's tool kit.

Future avenues

Ecologists are using these new tools to study large-scale, dynamic ecological phenomena such as interannual variation in regional terrestrial primary production, dynamics of marine primary production, and potential population responses to climate change.

BEST OF LUCK