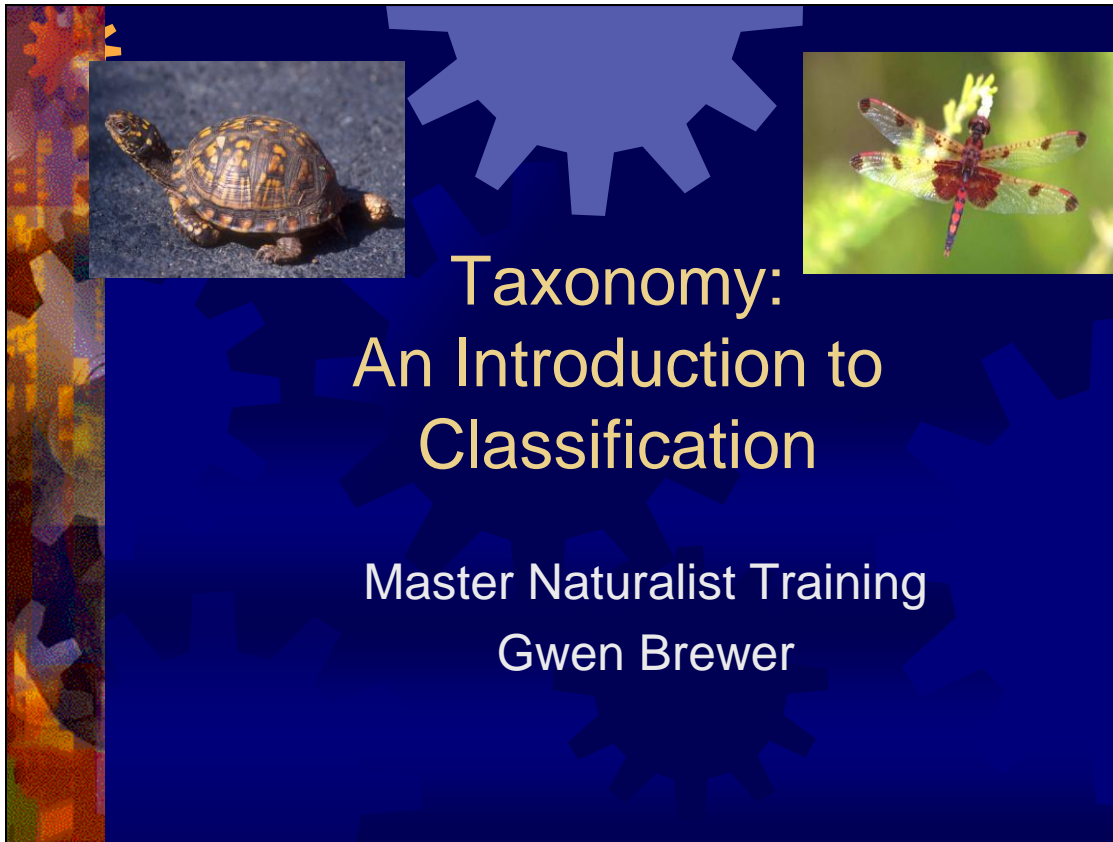


Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 1



Taxonomy:
An Introduction to
Classification

Master Naturalist Training
Gwen Brewer

Welcome to the wonderful world of taxonomy! You will see that there are still plenty of controversies and things to be worked out in this topic area. This presentation will go over some definitions, a little history, characters and systems for classification, species concepts, and Kingdoms and their characteristics to whet your appetites for topic areas to come.

(NOTE: images cannot be used other than in the presentation without permission- credit to George Jett)

Unit 2: Taxonomy - Pre-Reading

Gwen Brewer
Slide 2

Why Do We Classify?

"The first part of knowledge is getting the names right." (Chinese proverb)



The slide features four distinct biological images arranged in a 2x2 grid. The top-left image shows a close-up of a single white flower with a yellow center and green leaves. The top-right image shows a black beetle with white spots on its back, resting on a piece of wood. The bottom-left image shows a cluster of bright orange flowers with green foliage. The bottom-right image shows a green tree frog with white stripes on its back, perched on a brown branch. A small copyright notice '© 2006 4886 411' is visible in the bottom-left corner of the frog image.

The biological world contains an incredible amount of diversity. A few examples are pictured here. In order to communicate about these organisms and start to understand their relationships to one another, names are an important first step.

(Images not for use outside of presentation)

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 3



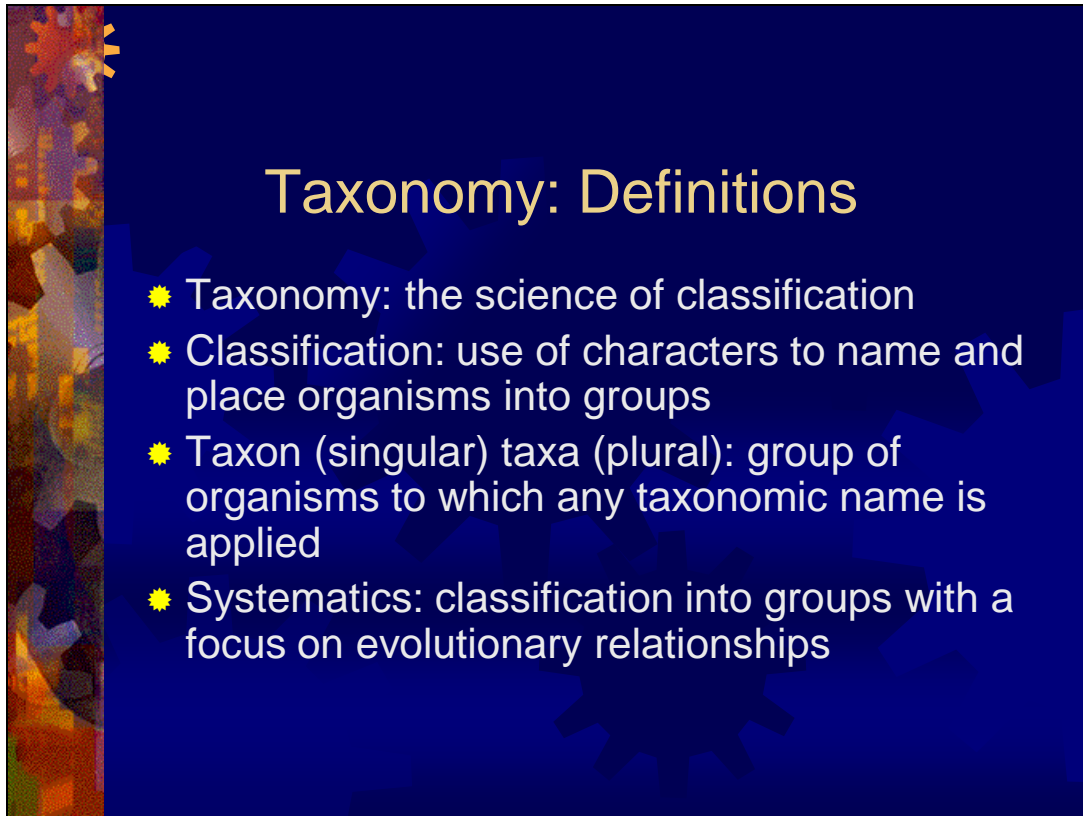
Why Do We Classify?

- ☀ Communication
- ☀ Understanding relationships
 - Desire to make sense of the world around us (order)
 - Recognizing patterns helps us understand how and why things work as they do

We as humans have a natural tendency to want to understand and organize the world around us. These were skills that helped us to be successful through our evolution. As the former slide stated, we also need to name things to be able to communicate about them. By using a common language for scientific names (Latin), this communication is possible worldwide. One interesting thing to contemplate is how our basic worldview structures our classification system and how we order our world.

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 4



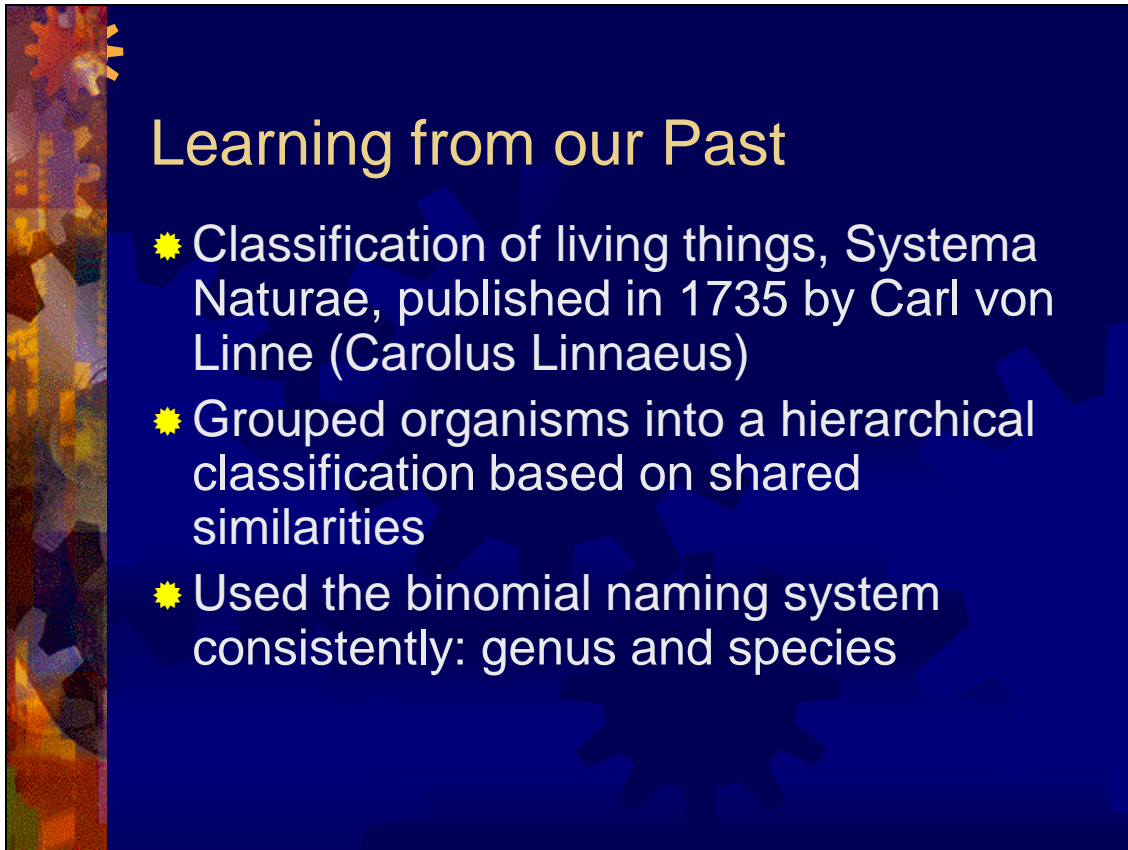
Taxonomy: Definitions

- ☀ Taxonomy: the science of classification
- ☀ Classification: use of characters to name and place organisms into groups
- ☀ Taxon (singular) taxa (plural): group of organisms to which any taxonomic name is applied
- ☀ Systematics: classification into groups with a focus on evolutionary relationships

Time for some definitions- and there are plenty in this field. Like many scientific fields, this one just about requires you to learn a new language. Let's follow through these connected words.

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 5



Learning from our Past

- ☀ Classification of living things, *Systema Naturae*, published in 1735 by Carl von Linne (Carolus Linnaeus)
- ☀ Grouped organisms into a hierarchical classification based on shared similarities
- ☀ Used the binomial naming system consistently: genus and species

Now that we have a few terms under our belts, let's take a look back at classification systems past and present. The classification used today got its formal start with Linnaeus back in the early 1700's. Like others before him, he grouped organisms based on similarities that they shared- these could be external or internal characters. Linnaeus took information from his investigations and those of others and put it all into one large document, the *Systema Naturae*, and also used consistently a certain way of assigning names to species- a 2-part specific epithet with genus and species. Latin was the scientific language of the day, and Carl von Linne liked it so much that he Latinized his own name.

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 6

What are the rules for naming species and other groups?

Binomial nomenclature

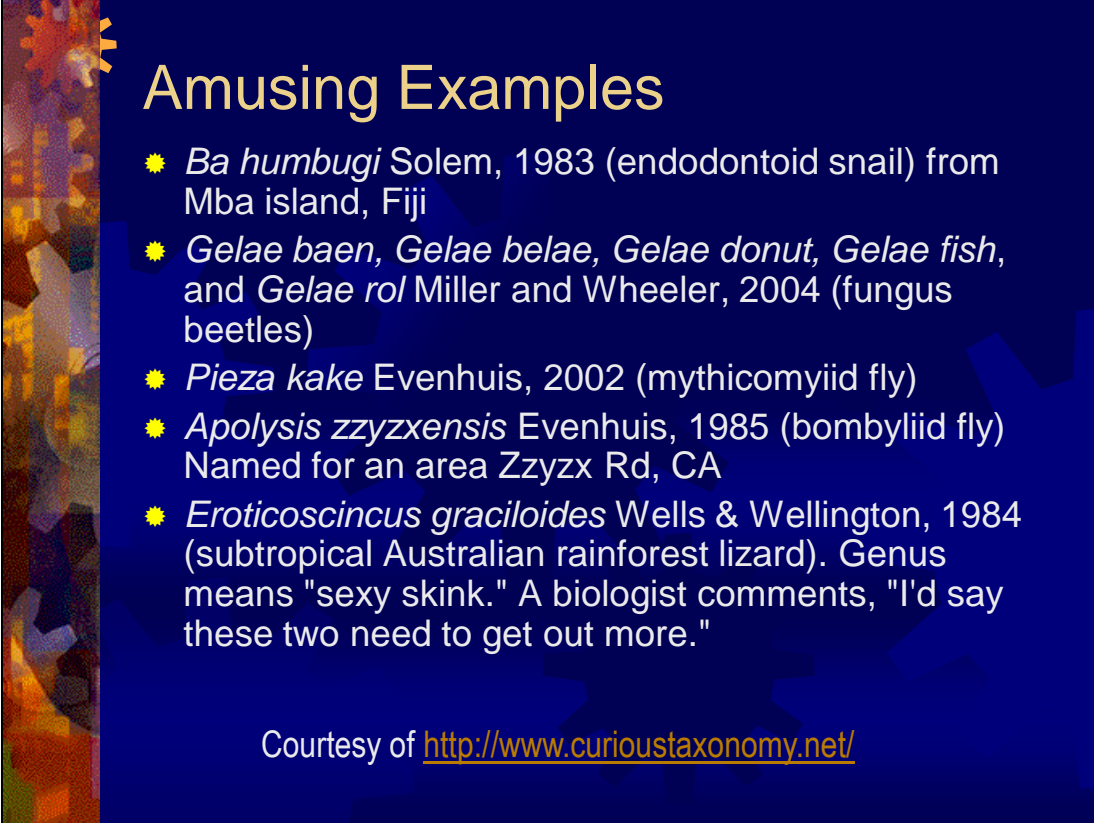
- Latinized, unique for species
- Genus capitalized, species not capitalized
- Underline or use italics
- Author's name and date of publication may be included
- A type specimen should be available

As of 1993, paleontologist Edward Drinker Cope is the type specimen for *Homo sapiens* Linnaeus, 1758. Robert Bakker formally described his skull, and it was approved by the ICZN.

The structure for naming and Latin convention of Linnaeus stuck. Species are still named using a binomial (two names) with the format described here. It is important to note that the name of a species must have these two parts. Type specimens are the individual specimens that represent the named species, often the first described individual given that specific epithet. Who is the type specimen for humans? Edward Drinker Cope. ICZN stands for the International Commission on Zoological Nomenclature.

Unit 2: Taxonomy - Pre-Reading

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Slide 7



Amusing Examples

- *Ba humbugi* Solem, 1983 (endodontoid snail) from Mba island, Fiji
- *Gelae baen*, *Gelae belae*, *Gelae donut*, *Gelae fish*, and *Gelae rol* Miller and Wheeler, 2004 (fungus beetles)
- *Pieza kake* Evenhuis, 2002 (mythicomyiid fly)
- *Apolysis zzyzxensis* Evenhuis, 1985 (bombyliid fly)
Named for an area Zzyzx Rd, CA
- *Erotoscincus graciloides* Wells & Wellington, 1984 (subtropical Australian rainforest lizard). Genus means "sexy skink." A biologist comments, "I'd say these two need to get out more."

Courtesy of <http://www.curioustaxonomy.net/>

Some scientists spend too much time in a lab or under harsh conditions that seem to warp their sense of humor a bit. Here are some funny examples of real scientific names. A fun website with these and more is listed at the bottom of the page.

Unit 2: Taxonomy - Pre-Reading

Gwen Brewer
Slide 8



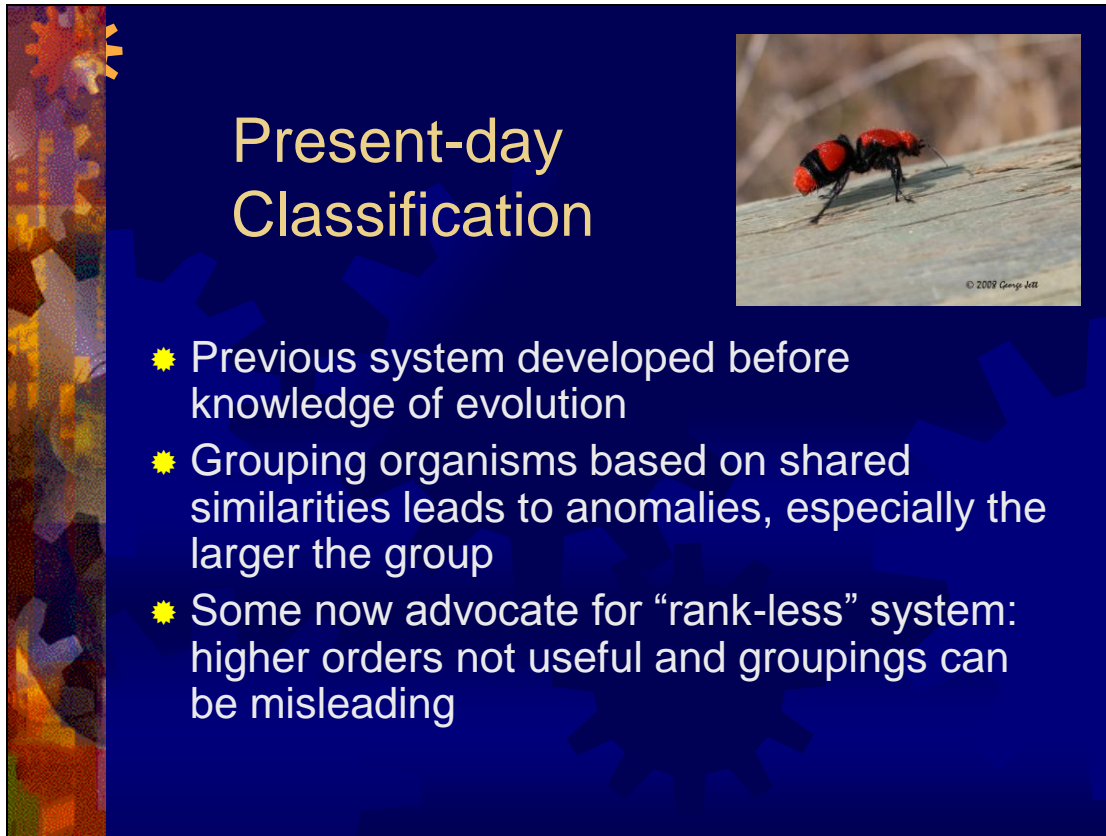
Taxonomic Levels (and how to remember them!)

* Kingdom	* King	* Kids
* Phylum or Division	* Phillip or David	* Prefer or Devour
* Class	* Came	* Candy
* Order	* Over	* Over
* Family	* For	* Fine
* Genus	* Great	* Green
* Species	* Spaghetti	* Salads

So far we have just looked at the genus and species levels of taxonomy. Higher levels of organization are also used to organize similar groups. Various mnemonics are used to remember this order- or make up your own. Phylum is used for animals and Division is used for plants.


Unit 2: Taxonomy - Pre-Reading

Gwen Brewer
Slide 9



Present-day Classification

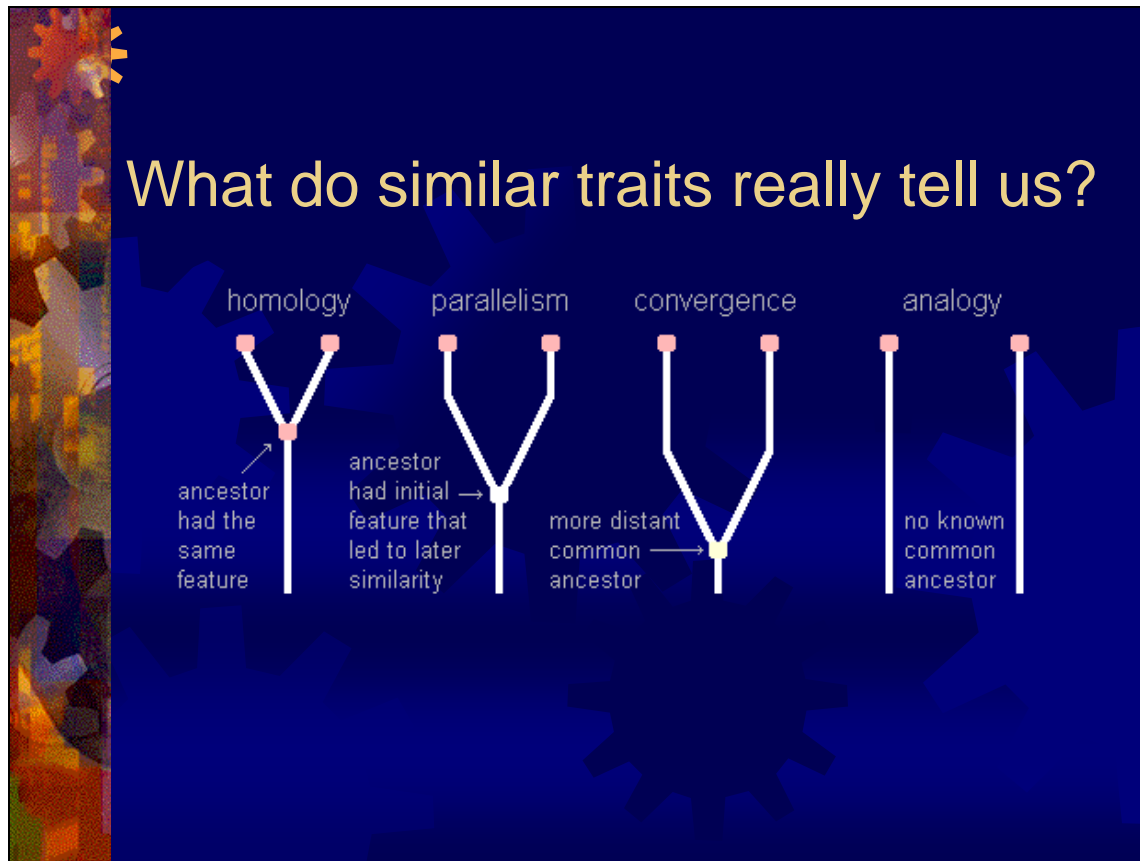
- Previous system developed before knowledge of evolution
- Grouping organisms based on shared similarities leads to anomalies, especially the larger the group
- Some now advocate for “rank-less” system: higher orders not useful and groupings can be misleading



All that having been said, today we understand the world differently than in the time of Linnaeus. Specifically, we know how evolution has shaped the origin of new species. We also have a wider variety of characteristics to use to classify organisms. Genetic characters have largely changed the face of the science of classification and given us the focus on systematics—thinking about evolutionary relationships to classify organisms into groups and examine relatedness. The use of molecular information and focus on evolution has led some to conclude that groupings above genus and species are suspect and not useful.

Unit 2: Taxonomy – Pre-Reading


Gwen Brewer
Slide 10



Let's take a closer look at this change in thinking about taxonomy, the science of classification. Here come some more terms! One challenge is the interpretation of characteristics. What does it really mean if organisms share similarities? Does that necessarily mean that they are closely related? This diagram illustrates several explanations for similarity in traits. Imagine that there is a time scale along the left side of the diagram. Traits may be similar due to ancestry or relatedness, but traits may also be similar when organisms respond to the same environmental pressures in the same way through time.

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 11



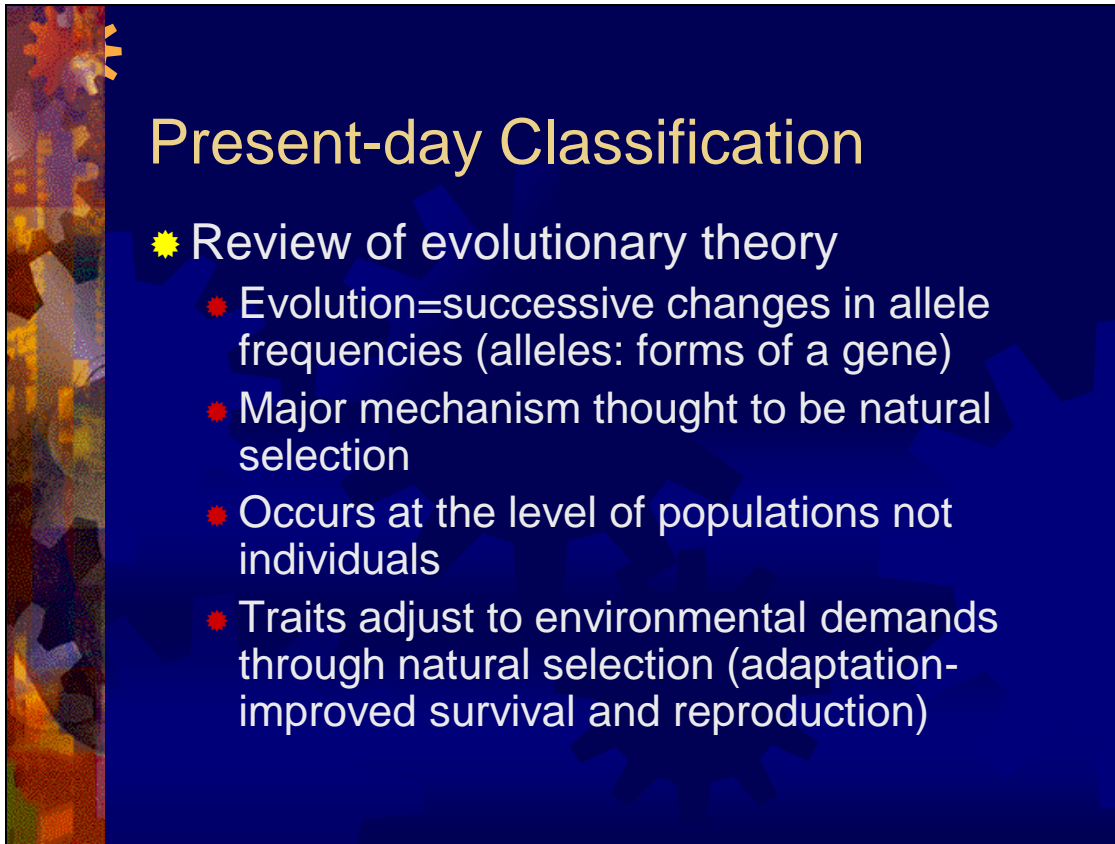
Present-day Classification

- ☀ Darwin/Wallace's theory of evolution by natural selection:
 - More offspring are produced than can survive
 - Competition for limited resources
 - There is variation among individuals
 - Some individuals are more successful
 - Variation is heritable
 - Proportion of favorable characteristics increases in successive generations

Taking a further look into what makes organisms similar or not, and the use of evolution as a basis for taxonomy, a review of evolutionary theory is helpful here. This is Darwin's and Wallace's basic formulation of evolution by natural selection, the most familiar pathway to evolution.

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 12



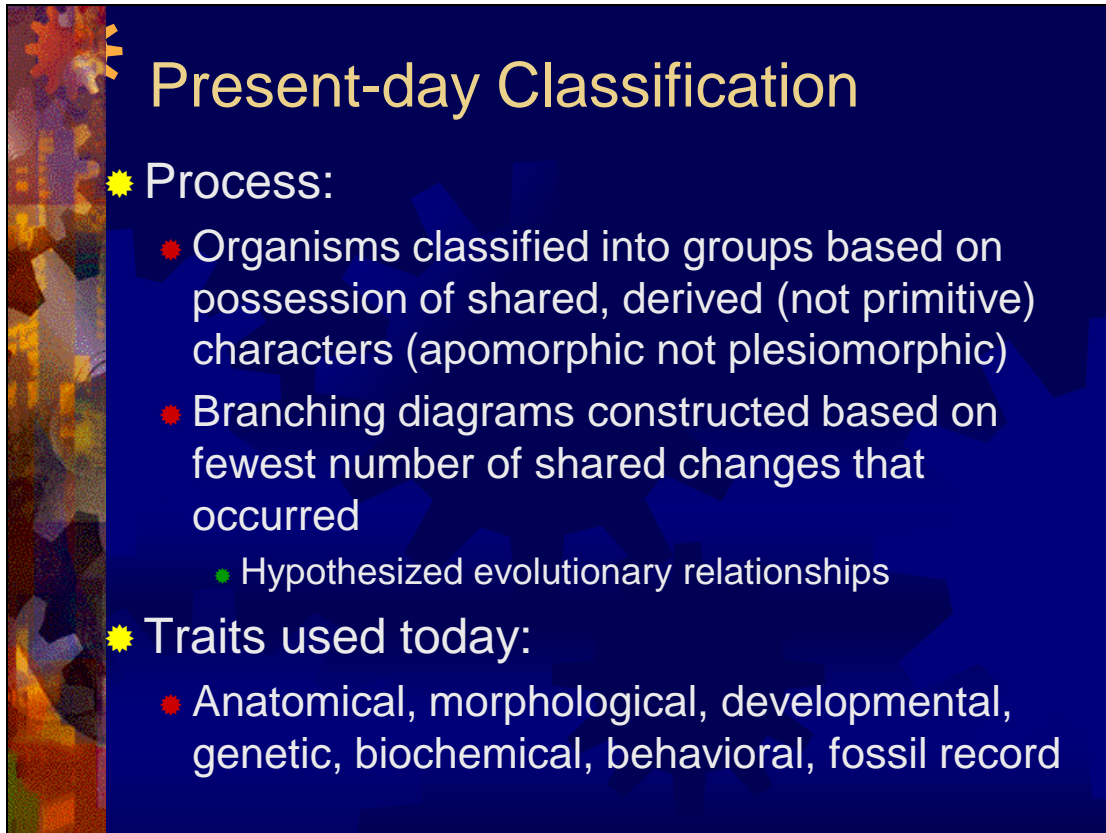
Present-day Classification

- ☀ Review of evolutionary theory
 - Evolution=successive changes in allele frequencies (alleles: forms of a gene)
 - Major mechanism thought to be natural selection
 - Occurs at the level of populations not individuals
 - Traits adjust to environmental demands through natural selection (adaptation-improved survival and reproduction)

But what is evolution anyway? With our current understanding of molecular genetics, we view this a little differently than Darwin and Wallace did. One of the most important things to note about evolution is that populations evolve, individuals don't. "Survival of the fittest" doesn't quite capture evolution by natural selection either- the key is reproduction, not just survival.

Unit 2: Taxonomy – Pre-Reading

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Slide 13



Present-day Classification

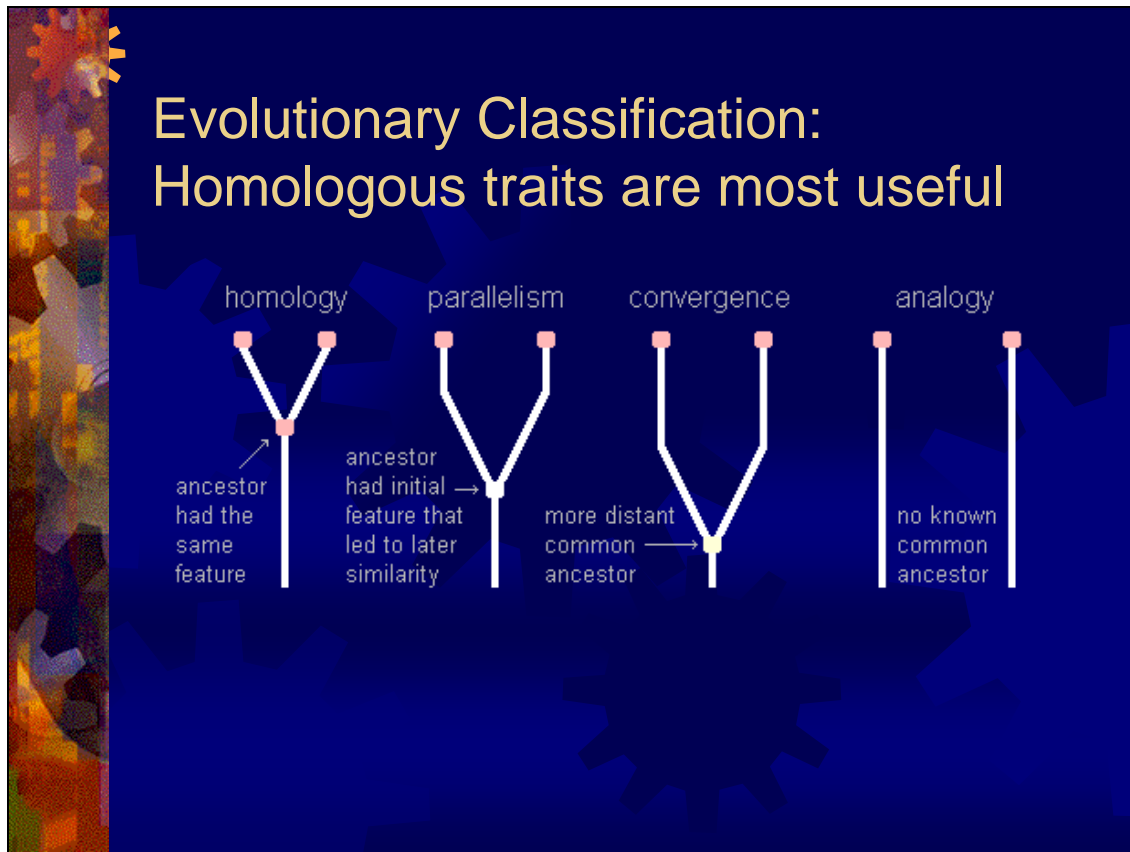
- ☀ Process:
 - Organisms classified into groups based on possession of shared, derived (not primitive) characters (apomorphic not plesiomorphic)
 - Branching diagrams constructed based on fewest number of shared changes that occurred
 - Hypothesized evolutionary relationships
- ☀ Traits used today:
 - Anatomical, morphological, developmental, genetic, biochemical, behavioral, fossil record

With a background of evolutionary theory, how do modern-day taxonomists work to classify organisms? The kinds of traits they look for are those that are both shared and derived. These traits are also referred to as apomorphic- apo: “from or away” from a “primitive” form (morph); opposite is plesiomorphic (“near” “form”). There are lots more terms to describe traits but I’ll spare you!

These useful traits are put together into branching diagrams (similar to a family tree) essentially in the most simple way possible. This branching diagram then shows a set of hypothesized evolutionary relationships between the organisms. The traits can (and should) include a mixture of different types like those listed here.

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Going back to our look at what can make organisms have similar traits, we can identify that it is homologous traits that are the shared derived characters that taxonomists find most useful to reconstruct evolutionary histories. Can you see how the use of other kinds of traits could be misleading?

Unit 2: Taxonomy - Pre-Reading

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Slide 15

Picturing Classification

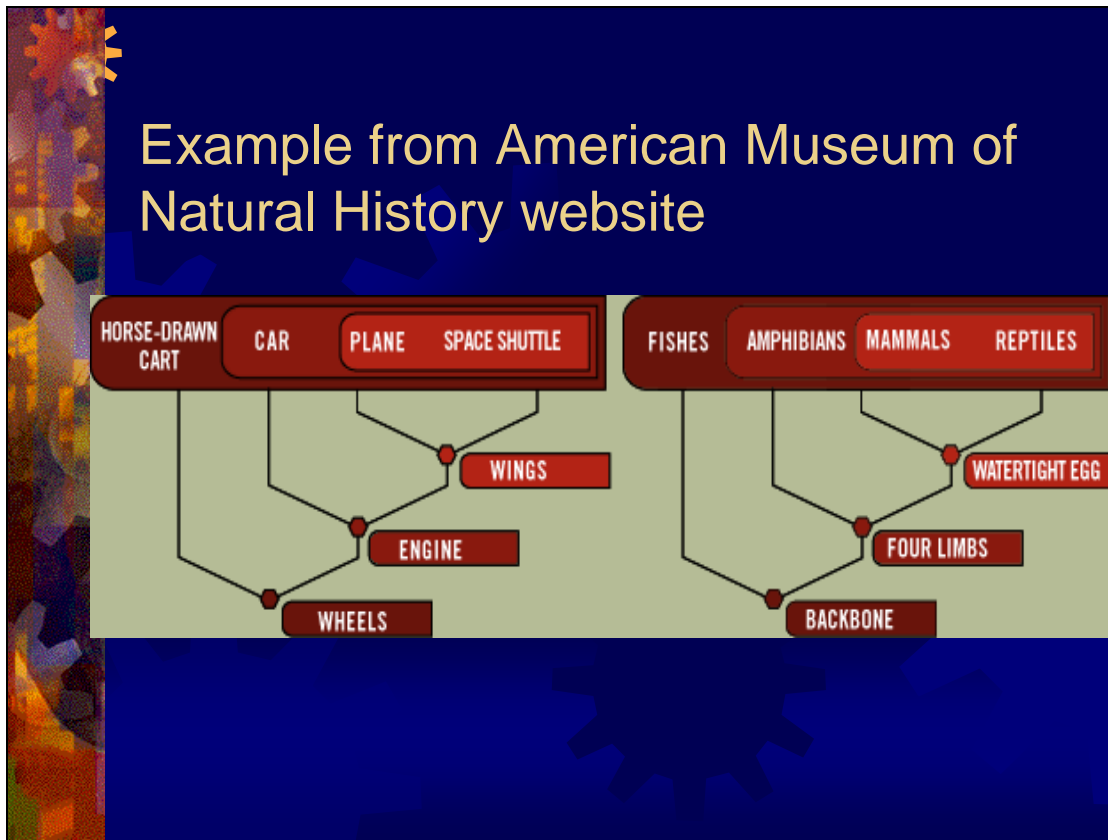
The image displays two types of classification diagrams. On the left is a **CLADOGRAM** with four terminal taxa: Lamprey (D), Shark (A), Salmon (B), and Lizard (C). The branching pattern shows Lamprey (D) as the outgroup, with Shark (A) and Salmon (B) as sister taxa, and Lizard (C) as the sister taxon to the (A, B) clade. On the right is a **PHYLOGENETIC TREE** representing one of the 12 possible trees that can be built from the cladogram data. It includes a hypothetical ancestor (Z) at the base, a hypothetical descendent (X) on the branch leading to Salmon (B) and Lizard (C), and a green node (A) on the branch leading to Shark (A). A vertical graduated bar to the right of the tree indicates units of time or genetic divergence.

- cladogram shows patterns of relatedness from the distribution of characters
- diagram on the right presents one of 12 possible phylogenetic trees that can be built from the cladogram data
- graduated bar next to the tree can have various units, including time and base pairs (for genetic divergence)

Phylogenetic trees have long been used to picture relationships. Note that the cladogram does not show the exact pattern of ancestry and that the phylogenetic tree includes a hypothetical ancestor (letter Z) and a hypothetical descendent (X).

Unit 2: Taxonomy - Pre-Reading

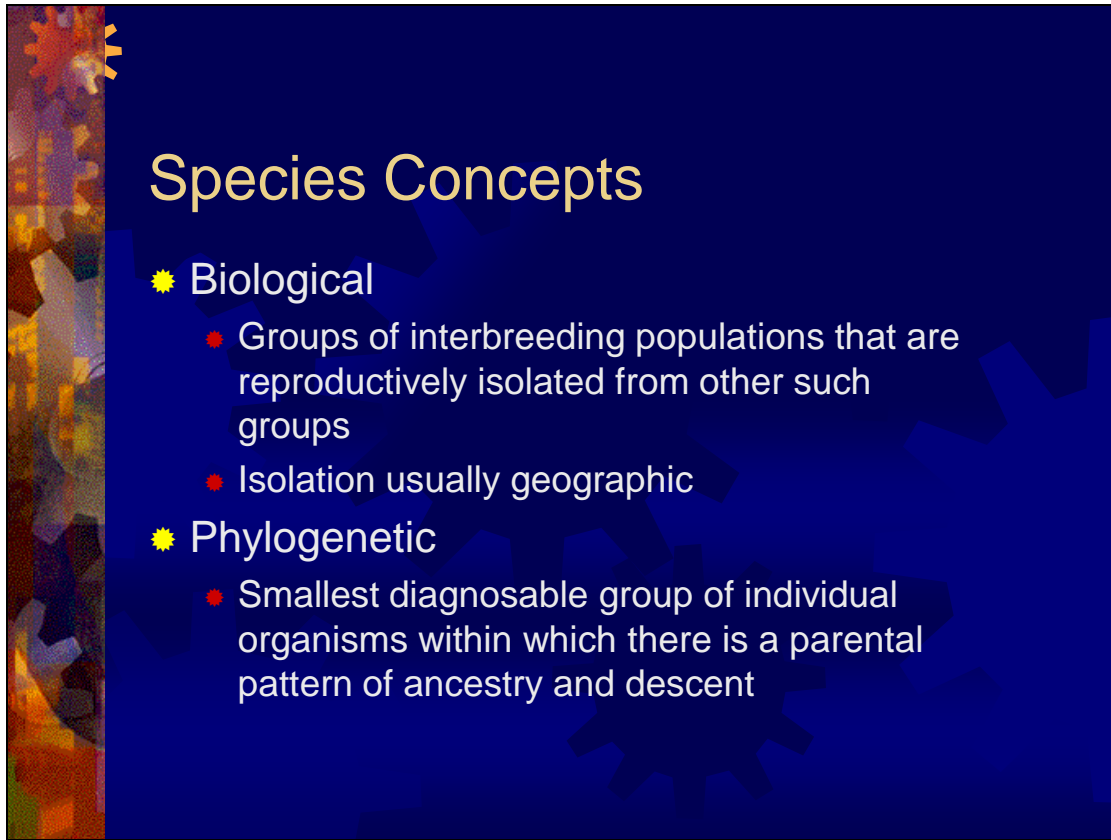
Gwen Brewer
Slide 16



Here is an example from the AMNH website of the type of branching diagram that taxonomists use. Note that in these diagrams, we can picture time proceeding along the vertical axis and the number of shared characters increasing from left to right. The red nodes indicate a feature coming on the scene. All of the example objects/organisms appear at the same time level across the top since they are all still in existence today. Each object/organism has the characteristics of the node it branches off from and all of the nodes to its left. We will try our hand at constructing this sort of diagram during class time.

Unit 2: Taxonomy – Pre-Reading

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Species Concepts

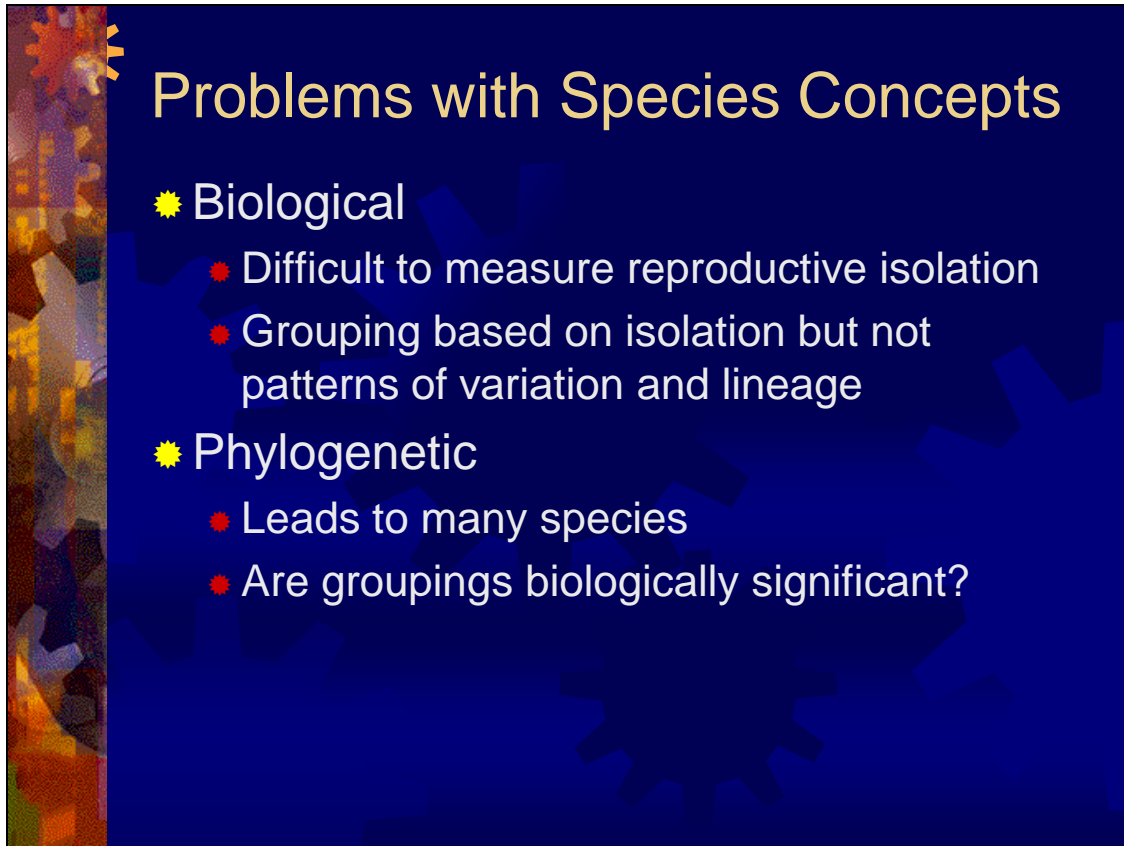
- Biological
 - Groups of interbreeding populations that are reproductively isolated from other such groups
 - Isolation usually geographic
- Phylogenetic
 - Smallest diagnosable group of individual organisms within which there is a parental pattern of ancestry and descent

We now have some experience with thinking about taxonomy and classification at the higher levels of organization. Now let's take a closer look at species and how they are determined, then we will go back to the higher levels and look at some examples. This will set the stage for coming sessions in your Master Naturalist training.

Just like with classification in general, determining species has become less straightforward with our ability to use molecular characters. These two species concepts, or ways to define and identify species, are still the subject of scientific debate. Each has its merits and problems.

Unit 2: Taxonomy – Pre-Reading

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Problems with Species Concepts

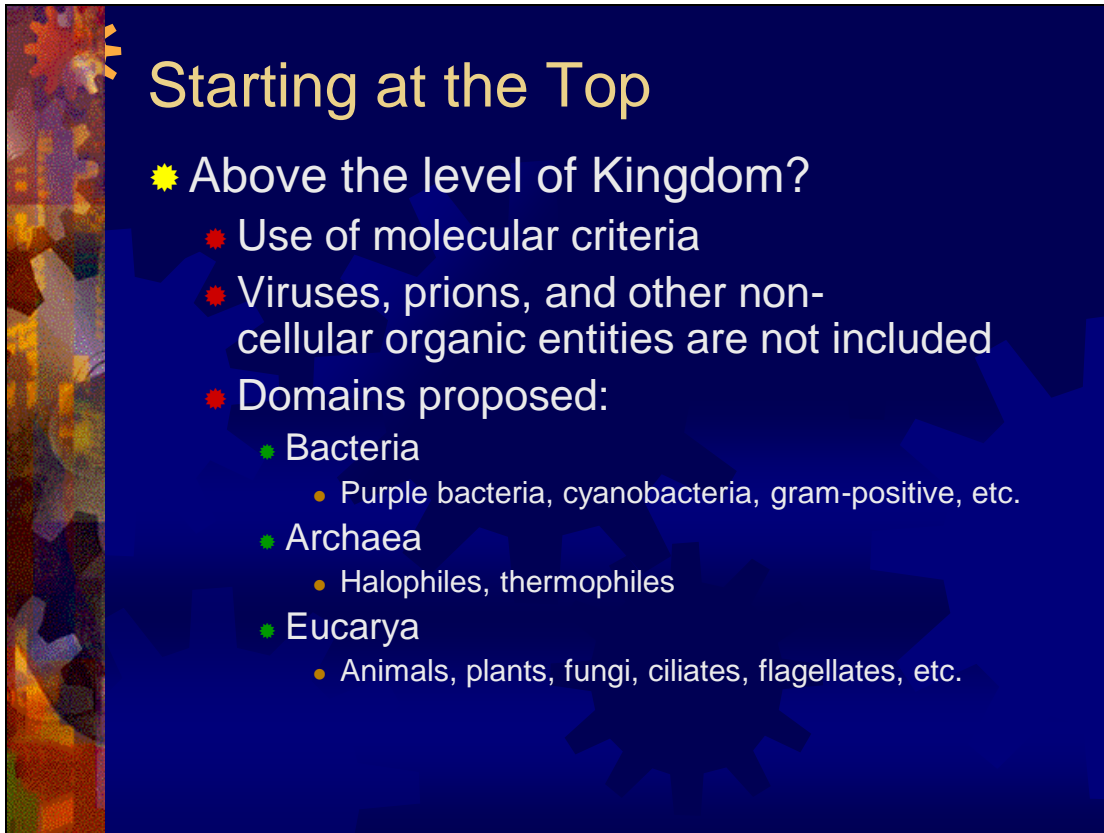
- ☀ Biological
 - Difficult to measure reproductive isolation
 - Grouping based on isolation but not patterns of variation and lineage
- ☀ Phylogenetic
 - Leads to many species
 - Are groupings biologically significant?

The biological species concept is appealing because it seems to be more what the animals are telling us. However, it is not as firmly based in evolutionary theory and it is difficult to tell if groups are truly isolated reproductively in the field.

The phylogenetic species concept, although relying on patterns of genetic relatedness, can lead to many groups being identified as separate species and the biological relevance of these groups can be questionable.

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Starting at the Top

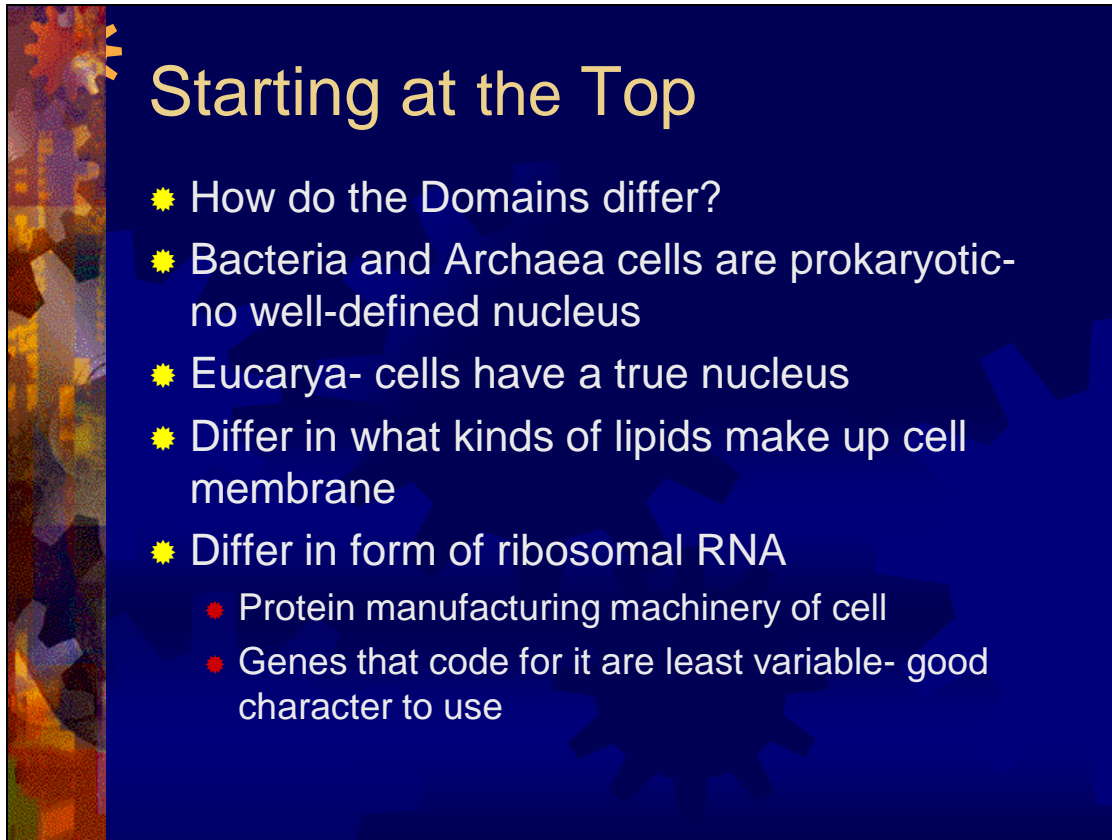
- ☀ Above the level of Kingdom?
 - Use of molecular criteria
 - Viruses, prions, and other non-cellular organic entities are not included
 - Domains proposed:
 - Bacteria
 - Purple bacteria, cyanobacteria, gram-positive, etc.
 - Archaea
 - Halophiles, thermophiles
 - Eucarya
 - Animals, plants, fungi, ciliates, flagellates, etc.

Okay- let's go back up the levels of organization and get into another set of controversies! You can see that this taxonomy thing is not all so straightforward and does not fit into a nice formula that everyone agrees on.

Remember the most inclusive level of organization from our mnemonics to remember the levels? Kingdom. Recent work using molecular criteria suggests that actually a level more inclusive than Kingdom can be identified: Domain. The Domains and the organisms they include are listed here.

Unit 2: Taxonomy – Pre-Reading

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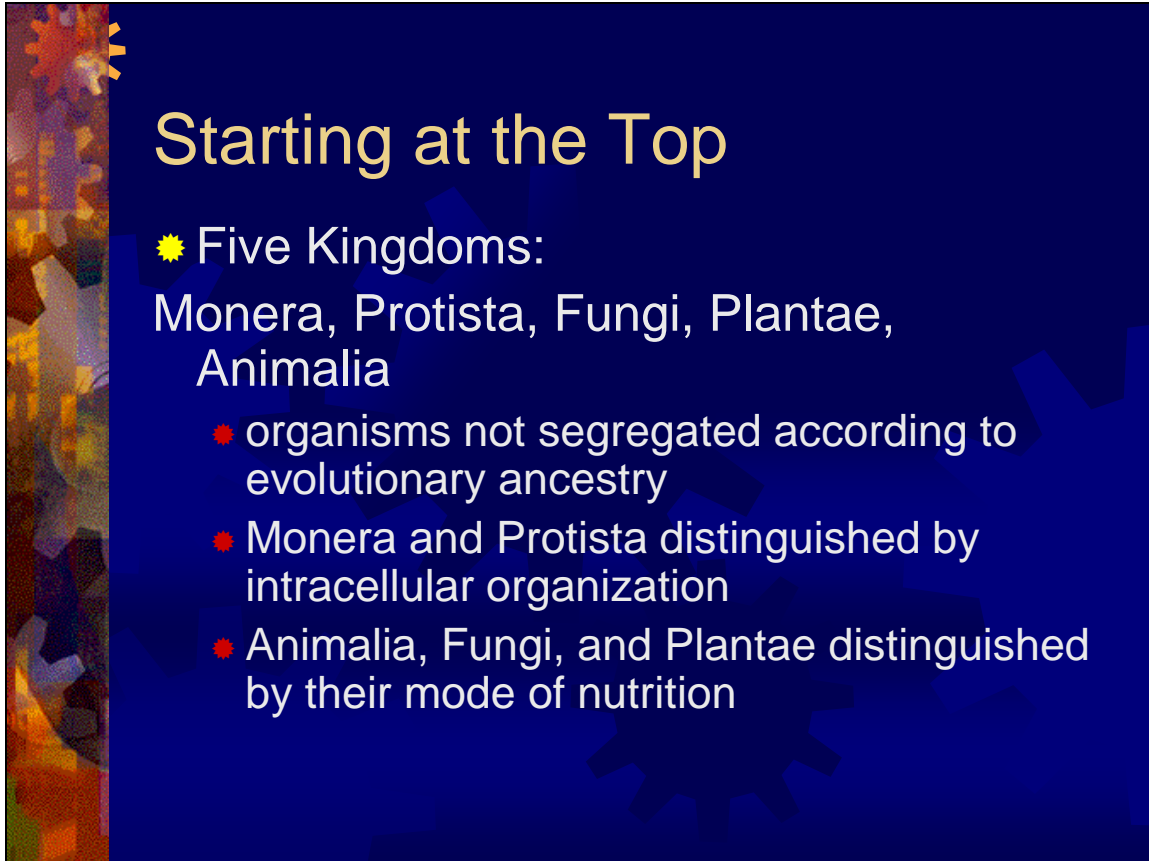
Starting at the Top

- How do the Domains differ?
- Bacteria and Archaea cells are prokaryotic- no well-defined nucleus
- Eucarya- cells have a true nucleus
- Differ in what kinds of lipids make up cell membrane
- Differ in form of ribosomal RNA
 - Protein manufacturing machinery of cell
 - Genes that code for it are least variable- good character to use

Domains are defined by these characteristics.

Unit 2: Taxonomy – Pre-Reading

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Slide 21



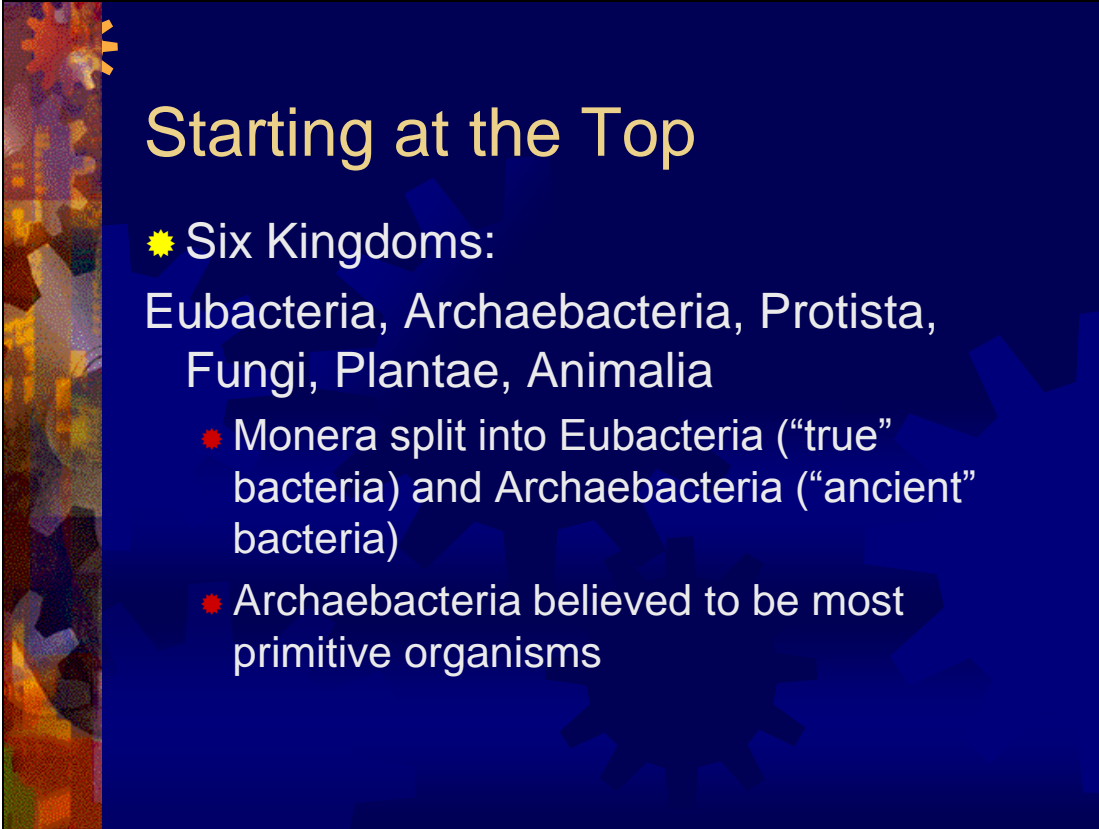
Starting at the Top

- Five Kingdoms:
Monera, Protista, Fungi, Plantae, Animalia
 - organisms not segregated according to evolutionary ancestry
 - Monera and Protista distinguished by intracellular organization
 - Animalia, Fungi, and Plantae distinguished by their mode of nutrition

Let's go back to Kingdoms. The typical arrangement has been to use these 5 Kingdoms, but these concepts were formed without the benefit of information on evolutionary ancestry.

Unit 2: Taxonomy – Pre-Reading

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Starting at the Top

- ★ Six Kingdoms:
Eubacteria, Archaeobacteria, Protista,
Fungi, Plantae, Animalia
 - Monera split into Eubacteria (“true” bacteria) and Archaeobacteria (“ancient” bacteria)
 - Archaeobacteria believed to be most primitive organisms

Taking a look at molecular evidence, six Kingdoms are now proposed for general use. The additional Kingdom comes from splitting the Monera into Eubacteria and Archaeobacteria.

Unit 2: Taxonomy – Pre-Reading

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Characteristics of Kingdoms

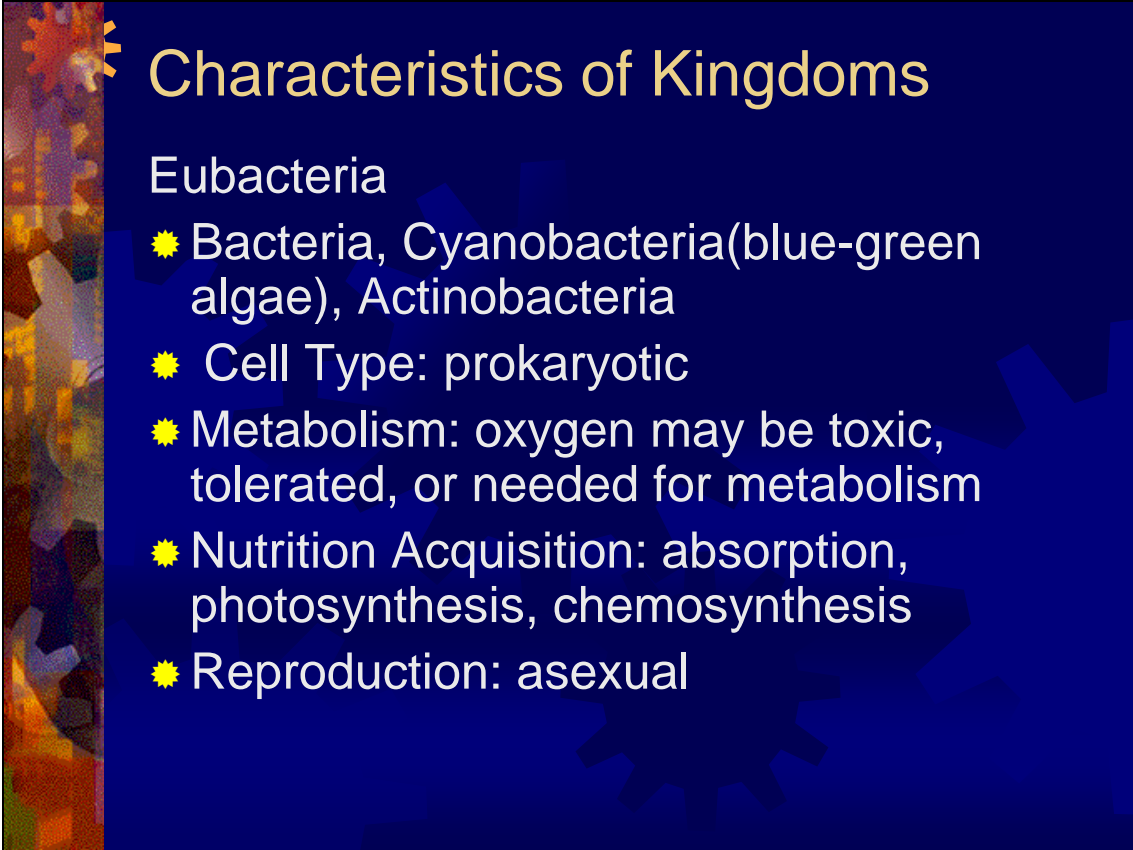
Archaeobacteria

- ☀ Methanogens, Halophiles (salt), Thermophiles (warm), Psychrophiles (cold)
- ☀ Cell Type: prokaryotic
- ☀ Metabolism: oxygen, hydrogen, carbon dioxide, sulfur, sulfide
- ☀ Nutrition Acquisition: absorption, non-photosynthetic photophosphorylation, chemosynthesis
- ☀ Reproduction: asexual- binary fission, budding, or fragmentation

Let's go through the characteristics of these six Kingdoms. Keep these descriptions in mind as you proceed in the course to learn about different groups of organisms. For each Kingdom, I will show examples, cell type, metabolism, how nutrients are acquired, and type of reproduction. Some groups are quite variable in these characteristics while others are not. As you can see, the Archaeobacteria are in the variable category- living in some of the most inhospitable environments on the planet. These organisms have a cell wall made of a different material than Eubacteria (proteins and noncellulosic polysaccharides rather than murein) and ribosomal or messenger RNA more like eukaryotes.

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Characteristics of Kingdoms

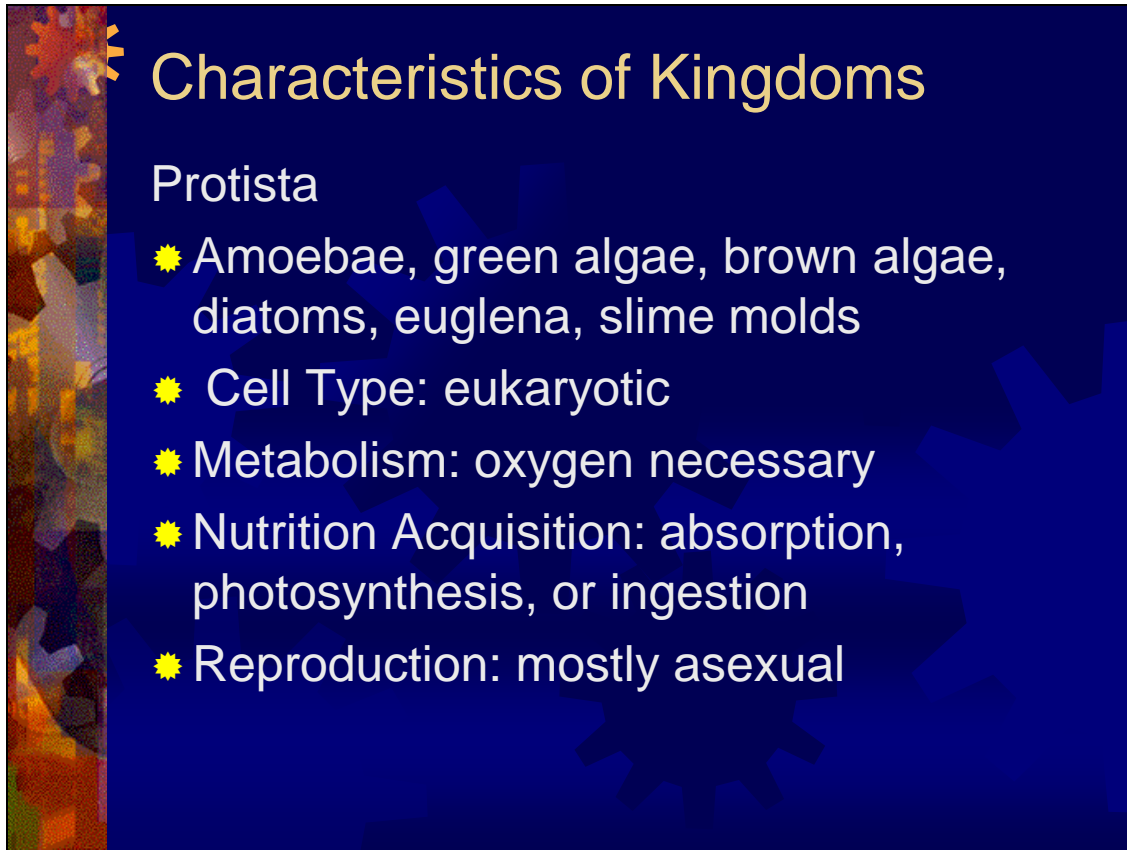
Eubacteria

- ☀ Bacteria, Cyanobacteria (blue-green algae), Actinobacteria
- ☀ Cell Type: prokaryotic
- ☀ Metabolism: oxygen may be toxic, tolerated, or needed for metabolism
- ☀ Nutrition Acquisition: absorption, photosynthesis, chemosynthesis
- ☀ Reproduction: asexual

The Eubacteria are more familiar, but still have a variety of ways to obtain nutrients and variable tolerance/need for oxygen.

Unit 2: Taxonomy – Pre-Reading

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Slide 25



Characteristics of Kingdoms

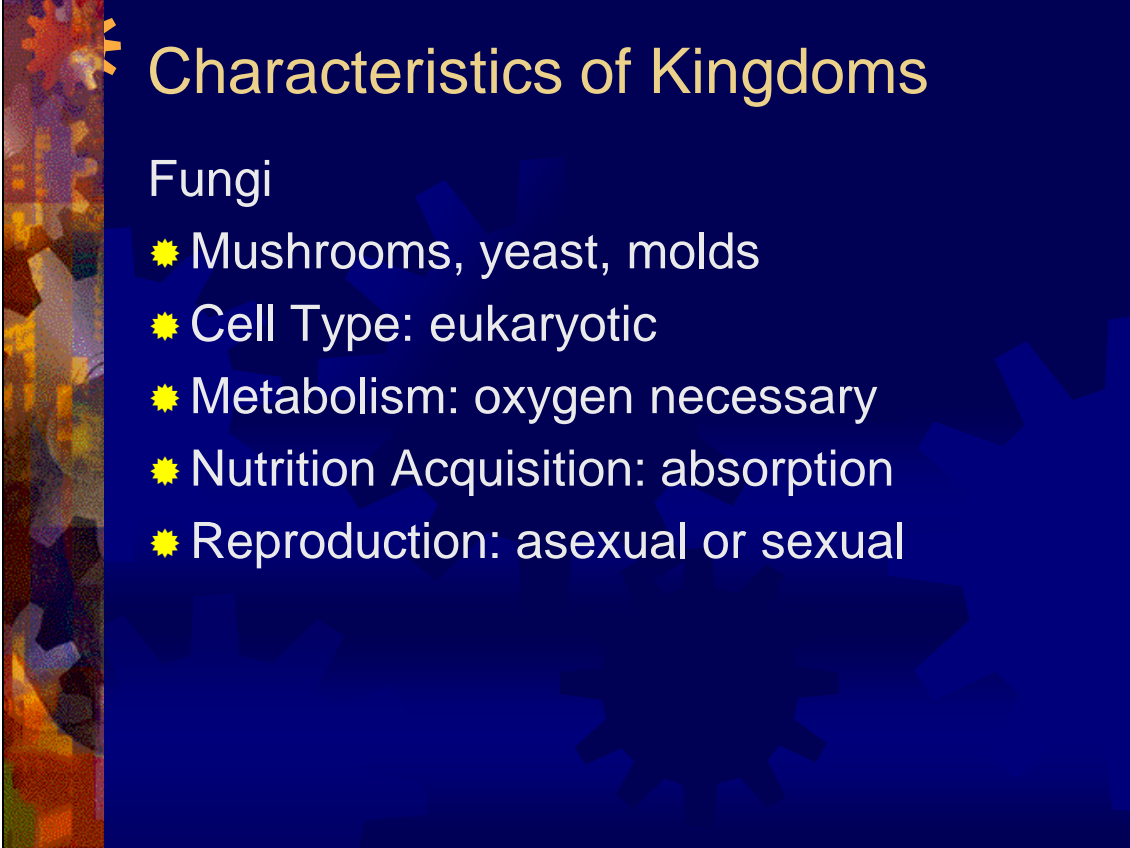
Protista

- ☀ Amoebae, green algae, brown algae, diatoms, euglena, slime molds
- ☀ Cell Type: eukaryotic
- ☀ Metabolism: oxygen necessary
- ☀ Nutrition Acquisition: absorption, photosynthesis, or ingestion
- ☀ Reproduction: mostly asexual

Protista need oxygen but still have an array of ways to get the nutrients they need. They also have eukaryotic cells- those with true nuclei.

Unit 2: Taxonomy – Pre-Reading

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Slide 26



Characteristics of Kingdoms


Fungi

- ☀ Mushrooms, yeast, molds
- ☀ Cell Type: eukaryotic
- ☀ Metabolism: oxygen necessary
- ☀ Nutrition Acquisition: absorption
- ☀ Reproduction: asexual or sexual

Fungi are even less variable for these categories compared to previous groups, although reproduction can vary between sexual and asexual. We are getting into groups that you would at least consider eating now! We will look more in-depth at this Kingdom and the coming two after an overview of the Kingdoms.

Unit 2: Taxonomy – Pre-Reading

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Characteristics of Kingdoms

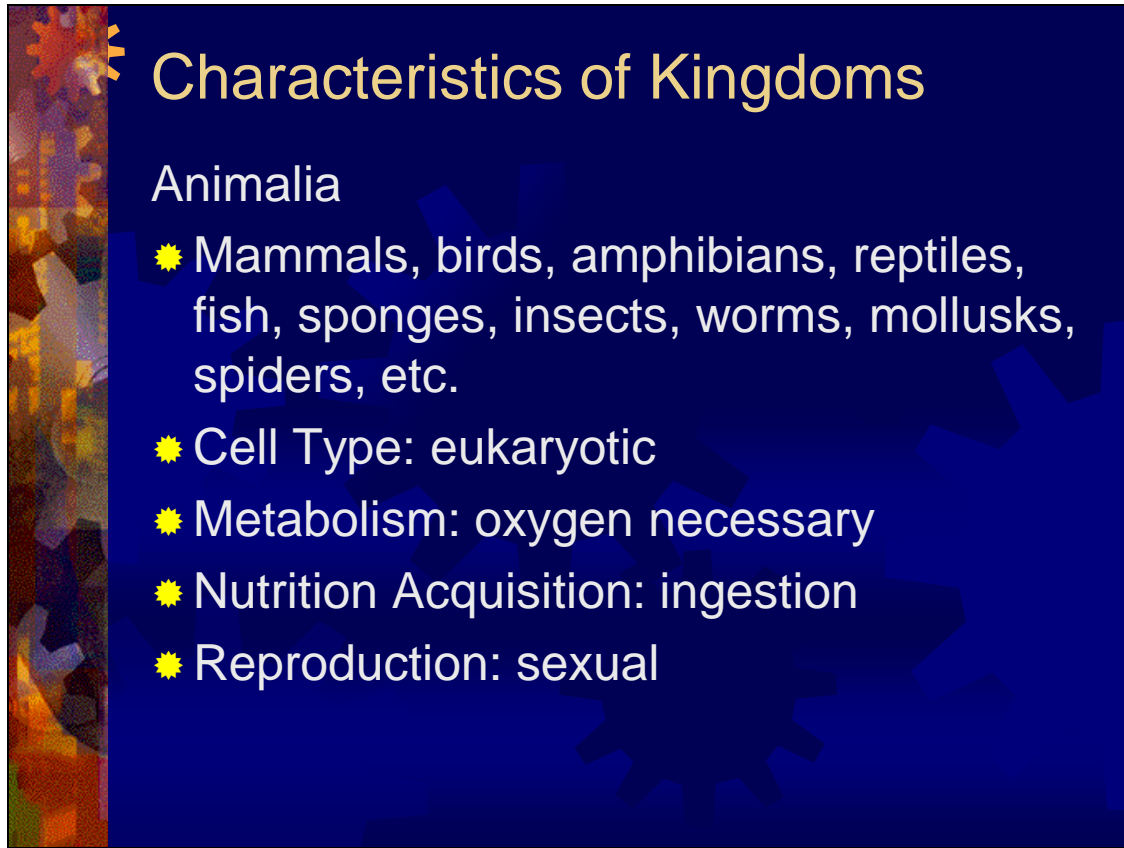
Plantae

- ☀ Mosses, angiosperms (flowering plants), gymnosperms, liverworts, ferns
- ☀ Cell Type: eukaryotic
- ☀ Metabolism: oxygen necessary
- ☀ Nutrition Acquisition: photosynthesis
- ☀ Reproduction: asexual (mitosis) or sexual

Despite the amazing array of plants, many basic characteristics are shared.

Unit 2: Taxonomy - Pre-Reading

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Slide 28



Characteristics of Kingdoms

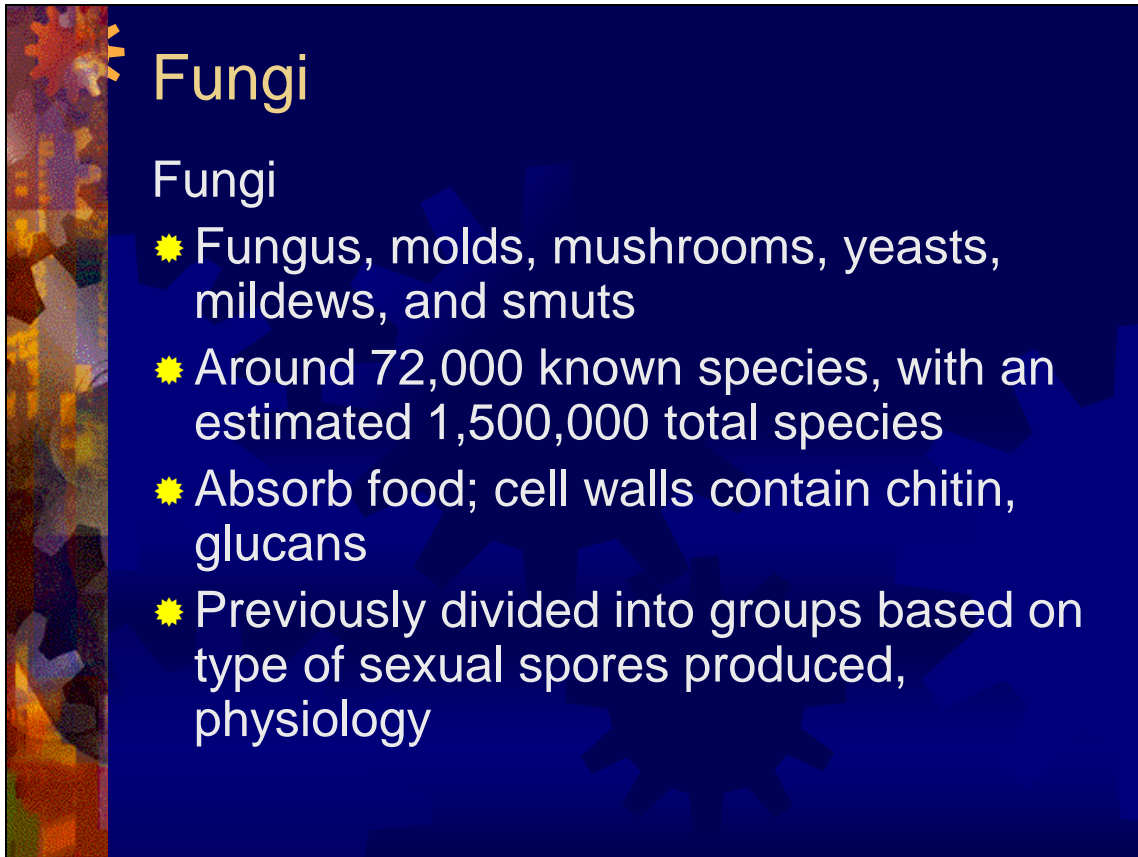
Animalia

- Mammals, birds, amphibians, reptiles, fish, sponges, insects, worms, mollusks, spiders, etc.
- Cell Type: eukaryotic
- Metabolism: oxygen necessary
- Nutrition Acquisition: ingestion
- Reproduction: sexual

The same can be said for animals.

Unit 2: Taxonomy – Pre-Reading

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Slide 29



Fungi

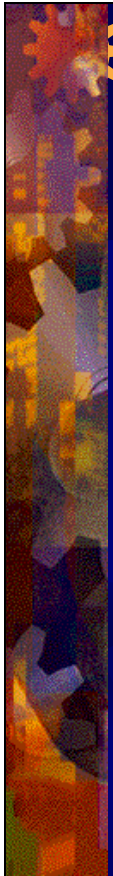
Fungi

- ✦ Fungus, molds, mushrooms, yeasts, mildews, and smuts
- ✦ Around 72,000 known species, with an estimated 1,500,000 total species
- ✦ Absorb food; cell walls contain chitin, glucans
- ✦ Previously divided into groups based on type of sexual spores produced, physiology

Let's take a closer look at three of the Kingdoms, as you will be covering organisms in these during the training. We will go over example organisms, number of species, and some other characteristics of each of these groups. I will present what has been used to group these organisms into less general levels of organization, but this is an active field of study and the addition of molecular data may be changing groupings.

Unit 2: Taxonomy - Pre-Reading

Gwen Brewer
Slide 30



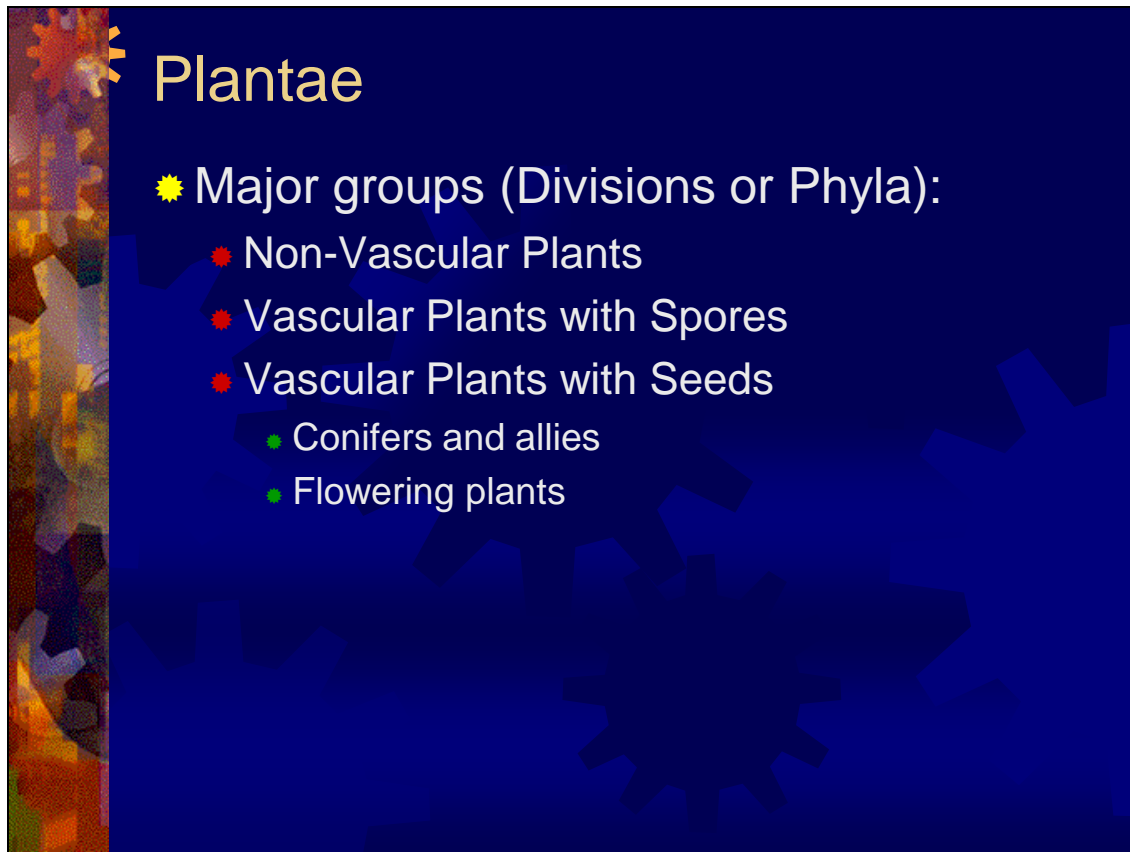
Plantae

- About 270,000 species (likely over 300,000)
- Have chlorophyll (photosynthesis), cellulose in cell walls, don't have own means of locomotion
- Previously divided into groups according to whether they can circulate or need to absorb fluids; form of reproduction; size/stature

You will hear a lot more about plants in a future session.

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 31




Plantae

- Major groups (Divisions or Phyla):
 - Non-Vascular Plants
 - Vascular Plants with Spores
 - Vascular Plants with Seeds
 - Conifers and allies
 - Flowering plants

Plants are divided into non-vascular and vascular, and vascular plants according to whether they produce spores or seeds. Vascular plants have specialized tissues that circulate resources throughout the plant. Non-vascular plants may only have specialized tissues that transport water and have no true roots, stems, or leaves.

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 32



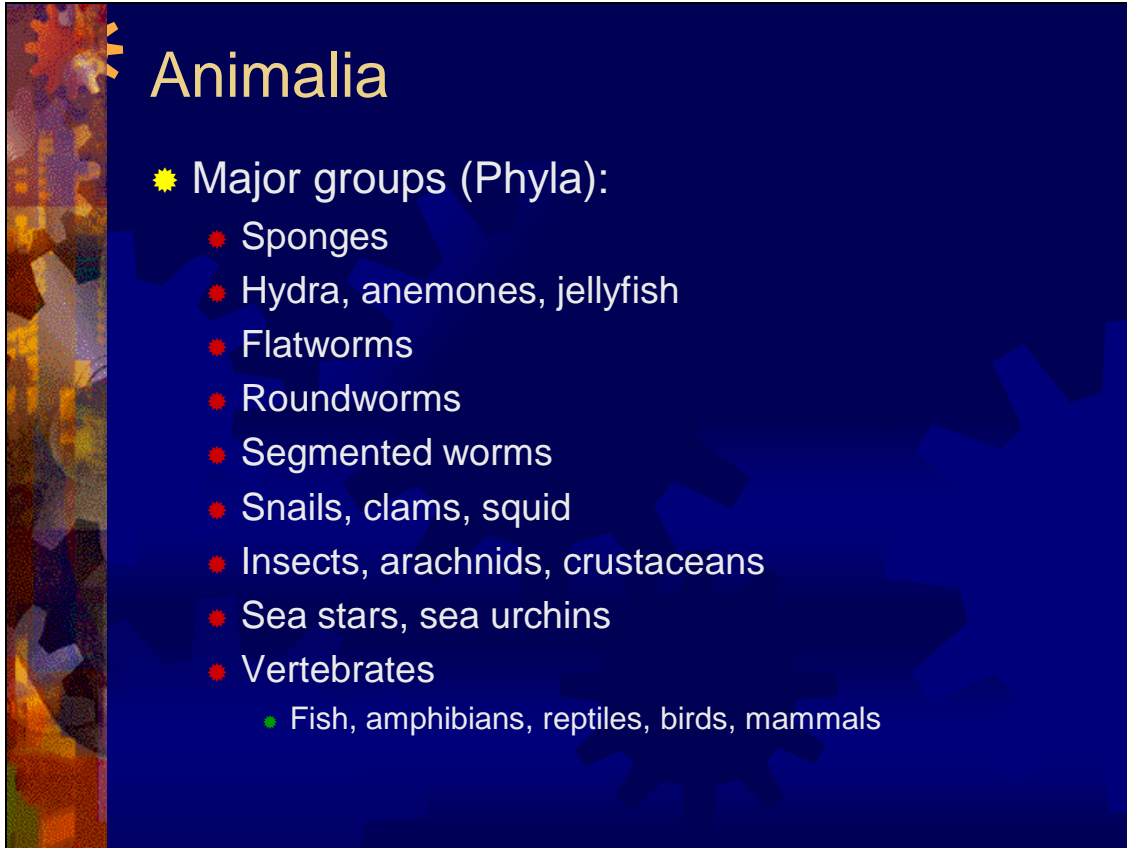
Animalia

- ☀ Over 1,300,000 named species
- ☀ Almost 10 million species estimated to exist
- ☀ Ingest food and have own means of locomotion; cell walls not rigid
- ☀ Previously divided into groups according to body plan, developmental, anatomical, physiological characteristics

There are an amazing number of animal species that have not yet been named. Can you guess which group of animals is thought to have the most unnamed species? (Insects)

Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 33



Animalia

- Major groups (Phyla):
 - Sponges
 - Hydra, anemones, jellyfish
 - Flatworms
 - Roundworms
 - Segmented worms
 - Snails, clams, squid
 - Insects, arachnids, crustaceans
 - Sea stars, sea urchins
 - Vertebrates
 - Fish, amphibians, reptiles, birds, mammals

You are likely familiar with the various groups of animals. Future lectures in this training will focus more on the vertebrates than on the invertebrates.

Unit 2: Taxonomy – Pre-Reading

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What is the connection between Taxonomy and Conservation?

"Only by understanding the environment and how it works can we make the necessary decisions to protect it.


Only by evaluating all our precious natural and human resources can we hope to build a sustainable future."

(UN Secretary-General Kofi Annan, 30 Mar 2005)

By now, you may be wondering if this taxonomy stuff has an application to conservation. What does all of that naming and classifying do to help the organisms? Kofi Annan would argue that understanding what is there is an integral part of being able to protect and sustain it. I hope you agree!

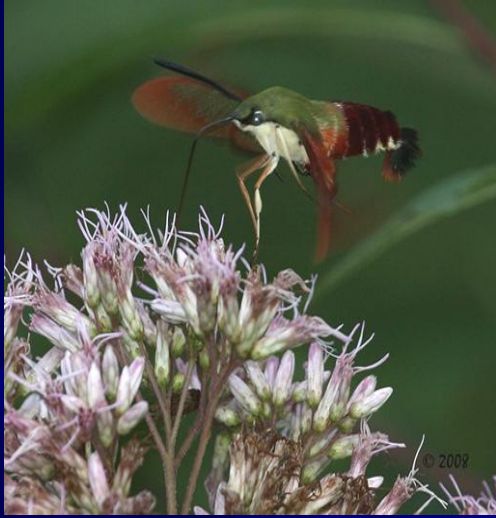
Unit 2: Taxonomy – Pre-Reading

Gwen Brewer
Slide 35



What's next?

- Think about how evolutionary processes have shaped the structure, life history, and behavior of organisms
- Use your powers of observation to look for patterns, similarities, and differences in the natural world



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Now that you have some background in taxonomy, take this understanding into future training sessions and especially outdoors to enrich your appreciation and ability to protect our unique natural resources!

(Image not for use outside of presentation- credit George Jett)