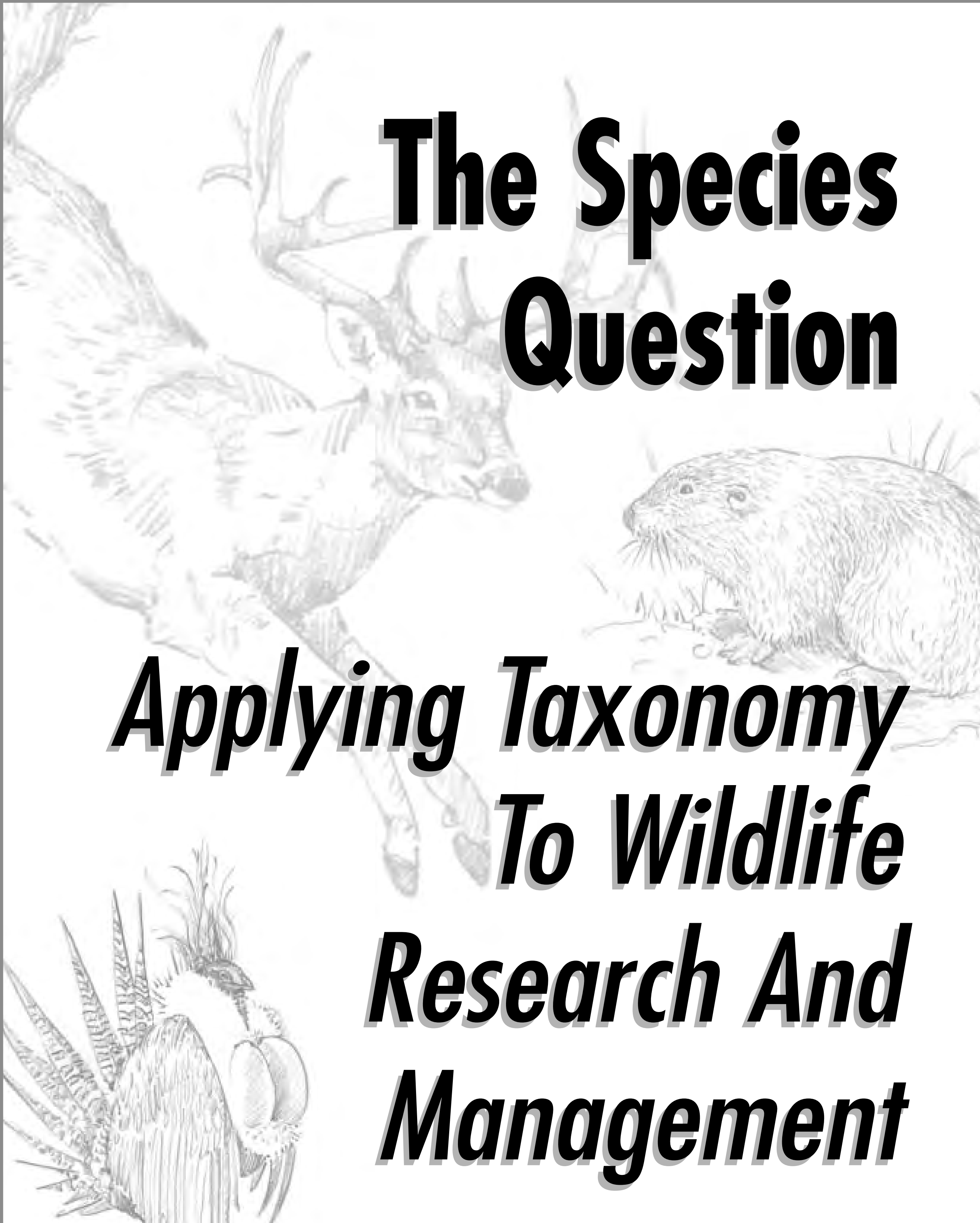
The Species Question

Applying Taxonomy To Wildlife Research And Management



STATE OF COLORADO

Bill Owens, Governor
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WILDLIFE
AN EQUAL OPPORTUNITY EMPLOYER

Bruce McCloskey, Director
6060 Broadway
Denver, Colorado 80216
Telephone: (303) 297-1192

*For Wildlife-
For People*

September 1, 2006

Dear Educator,

Colorado has long been committed to the conservation of all wildlife species, whether hunted, or fished, or viewed. One of the nation's great wildlife restoration success stories—the American Peregrine Falcon—had its beginnings here in the early 1970's. A Colorado biologist rappelled over cliffs more than 500 feet high, dangled from a thin rope and dodged swooping Peregrines to retrieve their DDT-thinned eggs. He tucked them into his vest and made all-night drives across the state for artificial incubation and hatching. Other successes, such as the restoration and recovery of prairie grouse, lynx, river otter and a number of native fishes, also have their roots in the efforts of Colorado Division of Wildlife professionals.

Science-based management decisions are essential to securing species at risk, as well as conserving all the state's wildlife species. The numbers of scientific disciplines that influence and inform wildlife management are staggering. Advances in taxonomy and molecular biology, in particular, have affected how biologists think about and identify species and subspecies. We invite you and your students to explore new developments in the frontiers of science with us as we harness innovative technologies and ideas and use them to maintain healthy, diverse and abundant wildlife.

Sincerely,

Bruce L. McCloskey
Director

Acknowledgments

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Applying Taxonomy To Wildlife Research And Management

Taxonomy—
It's Not Just for Geeks Anymore!

Taxonomy is the science-based hierarchical classification of the world's species. Over the centuries, taxonomy has been used to organize, interpret, and understand the diversity of life on Earth.

As a science, taxonomy had traditionally been viewed as an obscure discipline involving brainy professors and highbrow science know-it-alls who would memorize and interpret thousands of Latin species names. Few paid attention to advances in the field or to the many scathing disputes between taxonomists. A decision to place an organism in the genus *Spea* rather than *Scaphiopus* would not make the front page of the newspaper, or even the back page for that matter. Educators such as yourself would cruise through the taxonomy section of the textbook as quickly as possible, and move on to more vital topics. In a word, taxonomy was BORING.

Public and academic indifference to taxonomy was lost forever when precise taxonomic recognition of species and subspecies came to be the basis for protection under the Endangered Species Act (ESA). Signed into law by President Richard Nixon in 1973, the law is considered one of the most stringent environmental protection documents ever enacted. The penalties are stiff. Anyone found to take, harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect a listed species could receive jail terms and large fines. The ESA also impacts land use decisions, which can in turn impact individuals, families, communities and economies in unforeseen ways. In addition, each state's wildlife management options are restricted by a species status. Some species management falls under the purview of the Federal government.

Now that taxonomy can literally hit somebody "where they live," the ideas and methods of delineating species have become everyone's business. While no conscientious person would seek to propel a fellow creature into the long night of extinction, few would want to limit what they could do with their property or their life without good evidence that it really mattered to a species' survival.

It turns out that sometimes hard evidence is slow in coming. Many of the ideas scientists hold about species, including the concept of species itself, are undergoing revision. With advances in molecular biology, we find that some animals that look alike are in no way related. Contrarily, some that look different have nearly identical genetics! For students (or anyone, for that matter) used to clean, clear-cut answers, this module on taxonomy and systematics might be "annoying." Each concept of species has its deficiencies, so modern-day biologists rely on legal definitions and agreed upon conventions. They employ techniques of cladistics and evolutionary systematics to determine both the relatedness of organisms and their potential for a unique evolutionary future. Once viewed as a "stagnant" science—taxonomy is exciting and challenging. As you and your students join us in our discoveries, our questions, and our arguments, you will develop a clearer understanding of the nature of scientific knowledge and the scientific process, the human dimension of science, and the value of peer review.

What is This?

This six-lesson module, designed for almost two weeks of classroom instruction, begins with basic high school level taxonomy and classification, and then introduces the larger field of systematics. The module is designed to supplement or replace the activities found in most high school biology textbooks that address these topics. It is the second module developed by the DOW to address the specific learning objectives of high school students. Materials are inquiry based, develop critical thinking skills, supply evidence to support each concept, and include real data from recent research projects. The last two lessons also emphasize the ethical tradition of scientists; the value of peer review, truthful reporting about methods and outcomes of investigations, and making public the results of scientific work.

Using *The Species Question: Applying Taxonomy To Wildlife Research And Management* in Your Classroom

The lessons in this module are designed to be taught in sequence. For each activity, the students take on the role of a wildlife biologist, receive an introduction to the problem and to their task, and choose and analyze relevant information.

There are DOW Education Coordinators throughout the state that may be able to provide additional materials, such as sage grouse wings, to supplement these lessons or to provide resources on other biology topics. Feel free to contact your Education Coordinator at any time—they would love to hear from you:

Leigh Gillette, Education Coordinator,
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Correlation to the Colorado Model Content Standards

The Species Question: Applying Taxonomy To Wildlife Research And Management supports teachers in their efforts to provide the knowledge and skills specified in the Colorado Model Content Standards and the corresponding grade level assessment frameworks.

COLORADO MODEL CONTENT STANDARDS

Science	Lesson 1: The Species Question	Lesson 2: Birds Of A Feather	Lesson 3: Taxonomy Through The Ages	Lesson 4: Understanding Ungulate Phylogeny	Lesson 5: The Pocket Gopher Cladogram Conundrum	Lesson 6: Déjà Vu
1: Students understand the processes of scientific investigation and design. They conduct, communicate about and evaluate such investigations.		X		X	X	X
3.1: Students know and understand the characteristics of living things, the diversity of life, and how living things interact with each other and with their environment.	X	X	X	X	X	X
3.3: Students know and understand how the human body functions, factors that influence its structures and functions, and how these structures and functions compare with those of other organisms.		X		X	X	X
5: Students know and understand interrelations among science, technology, and human activity and how they can affect the world.			X	X	X	X
6: Students understand that science involves a particular way of knowing and understand common connections among scientific disciplines.	X	X	X	X	X	X

COLORADO MODEL CONTENT STANDARDS

Reading and Writing	Lesson 1: The Species Question	Lesson 2: Birds Of A Feather	Lesson 3: Taxonomy Through The Ages	Lesson 4: Understanding Ungulate Phylogeny	Lesson 5: The Pocket Gopher Cladogram Conundrum	Lesson 6: Déjà Vu
1: Students read and understand a variety of materials.	X	X	X	X	X	X
2: Students write and speak for a variety of purposes and audiences.		X	X			X
3: Students write and speak using conventional grammar, usage, sentence structure, punctuation, capitalization, and spelling.	X	X	X	X	X	X
4: Students apply thinking skills to their reading, writing, speaking, listening, and viewing.	X	X	X	X	X	X
5: Students read to locate, select, and make use of relevant information from a variety of media, reference, and technological sources.	X		X			X

COLORADO MODEL CONTENT STANDARDS

Mathematics	Lesson 1: The Species Question	Lesson 2: Birds Of A Feather	Lesson 3: Taxonomy Through The Ages	Lesson 4: Understanding Ungulate Phylogeny	Lesson 5: The Pocket Gopher Cladogram Conundrum	Lesson 6: Déjà Vu
1: Students develop number sense and use numbers and number relationships in problem-solving situations and communicate the reasoning used in solving these problems.		X				
3: Students use data collections and analysis, statistics, and probability in problem-solving situations and communicate the reasoning used in solving these problems.		X				

COLORADO MODEL CONTENT STANDARDS

Geography	Lesson 1: The Species Question	Lesson 2: Birds Of A Feather	Lesson 3: Taxonomy Through The Ages	Lesson 4: Understanding Ungulate Phylogeny	Lesson 5: The Pocket Gopher Cladogram Conundrum	Lesson 6: Déjà Vu
2: Students know the physical and human characteristics of places, and use this knowledge to define and study regions and their patterns of change.						X
3: Students understand how physical processes shape Earth's surface patterns and systems.	X	X	X			
5: Students understand the effects of interactions between human and physical systems and the changes in meaning, use and importance of resources.	X		X			X
6: Students apply knowledge of people, places, and environments to understand the past and present and to plan for the future.	X	X	X			X

Notes

Lesson 1

Educator's Overview

The Species Question

Summary

Students read an article, then discuss and evaluate the strengths and weaknesses of several species concepts. They then discuss the consequences of conflicting definitions on a state wildlife agency's ability to conserve species and the ecosystems upon which they depend.

Duration

One 45-minute class period

Vocabulary

Biodiversity

Clones

Distinct Population Segment (DPS)

Endangered

Hybrid

Morphological

Niche

Reproductive isolation

Species Concepts
- *Biological species concept*
- *Ecological species concept*
- *Isolation species concept*
- *Morphological species concept*

Subspecies

Threatened

Wildlife

Wildlife management

Learning Objectives

After completing this activity, students will be able to:

- Identify the strengths and weaknesses of the species definition used in their textbook.
- Compare various species concepts and make a note of the variety of characteristics (physical, molecular, geographical, ecological, and so on) that biologists use to identify organisms.
- Make a case for the necessity of a legal definition of species for wildlife managers.

Background

In biology, a species is the basic unit of biodiversity. It often corresponds to the way people identify different kinds of organisms. We "name" living things using this concept, either with standard scientific binomial (or trinomial) nomenclature or in everyday vernacular. Something is a dog, a cat, or a turtle.

Traditionally, people relied on observations of anatomical differences and breeding behavior to distinguish species. Before Darwin, species were thought to represent independent acts of creation, and were considered immutable. A century and a half later, with the arrival of evolution theory, the discovery of genes and the advances in microbiological research—including DNA analysis—a great deal of knowledge about the differences and similarities between organisms has become available. Species evolve—they change over time. Species concepts also evolve; and the scientific community seems to have more disagreement about what constitutes a species now than ever before.

It may come as a shock to your students to discover that there is no commonly accepted definition of what a species is. While the class textbook probably contains some version of the biological species concept that has predominated secondary texts over the past 60 years, that definition has some serious drawbacks. The textbook definition provides a starting place for students to study the variety of life, but it is important for educators to emphasize that it is simply one of many species concepts. Definitions are a lot like hypotheses—scientists must continually test their usefulness in the light of new information.

For wildlife professionals and other scientists tasked with preserving the variety of life on earth, the species question is important. Some working definition of species is needed to frame and implement biological laws—such as the Endangered Species Act.

Teaching Strategies

1. Thoroughly read the student materials for *The Species Question*.

2. Give each student the first reading packet, *The Species Question*.

3. After giving students sufficient time to read the packet, discuss the many species concepts as a class. What are some of the reasons that there is little agreement on species concepts? *There are huge differences among the kinds of organisms; organisms have different kinds of reproduction (sexual or asexual), some organisms look similar and live in the same environment but do not interbreed, while others look very different and live in radically different environments yet can interbreed and produce fertile offspring, and so on.*

4. Discuss the various species concepts in terms of the scientific process. Why is the definition of species being disputed? *New information about genetics and evolution has caused scientists to reevaluate their ideas about living organisms.*

5. Why is a legal definition of species needed? *Wildlife managers and others must make decisions and take actions to maintain healthy populations of organisms and their habitats. In order to avoid confusion and possibly court battles, they need to agree on what populations need protection.*

Assessment

Students' comparison of their textbooks' species definition with the characteristics used by wildlife biologists to determine species serves as an assessment for this activity.

Materials and Preparation

- *Student Reading Pages for* The Species Question—*one photocopy per student*
- *Access to biology textbook and internet*

Extensions

- Students could read and evaluate the *Policy Regarding the Recognition of Distinct Vertebrate Population under the Endangered Species Act*. The document can be found at:

  http://www.fws.gov/endangered/federalregister/1996/p960207c.pdf.

  There was considerable national debate during the drafting and public comment period of this document. The recommendations and criticisms are summarized and addressed by the Department of the Interior. After students read these arguments, do they agree or disagree with the responses?

Key

1. How many different definitions of species did you find? ***Answer varies***

2. List at least three other species concepts that you found: ***Answers will vary, but some of the other species concepts are Recognition, Evolutionary, Phylogenetic, Diagnosability, Cohesion, Genealogical, Cladistic, and Pluralistic.***

3. What is your biology textbook's definition of species? ***Answer varies***

4. Does the textbook definition share any of the characteristics used to determine a distinct population segment? If so, which ones? ***Answer varies***

5. Why is a legal definition of species necessary? ***State and federal laws require that wildlife agencies protect wildlife species and biodiversity. There needs to be a clear and consistent way to determine whether an organism is a species so that the organism can be managed appropriately.***

Notes

Lesson 1

Student Pages

The Species Question

"It is the policy of the state of Colorado that the wildlife and their environment are to be protected, preserved, enhanced and managed for the use, benefit, and enjoyment of the people of this state and its visitors."

—Colorado Revised Statutes 33-1-101 (1)

The Colorado Division of Wildlife (DOW) is the state agency responsible for protecting and managing wildlife and habitat, and providing wildlife related recreation. The DOW employs trained biologists and other specialists to "manage" wildlife—to use scientific knowledge to maintain healthy populations of wildlife and its habitat and preserve biodiversity. ***Wildlife*** includes all non-domestic mammals, birds, fish, amphibians, reptiles, mollusks, and crustaceans that occur within the boundaries of the state. ***Biodiversity*** is short for biological diversity. It includes the variety of species, the genetic differences within species, and the variety of ecosystems in the state.

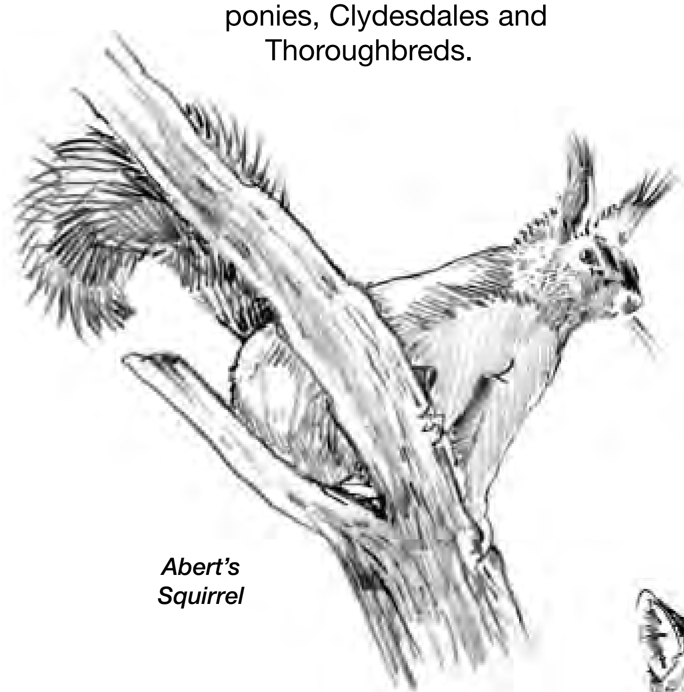
Kingfisher

Biologists at the DOW also abide by federal wildlife laws. One of the most important of these laws is the ***Endangered Species Act (ESA)*** of 1973 that protects plants and animals from becoming extinct in this country. Under the ESA, species may be listed as either "endangered" or "threatened." ***Endangered*** means a species is in danger of extinction throughout all or a significant portion of its range. ***Threatened*** means a species is likely to become endangered within the near future throughout all or a significant portion of its range.

What is a Species?

Before a species can be managed and protected, it must be identified. Unfortunately, what might seem to be the simplest task in biology can be one of the most baffling. What is a species? You would think that the question would have been answered ages ago, but it crops up repeatedly in many different circumstances. As experts try to create definitions of species to apply to the various types organisms that they are studying, each seems to have its shortcomings.

One of the oldest methods for identifying species is to group organisms that are similar to each other in appearance and behavior. This is the ***morphological*** *or* ***phenetic species concept***, where organisms with similar physical traits are lumped together as species. Using this definition, Chihuahuas, Saint Bernards, Pugs, and German Shepherds could all be different species. So could Shetland ponies, Clydesdales and Thoroughbreds.



Abert's Squirrel

Then there is the ***ecological species concept***, which defines a species by its ***niche*** or ecological role—the set of resources it consumes and habitats it occupies. This definition might work well for an organism such as an Abert's squirrel, which only lives in ponderosa pine forests and only eats ponderosa pine nuts. It is a bit more challenging to apply to a coyote, which lives in nearly every part of the state and eats virtually anything. Would a coyote living in a spruce/fir forest eating red squirrels be a different species than a coyote living in the grasslands eating rabbits?

Dog Gone It!

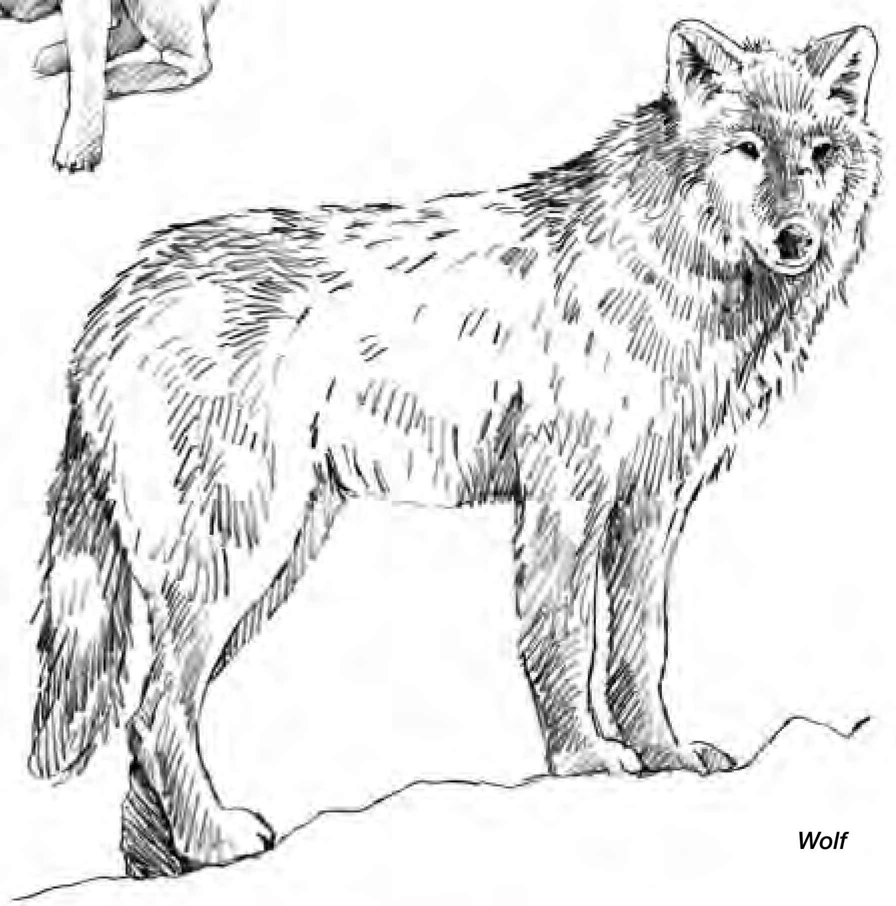
One of the more widely accepted definitions—and possibly the one found in your biology textbook—says a species is a group of organisms that are genetically similar enough to breed and produce viable and fertile offspring. This ***biological species concept*** seems simple enough, and seems to incorporate both the morphological and ecological species concepts. After all, if organisms are able to breed, they must have similar characteristics, behavior and ecology.

Coyote

Looking at different canines, we find that even this definition has its problems. For example, pugs do not look like wolves, coyotes, jackals, or dingos. Pugs often occupy the plush chair in the living room, while wolves are adapted to forests, jackals to dry grasslands in Africa and so on. Nevertheless, given the opportunity, pugs can interbreed with all these species and produce fertile offspring. Given that all the wild canines mentioned can potentially interbreed with domestic dogs like the pug, are they all one species?

It gets even more complicated. Coyotes and wolves can and do interbreed in areas where their ranges overlap, but only female coyotes mate with male wolves and their offspring only breed with wolves. What prevents male coyotes from mating with female wolves? Moreover, in Africa, where there are several different types of jackal sharing the same habitat, they completely ignore each other. If mated under artificial conditions, these jackals can produce fertile offspring.

Pug



Wolf

Cats Too!

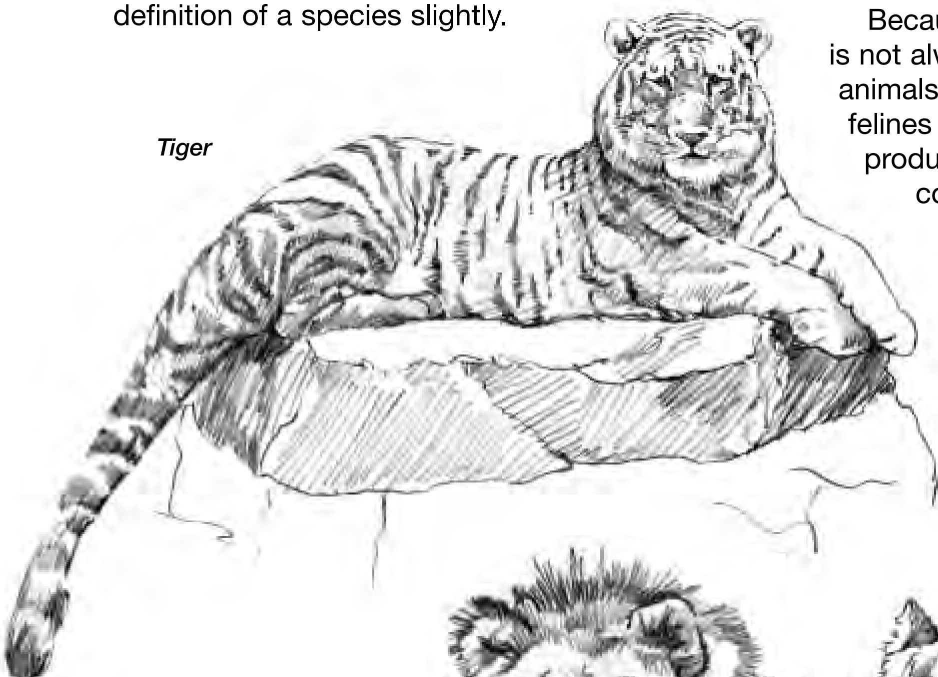
This problem is not just limited to canines. Lions and tigers normally do not share the same habitat. Lions live on the African savannah (grasslands) and tigers inhabit the jungles of Asia. However, when they are placed together in zoos, they court, mate, and produce fertile tigons and ligers.

One noted zoologist attempted to address this issue by changing the definition of a species slightly. His ***isolation species concept*** defined a species as groups of interbreeding natural populations that are reproductively isolated from other such groups. ***Reproductive isolation*** means that a population of animals cannot mate with another population of animals due to some barrier or factor such as:

- Differences in behavior
- Physical or geographical barriers
- Incompatible mating structures

Because reproductive isolation is not always complete, some animals—such as the canines and felines already mentioned—can produce fertile offspring when in contact with one another. Others, such as the horse and the donkey, can produce a healthy offspring—a mule—that is infertile. As another working definition, the fertile or infertile offspring of normally isolated populations are called ***hybrids***.

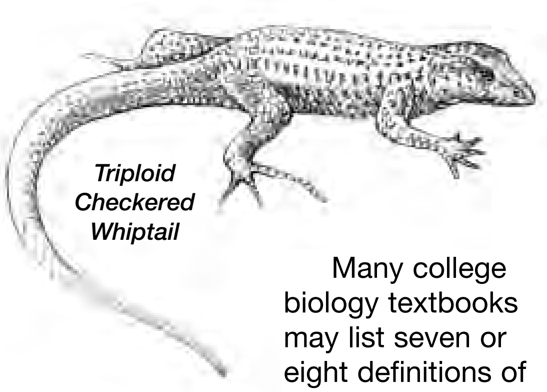
Tiger



Lion

Just for Laughs

So far, all of these definitions of species have been for organisms that reproduce sexually—where there are two parents, male and female. What definition could be used for organisms that do not need mates to reproduce? Most of these species' offspring are exact copies of themselves—***clones***. For the most part, wildlife biologists do not need to worry so much about these types of organisms, since most are bacteria, fungi, plants or some other living thing that does not count as "wildlife" under the law. However, some "female" reptiles, amphibians, and fish can reproduce without a mate, or become "male" when need be.



Triploid Checkered Whiptail

Many college biology textbooks may list seven or eight definitions of "species!" Just for laughs, type "define species" or "species concepts" into an internet search engine such as Google, MSN Search, Yahoo, or whichever search service you have available. How many different definitions of species did you find? ______________
List at least three other species concepts that you found:

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Let's Get Practical!

It is really a challenge to come up with a definition for a species that works in every case. Because laws to protect wildlife and biodiversity depend on defining which organisms are species, all the conflicting definitions posed a problem for state and federal wildlife agencies. A legal definition of species was needed.

The Endangered Species Act was revised in 1978 to define the term "species" to include "any subspecies of fish or wildlife or plants, and any distinct population segment of any species or vertebrate fish or wildlife which interbreeds when mature." A ***subspecies*** is a population of a species whose members have certain physical and hereditary characteristics distinct from other populations of that species. What is a "distinct population segment (DPS)?"

For several years after this, there was confusion. Since the scientific meanings of species and subspecies can vary, the meaning of "distinct population segment" was critically important. Congress was besieged with requests to clarify the term's meaning. Congress instructed the Secretaries of the Department of the Interior and the Department of Commerce—the federal agencies charged with implementing the ESA—with providing a clear and consistent definition. In February of 1996, the Departments adopted a policy to clarify their interpretation of DPS for the purpose of listing, delisting, and reclassifying species under the ESA.

The policy used three “tests” to determine whether the population of animals was a ***distinct population segment***:

1. Discreteness (distinct physical, physiological, ecological, or behavioral characteristics) of the population segment in relation to the remainder of the species to which it belongs;

2. The significance of the population segment (genetic differences, unique lineage and area of occurrence) to the species to which it belongs; and

3. The population segment’s conservation status (threatened or endangered) in relation to the ESA’s standards for listing.

The characteristics that wildlife biologists needed to use to determine whether a certain population was a distinct population segment has since been used as a *de facto* (legal) definition of species. These characteristics are:

1. Usually *do not interbreed* with other populations;

2. Have *different appearance, behavior, or ecological niche* than other populations;

3. Have notably *different DNA (genetic material that determines inherited characteristics)*; and

4. Represent a *unique evolutionary lineage and contain the potential for a unique evolutionary future*.

Pika

What is your biology textbooks’ definition of species?

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Does the textbook definition share any of the characteristics used to determine a distinct population segment? If so, which ones?

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Why is a legal definition of species necessary?

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Lesson 2

Educator's Overview

Birds Of A Feather

Summary

Students carefully observe videos of sage grouse filmed at two separate locations in Colorado. They observe photos of the birds and examine data. Based on the physical and behavioral characteristics they observe, students hypothesize whether the birds are the same or different species.

Duration

One 45-minute class period

Vocabulary

Avian

Biodiversity

Carpal

Culmen

Game

Lek

Molt

Morphological

Tarsus

Learning Objectives

After completing this activity, students will be able to:

- Describe the morphological and behavioral differences of two populations of sage grouse
- Provide evidence that might support an argument for considering two populations of sage grouse as different species
- Identify evidence that would be needed to prove that two population of sage grouse represent separate species or variations of a single species

Background

In the mid-1990s, for the first time in decades, a wholly new species of bird was "found" in the continental United States. Like invisible ink suddenly materializing on blank paper, a new species of bird emerged in the sagebrush ecosystem of western Colorado and eastern Utah. Like invisible ink, the bird had been there all along, but researchers had not had the formula—the clues—to make them obvious.

The Gunnison sage grouse had long been assumed to be the same species as the greater sage grouse. Evidence collected for over 20 years demonstrated that the two differed starkly in size, appearance, behavior, and it turns out, DNA.

In this activity, students review the data that led to this fascinating discovery. Some students may actually be familiar with this story, possibly because of the location they live in (students in Gunnison perhaps?) or because they have read about this in the newspaper. If this is the case, please insist that students look at the evidence anyway. The story of the grouse presents one of the finest examples of the scientific process and "way of knowing."

Teaching Strategies

1. Thoroughly read the student materials for *Birds Of A Feather*, *A Closer Look*, and *Hidden In Plain View*.

2. Give each student the first reading packet, *Birds Of A Feather*.

3. After giving students sufficient time to read the packet, present the DVD: *Sage Grouse Observation*. Please allow students to view this short video several times.

4. After students have recorded their observations from watching the video, pass the laminated photos of the two sage grouse populations around the class and allow time for students to record further observations.

5. Give each student the second reading packet, *A Closer Look*, and allow the students to read the packet and answer the questions in small groups.

6. After discussing student findings as a class, take a poll to determine how many students think these two populations may be different species. Record the poll results in a visible place.

7. Give each student the last reading packet, *Hidden In Plain View*. After reading the packet, ask if any students are surprised with the results.

Assessment

Ask students to write a grant proposal requesting money to continue research on the two populations of sage grouse. Students must use evidence to persuade a government science organization that the two populations may be separate species, and must specifically state the nature of their new research and how that research would resolve the question.

Extensions

- Students research Gunnison sage grouse and report on any new information about the species.
- Recently, another grouse species was determined to be two different species. Students can research this decision to re-classify different populations of blue grouse. The interior species (found in Colorado) will retain the same scientific name (*Dendragapus obscurus*) but the common name has been changed to Dusky Grouse. The Pacific species has been split to Sooty Grouse (*D. fuliginosus*). The decision by the American Ornithologists Union can be viewed at this web site:

  http://www.aou.org/checklist/Suppl47.pdf

  Also, the scientific paper that confirmed the genetic differences between the grouse—Barrowclough, G.F., J.G. Groth, L.A. Mertz and R.J. Gutierrez. 2004. Phylogeographic structure, gene flow and species status in blue grouse (*Dendragapus obscurus*) Molecular Ecology 13:1911–1922.—can be found at:

  http://www.cnr.umn.edu/fwcb/research/Owls/lit%20folder/barrowclough%20et%20al.%202004.pdf

Materials and Preparation

- *Student Reading and Activity Pages for* Birds Of A Feather—*one photocopy per student*
- *Student Reading and Activity Pages for* A Closer Look—*one photocopy per student*
- *DVD player and monitor*
- *DVD:* Sage Grouse Observation
- *Laminated color photographs of Sage Grouse in Location A (Gunnison County) and Sage Grouse in Location B (Jackson County)*
- *Student Reading Pages*—Hidden in Plain View*, one photocopy per student*
- *Laminated color diagram comparing Gunnison Sage Grouse and Greater Sage Grouse*

A brief article can also be found in the 2006 September/October issue of *Colorado Outdoors*, published by the Colorado Division of Wildlife.

Key to *Birds Of A Feather*

1. Observations of Sage Grouse in Location A—Gunnison County
Answers may vary—these are possibilities: The male sage grouse in Gunnison County have thick feathers on the back and sides of their necks—it looks almost like a ponytail. These sage grouse seem to display at slower rates and they pop their air sacs nine times during each display. The males throw their neck feathers over their heads and wag their tails at the end of each display. They have distinct white markings on their tails.

2. Observation of Sage Grouse in Location B—Jackson County
Answers may vary—these are possibilities: The male sage grouse in Jackson County have thin feathers on the back and sides of their necks. They pop their air sacs twice during each display.

Key to *A Closer Look*

1. What general statement can you make about sage grouse wings when you compare males and females? ***Female sage grouse wings are smaller than male sage grouse wings.***

2. What general statement can you make when you compare sage grouse wings collected in Gunnison County with wings in Jackson County? ***Sage grouse wings collected in Gunnison County are smaller than sage grouse wings collected in Jackson County.***

3. Based on this additional data, what general statement can you make about sage grouse when you compare males and females? ***Female sage grouse are smaller than male sage grouse.***

4. What general statement can you make when you compare sage grouse in Gunnison County with sage grouse in Jackson County? ***The sage grouse in Gunnison County are smaller than the sage grouse in Jackson County.***

5. What are the legal criteria for defining a species?

- Usually ***do not interbreed*** with other populations;
- Have ***different appearance, behavior, or ecological niche*** than other populations;
- Have notably ***different DNA (genetic material that determines inherited characteristics)***; and
- Represent a ***unique evolutionary lineage and contain the potential for a unique evolutionary future***.

6. Based on your observations, do these populations of sage grouse meet any of the criteria to be considered different species? ***Yes, they are different in appearance and behavior. Since they are different sized, it would be logical that they would have different DNA.***

7. What other information would you need before you could determine whether these two populations of sage grouse belonged to different species? ***I would need to know if these birds would interbreed with each other if given the chance and I would have to analyze the DNA of both populations to determine if it was different.***

Notes

Lesson 2

Student Page

Birds Of A Feather

That Seventies Show!

It is the 1970's and biologists are studying sage grouse in Colorado. Since the 1950's, sage grouse have historically been grouped into two subspecies based on plumage and coloration. The western subspecies is limited to west-central Oregon and Washington, while the eastern subspecies occupies sagebrush habitat to the east of those states, including Colorado.

The sage grouse is one of North America's most spectacular birds. As its name suggests, sage grouse live only in sagebrush habitat, which provides the birds with food and shelter, and space for their traditional courting ritual. Each spring, males begin the mating ritual by competing for the best position in the center of grouse strutting grounds, called ***leks***.

Mates of all species of sage grouse are equipped with air sacs on their breasts, which they use to attract females. The mating call that male sage grouse make with their air sacs is audible a mile or more away, and has been compared to the sound of bubbles, or gulps, underwater. The superiority (as determined by other grouse) of the male's call, and the vigor and quality of the rapid head-shaking, strutting dance that accompanies it, determine its position in the lek. Dominant males occupy the center of the lek and win the opportunity to breed with the majority of females.

You are about to view a video of strutting male sage grouse filmed in two different locations in Colorado. Watch and listen carefully, then record your observations of the birds in both locations.

1. Observations of Sage Grouse in Location A—Gunnison County

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2. Observation of Sage Grouse in Location B—Jackson County

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Student Pages

A Closer Look

Photographers travel to Colorado from all parts of the world to capture the stunning sage grouse courtship on film. One well-known wildlife photographer has traveled to the leks in both Gunnison and Jackson Counties and has taken spectacular pictures. As you view his photos, add any observations you might have to your list.

Winging It

In Colorado, sage grouse are managed as a small ***game*** species, one that people can legally hunt for food. In order to sustain healthy populations of game animals, wildlife agencies such as the DOW regulate hunting by many means. These can include:

- *setting seasons*—establishing certain times of year people may hunt;
- *issuing licenses* that limit the number of people who may hunt; and
- *setting bag limits*—allowing only a certain number of animals to be harvested within a set time limit.

Game populations are closely monitored and hunting regulations are adjusted as needed to conserve these animals for future generations. The sage grouse harvest was monitored through wings turned in by hunters to DOW biologists. The wings indicate the age and sex of the grouse.

Photo courtesy of Bill Haggerty

How Do Sage Grouse Wings Indicate Age of the Birds?

All grouse have ten primary feathers—eventually. When the chicks hatch, they have only eight juvenile primaries on each wing. Juvenile primaries 9 and 10 emerge when the chicks are about a month old.

Grouse ***molt*** *(drop and replace) their primaries in sequence, starting with P1 and ending with P10. Adults and yearlings replace all ten of their primaries, but juveniles just replace the first eight. They do not molt P9 and P10 until they are 14–16 months old. In the fall, when hunting is permitted, P9 and P10 are new and pointed on the juvenile birds, pointed and worn on yearling birds, and rounded on adult birds.*

How do researchers tell the sex of the sage grouse by the wings? You will soon discover the answer!

Juvenile Sage Grouse Wing

Adult Sage Grouse

Dr. Clait Braun, an ***avian*** (bird) researcher with the DOW, began compiling the wing data for sage grouse populations in the mid-1970's. He measured three primary feathers (10, 9, and 1) on each wing. Here are the data he has for two different locations—the Gunnison Basin of southwestern Colorado and those from Jackson County in the northwestern part of the state:

	ADULT MALES			ADULT FEMALES		
	P10	P9	P1	P10	P9	P1
Gunnison County Mean Length (mm)	166	216	151	139	182	130
Jackson County Mean Length (mm)	179	230	167	147	193	141

What general statement can you make about sage grouse wings when you compare males and females?

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What general statement can you make when you compare sage grouse wings collected in Gunnison County with wings in Jackson County?

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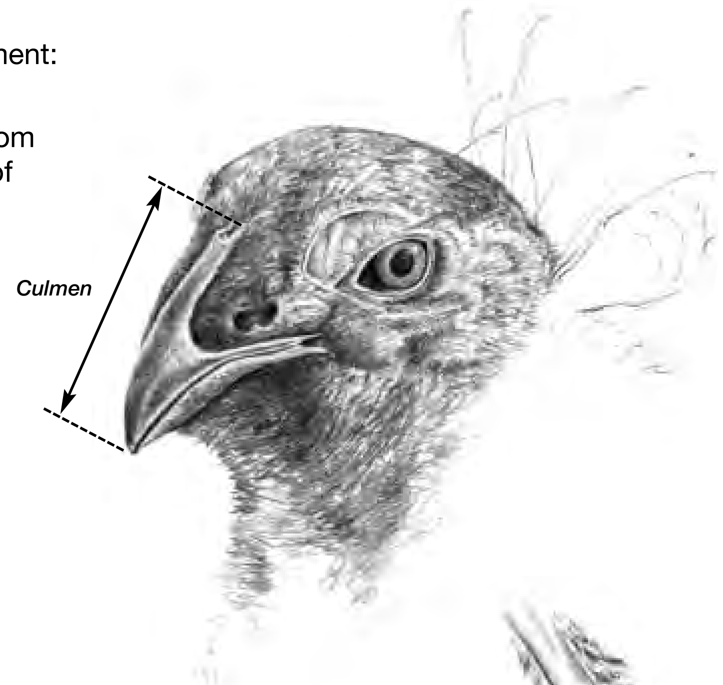
Dr. Braun had the same observations that you did and decided to investigate other ***morphological*** (physical) traits of the birds. He decided to compare other physical characteristics of the two populations of birds. Here is his data comparing various features of adult male and adult female sage grouse in Gunnison and Jackson Counties. All numbers represent the mean measurement for each feature.

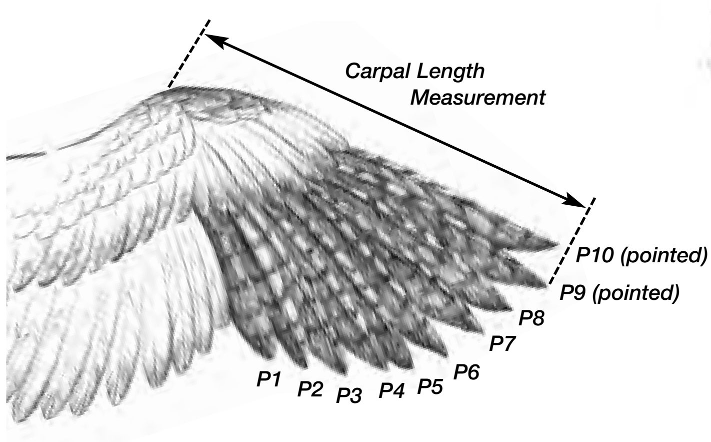
	GUNNISON COUNTY		JACKSON COUNTY	
	Adult Males	Adult Females	Adult Males	Adult Females
Live Body Mass (g)	2,141	1,204	3,190	1,745
Beak Measurements (mm) Culmen* Nostril to tip Width	 31.7 14.3 16.0	 28.0 12.9 13.8	 39.1 16.6 21.7	 30.6 14.5 17.1
Tarsus Length (mm)*	62.5	58.6	74.4	
Carpal Length (mm)*	304	260	340	284
Length of Tail Feathers (mm)	<315		347	

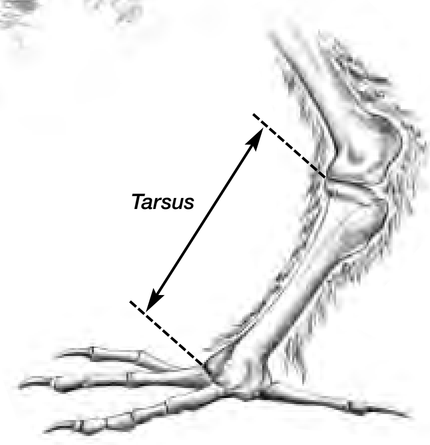
*Explanation of body part and measurement:

- ***Culmen:*** Straight-line measurement from the base of the upper beak to the tip of the upper beak
- ***Tarsus:*** Measurement from point where the leg joins the middle toe to the first joint in the leg
- ***Carpal:*** With the wing slightly flattened, measurement from the wrist bone of the wing to the tip of the longest primary feather



Juvenile Sage Grouse Wing





Based on this additional data, what general statement can you make about sage grouse when you compare males and females?

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What general statement can you make when you compare sage grouse in Gunnison County with sage grouse in Jackson County?

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What are the legal criteria for defining a species?

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2. ______________________________________

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3. ______________________________________

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4. ______________________________________

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Based on your observations, do these populations of sage grouse meet the criteria to be considered different species?

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What other information would you need before you could determine whether these two populations of sage grouse belonged to different species?

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Student Pages

Hidden In Plain View

In 1977, Dr. Clait Braun, an avian researcher with the DOW, noticed that sage grouse wings collected in the Gunnison Basin of southwestern Colorado were smaller than sage grouse wings collected in northern Colorado. He also noted that these grouse were one-third smaller than the sage grouse found farther north, and that the males had more distinct, whiter tail feathers and more elaborate filoplume feathers on their necks. Dr. Braun also documented differences in leg lengths and beak shapes. Based on these ***morphological*** (physical form and structure) differences, he began to think that the birds in the Gunnison Basin might be another subspecies.

Sound from the strutting grounds provided some of the first strong hints that the two groups might in fact be separate species. As an undergraduate student at the University of California at San Diego in the 1980's, Jessica Young had found herself listening to and trying to analyze hundreds of tapes of sage grouse as part of a biology project. She noticed different vocal patterns on tapes of sage grouse from the Gunnison Basin. While sage grouse from northern areas such as Jackson County consistently pop their air sacs twice in each of the many brief strut displays they perform, the Gunnison birds pop their air sacs nine times, and the sounds they produced are notably deeper.

Fascinated by startling differences in vocal patterns, she rounded up video and audio recorders and went to the leks to study the entire mating ritual. Male sage grouse in both the Gunnison and northern areas had a highly elaborate strut display that began with males taking a few steps, and then raising their wings and brushing them twice against the stiff feathers of the pouch to make swishing noises to accompany the mating calls. She noted that sage grouse in Gunnison had fewer displays per minute and would also throw their filoplumes over their head and wag their tail at the end of their display.

When Jessica Young tried to play male Gunnison County grouse vocalizations in the territories of Jackson County sage grouse, the females actively avoided the area. She had similar results when she tried to romance Gunnison females with the sounds of Jackson County sage grouse males. Young continued to study the Gunnison grouse and to collaborate with Dr. Braun while receiving a Ph.D. at Purdue and, later, after being named to the faculty at Western State College, which is in Gunnison.

At first, Dr. Braun was hesitant to come to the extraordinary conclusion that the Gunnison grouse was a separate species. Nevertheless, in time, he conceded that Dr. Young simply compiled too much *evidence* to conclude otherwise. Dr. Young's research on the behavioral differences of the sage grouse, along with Dr. Braun's documentation of morphological differences, led to analysis of the birds' genetics in 1999. The DNA studies, by Dr. Tom Quinn and Dr. Sara Oyler-McCance of Colorado State University, provided definitive evidence that the two groups were separate species.

This was the first time in decades that a new species of bird was described in the continental United States. The Gunnison sage grouse *did not interbreed* with the northern sage grouse; the two are strikingly *different in both appearance and behavior*; and detailed studies of the two groups' DNA showed that they were *far too distantly related* to be considered the same species. Unlike new species discoveries in remote parts of the globe, the Gunnison sage grouse had been in plain view all along!

By the way, the sources of the data provided for this activity were:

- Hupp, J.W. and C.E. Braun. 1991. Geographic variation among Sage Grouse in Colorado. *Wilson Bulletin* 103 (2), 255–261.
- Young, J.R., C.E. Braun, S.J. Oyler-McCance, J.W. Hupp, and T.W. Quinn. 2000. A new species of Sage-Grouse (*Phasianidae: Centrocercus*) from Southwestern Colorado. *Wilson Bulletin* 112 (4), 445–453.

Lesson 3

Educator's Overview

Taxonomy Through The Ages

Duration

Two or three 45-minute class periods

Vocabulary

Ancestral character

Binomial

Character

Clade

Cladistics

Cladogram

Classification system
- *Five-kingdom*
- *Three-domain*
- *Two-empire*

Derived character

DNA

Eukaryote

Gene

Gene sequencing

In-group

Marine

Natural selection

Out-group

Phylogenetics

Prokaryote

Selection

Strata

Systematics

Taxon (taxa)

Taxonomy

Terrestrial

Uniformitarianism

Summary

Student groups prepare taxonomic groupings that reflect the science of different time periods by rearranging pictures of 24 species of Colorado wildlife.

Learning Objectives

After completing this activity, students will be able to:

- Describe different systems of classifying organisms.
- Classify organisms using two different systems of classification.
- Define cladistics and describe its use.
- Describe the process used to construct a cladogram by comparing ancestral and derived characters.

Background

There is an amazing diversity of life. To be able to communicate about various organisms and have a significant way to study them, humans have always sought to sort species into meaningful groups, or ***taxa*** (***taxon***, singular). Before the advent of modern, genetically based studies of animals and plants, organisms were classified into different categories based on their physical characteristics. Often, these groupings were also reflective of the world view at the time and the importance placed on different attributes of the organism.

As advances in science have allowed us to understand how organisms arise and are related, classification became only one aspect of ***systematics***, the much larger field of biology that deals with the diversity of life. Systematics includes both ***taxonomy***, the science of naming and classifying organisms, and ***phylogenetics***, the study of the pattern of events that has led to the distribution and diversity of life.

Cladistics is a method of analysis that attempts to classify organisms by common ancestry. It has been around for almost fifty years, but has really become important in the past few decades, as a means of hypothesizing relationships among species that can then be tested with new molecular technologies. High school texts are now beginning to introduce students to these important concepts.

This activity takes students on a historical journey through the classical methods of taxonomy into the new age of systematics. This compact presentation of changes in scientific thought over time can also facilitate discussions on the processes of science and the relationship of scientific advances to human history.

Teaching Strategies

1. Thoroughly read the student materials for *Taxonomy Through The Ages*.

2. Divide the class into groups of two to four students.

3. Give each student a copy of the Colorado Wildlife Cards and the activity packet, *Taxonomy Through The Ages*.

4. Introduce the idea that scientific ideas and procedures may change as new discoveries and advances are made. Tell students that they will be exploring the developing science of the classification of organisms, and will later see how classification relates to larger species questions.

5. Tell students that they will work through parts I and II of the activity in their groups. Show them the resource materials (textbooks, library books, and internet) and the presentation materials that are available to them. To research classification of animals, one of the best Internet sites is University of Michigan Museum of Zoology Animal Diversity Web:

   http://animaldiversity.ummz.umich.edu/site/index.html

Students can type the scientific or common name into the search box and find the taxonomic groups of each species. This site also provides links to other taxonomy sites.

6. Allow class time for students to read through parts I and II of the activity and to prepare, present, and defend their classification posters to their classmates.

7. Point out to students that Aristotle's system might include some animals in the correct group. He might have grouped bats in the "bird" taxa. He may not have recognized bats as mammals, or for that matter, have had a category for mammals. His system might have also grouped an organism like a duck billed-platypus, another unusual mammal, in the taxa "Four-legged animals that lay eggs." The importance of certain attributes of species, such as having mammary glands, has changed over time.

8. As a class, read and discuss *Part III: Evolution Theory, Genetics, And Biotechnology*. Be sure that students understand the terms that are being used—particularly character, ancestral character, derived character, in-group and out-group. You may want to have students circle the in-groups and out-groups on the alternate forms of the cladogram provided.

Assessment

Students' preparation and defense of their classification posters serve as an assessment for this activity.

Extension

If the students' textbooks have additional examples of cladograms, review and discuss those as well.

Materials and Preparation

- *Student Reading and Activity Packet:* Taxonomy Through The Ages
- *Copies of Colorado Wildlife Cards—one per student*
- *Scissors*
- *Glue or tape*
- *Poster board, butcher paper or other presentation media*
- *Access to textbooks, library, and internet*

Taxonomy Through The Ages Keys

Key: Aristotle's Classification

Something similar to the following groupings of Blooded Animals should be presented:

- ***Four-legged Animals that Give Birth:***

Black-footed ferret,
Mustela nigripes

Lynx,
Lynx lynx

Mule deer,
Odocoileus hemionus

American elk,
Cervus elaphus

White-tailed deer,
Odocoileus virginianus

Bison,
Bison bison

Pronghorn,
Antilocapra americana

Black-tailed prairie dog,
Cynomys ludovicianus

Red fox,
Vulpes vulpes

Moose,
Alces alces

Mountain lion,
Felis concolor

Bighorn sheep,
Ovis canadensis

Mountain goat,
Oreamnos americanus

- ***Four-legged Animals that Lay Eggs:***

Wood frog,
Rana sylvatica
Boreal toad,
Bufo boreas
Tiger salamander,
Ambystoma tigrinum
Western box turtle/Ornate box turtle,
Terrapene ornate
Triploid checkered whiptail,
Cnemidophorus neotesselatus

- ***Snakes:***

Western rattlesnake,
Crotalus viridis

- ***Birds:***

Gunnison sage grouse,
Centrocercus minimus
Burrowing owl,
Athene cunicularia
Sandhill crane,
Grus canadensis
Little brown bat,
Myotis lucifugus

- ***Fishes:***

Rainbow trout,
Oncorhynchus mykiss

Key: Classical Taxonomic Classification of Colorado Wildlife Species

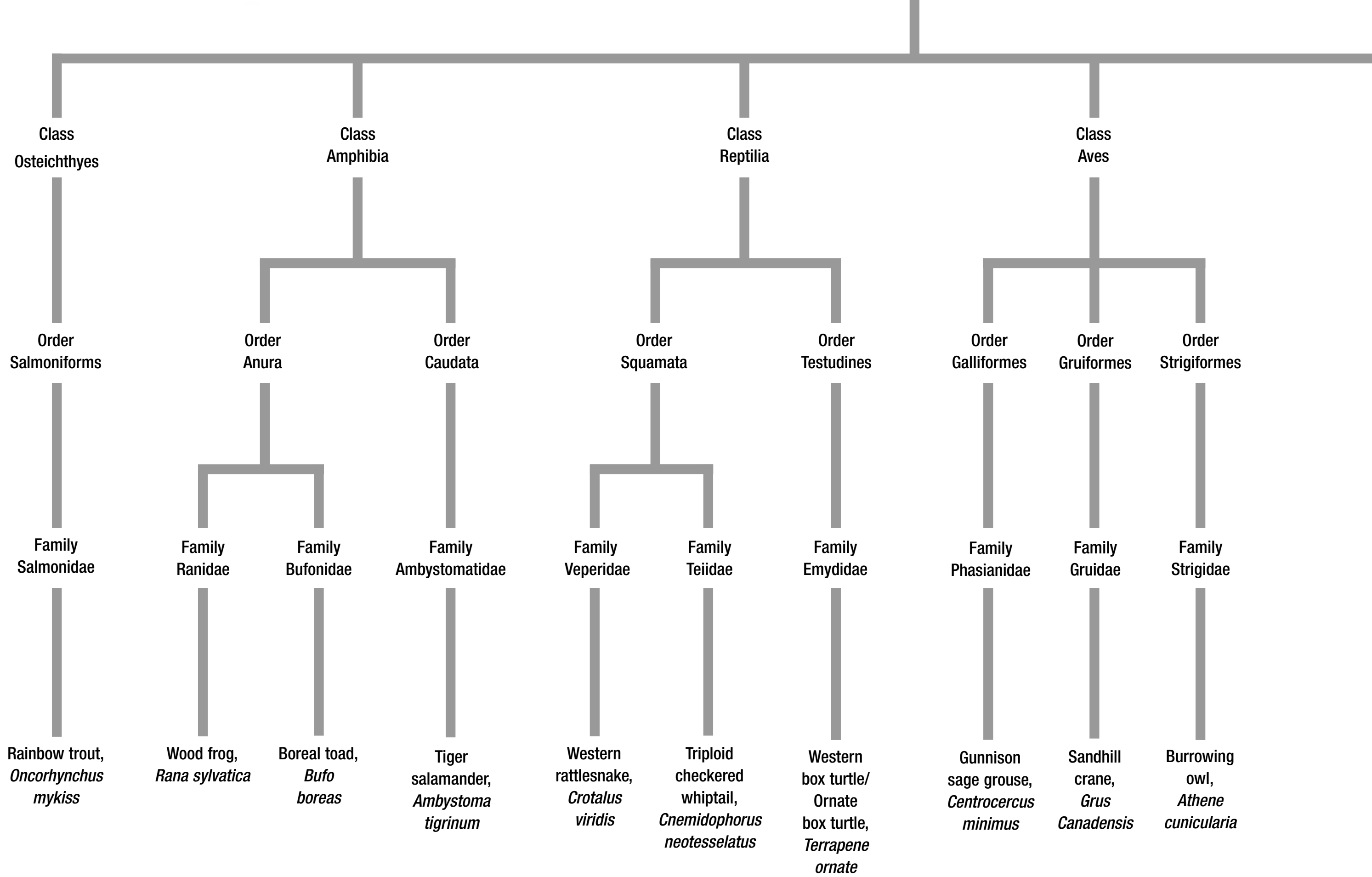
Colorado Wildlife Species	Classical Taxonomic Classification For Each Species The Following Groups Are Identical: Kingdom: Animalia Phylum: Chordata Subphylum: Vertebrata
Black-footed ferret	Class: Mammalia Order: Carnivora Family: Mustelidae Name: *Mustela nigripes*
Lynx	Class: Mammalia Order: Carnivora Family: Felidae Name: *Lynx lynx*
Mule deer	Class: Mammalia Order: Artiodactyla Family: Cervidae Name: *Odocoileus hemionus*
American elk	Class: Mammalia Order: Artiodactyla Family: Cervidae Name: *Cervus elaphus*
White-tailed deer	Class: Mammalia Order: Artiodactyla Family: Cervidae Name: *Odocoileus virginianus*

Colorado Wildlife Species	Classical Taxonomic Classification For Each Species The Following Groups Are Identical: Kingdom: Animalia Phylum: Chordata Subphylum: Vertebrata
Bison	Class: Mammalia Order: Artiodactyla Family: Bovidae Name: *Bison bison*
Pronghorn	Class: Mammalia Order: Artiodactyla Family: Antilocapridae Name: *Antilocapra americana*
Black-tailed prairie dog	Class: Mammalia Order: Rodentia Family: Sciuridae Name: *Cynomys ludovicianus*
Red fox	Class: Mammalia Order: Carnivora Family: Canidae Name: *Vulpes vulpes*
Moose	Class: Mammalia Order: Artiodactyla Family: Cervidae Name: *Alces alces*
Mountain lion	Class: Mammalia Order: Carnivora Family: Felidae Name: *Felis concolor*
Bighorn sheep	Class: Mammalia Order: Artiodactyla Family: Bovidae Name: *Ovis canadensis*
Mountain goat	Class: Mammalia Order: Artiodactyla Family: Bovidae Name: *Oreamnos americanus*
Burrowing owl	Class: Aves Order: Strigiformes Family: Strigidae Name: *Athene cunicularia*
Sandhill crane	Class: Aves Order: Gruiformes Family: Gruidae Name: *Grus canadensis*

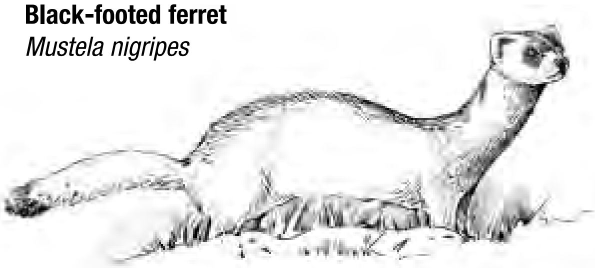
Colorado Wildlife Species	Classical Taxonomic Classification For Each Species The Following Groups Are Identical: Kingdom: Animalia Phylum: Chordata Subphylum: Vertebrata
Wood frog	Class: Amphibia Order: Anura Family: Ranidae Name: *Rana sylvatica*
Boreal toad	Class: Amphibia Order: Anura Family: Bufonidae Name: *Bufo boreas*
Tiger salamander	Class: Amphibia Order: Caudata Family: Ambystomatidae Name: *Ambystoma tigrinum*
Western rattlesnake	Class: Reptilia Order: Squamata Family: Viperidae Name: *Crotalus viridis*
Western box turtle/ Ornate box turtle	Class: Reptilia Order: Testudines Family: Emydidae Name: *Terrapene ornata*
Triploid checkered whiptail	Class: Reptilia Order: Squamata Family: Teiidae Name: *Cnemidophorus neotesselatus*
Gunnison sage grouse	Class: Aves Order: Galliformes Family: Phasianidae Name: *Centrocercus minimus*
Rainbow trout	Class: Osteichthyes Order: Salmoniformes Family: Salmonidae Name: *Oncorhynchus mykiss*
Little brown bat	Class: Mammalia Order: Chiroptera Family: Vespertilionidae Name: *Myotis lucifugus*

Key: Linnean Classification

Something similar to the following:



- Class Mammalia
  - Order Artiodactyla
    - Family Cervidae
      - Mule deer, *Odocoileus hemionus*
      - American elk, *Cervus elaphus*
      - White-tailed deer, *Odocoileus virginianus*
      - Moose, *Alces alces*
    - Family Bovidae
      - Bighorn sheep, *Ovis canadensis*
      - Mountain goat, *Oreamnos americanus*
      - Bison, *Bison bison*
    - Family Antilocapridae
      - Pronghorn, *Antilocapra americana*
  - Order Chiroptera
    - Family Vespertilionidae
      - Little brown bat, *Myotis lucifugus*
  - Order Rodentia
    - Family Sciuridae
      - Black-tailed prairie dog, *Cynomys ludovicianus*
  - Order Carnivora
    - Family Felidae
      - Lynx, *Lynx lynx*
      - Mountain lion, *Felis concolor*
    - Family Canidae
      - Red fox, *Vulpes vulpes*
    - Family Mustelidae
      - Black-footed ferret, *Mustela nigripes*

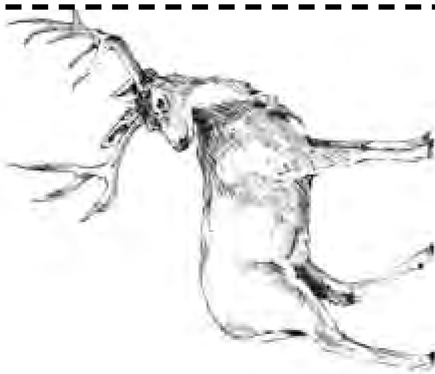


Black-footed ferret
Mustela nigripes

White-tailed deer
Odocoileus virginianus

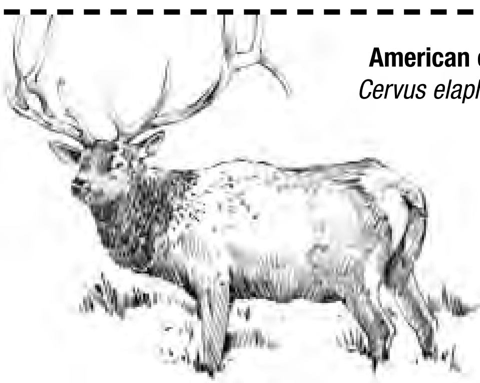
Lynx
Lynx lynx

Bison
Bison bison



Mule deer
Odocoileus hemionus

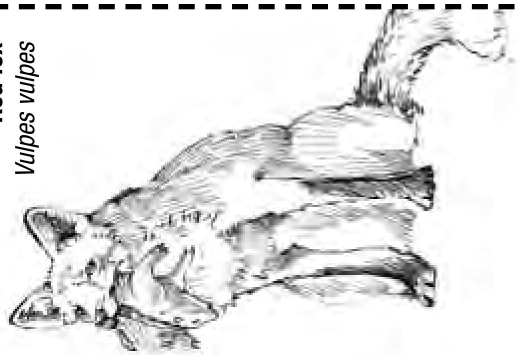
Pronghorn
Antilocapra americana



American elk
Cervus elaphus

Black-tailed prairie dog
Cynomys ludovicianus

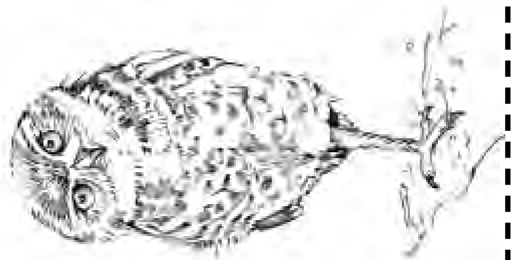
Red fox
Vulpes vulpes



Mountain goat
Oreamnos americanus

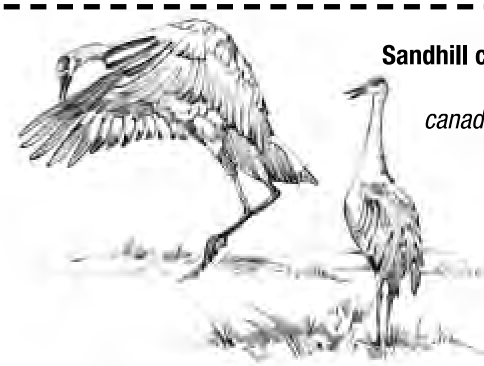
Moose
Alces alces

Burrowing owl
Athene cunicularia

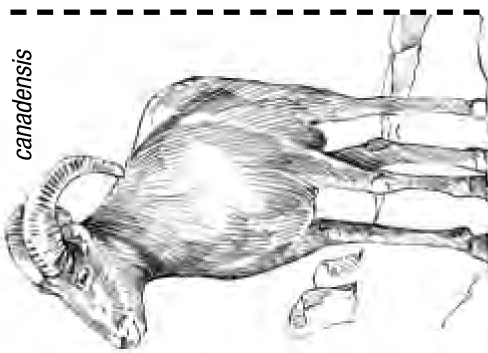


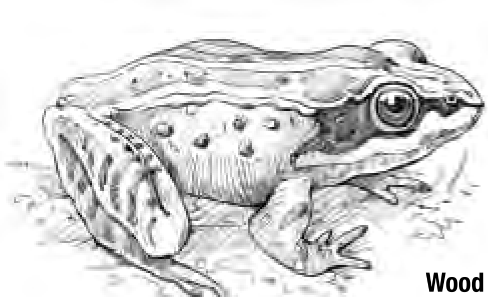
Mountain lion
Felis concolor

Sandhill crane
Grus canadensis



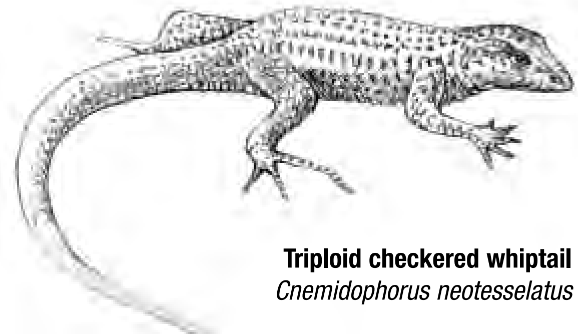
Bighorn sheep
Ovis canadensis





Wood frog
Rana sylvatica

Boreal toad
Bufo boreas

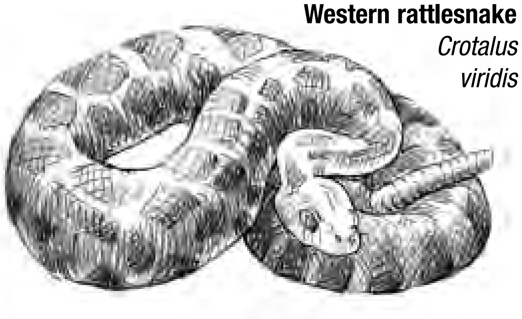


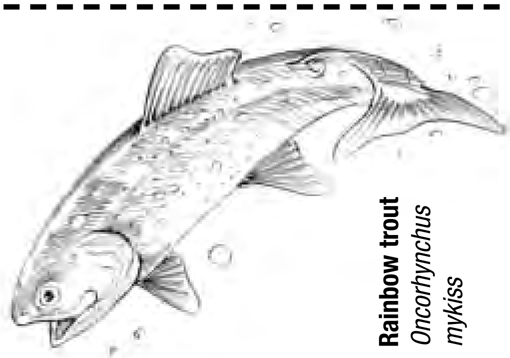
Triploid checkered whiptail
Cnemidophorus neotesselatus

Tiger salamander
Ambystoma tigrinum

Gunnison sage grouse
Centrocercus minimus

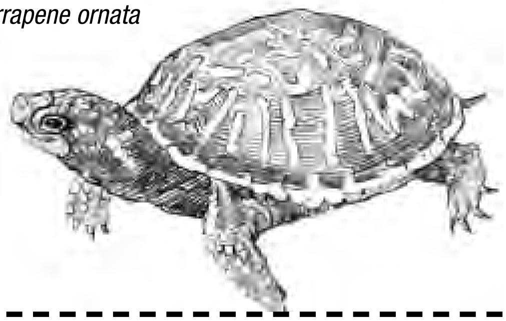
Western rattlesnake
Crotalus viridis



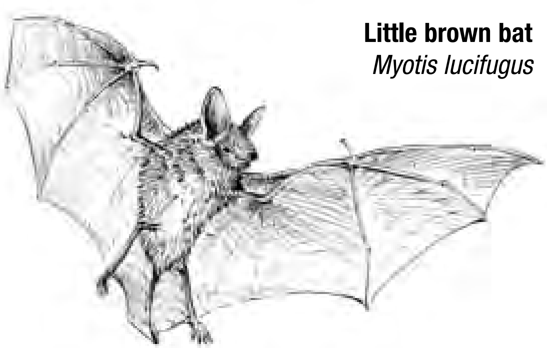


Rainbow trout
Oncorhynchus mykiss

Western box turtle/Ornate box turtle
Terrapene ornata



Little brown bat
Myotis lucifugus



Lesson 3

Student Pages

Taxonomy Through The Ages

Since ancient times, humans have been grouping and classifying all types of things. Sorting objects or living things into categories may have begun as a primal means of survival. Labeling or identifying other people or tribes as friends or enemies, plants as edible or poisonous, or animals as safe or dangerous could definitely help keep one alive.

This time-honored human method of bringing order to the world also helps us organize information we have about organisms and biodiversity. For example, if someone discovers a new species and groups it with similar animals that have already been studied, he would not need to analyze everything about the new organism from scratch. The process of sorting out and classifying life also helps biologists answer many species questions.

The science of naming, describing and classifying organisms into groups is called ***taxonomy***. Each named group of organisms is called a ***taxon***, and the plural of this word—many groups—is ***taxa***.

Part I: Aristotle

Aristotle (384–322 B.C.E.), an over-achieving Greek philosopher, was the first to develop a widely used system of classification for living things. He sorted animals according to their actions or way of life, as well as their physical features or parts. Aristotle based his groupings on his observations of ***marine*** (ocean) and ***terrestrial*** (land) life and his dissections of various animals. He divided the animals into two types: those with blood, and those without blood (or at least without red blood).

The blooded animals were further divided into two groups: animals that gave birth and animals that laid eggs. The animals that gave birth were placed into three groups: humans, whales, and four-legged animals that gave birth. Animals that laid eggs were grouped into these categories: birds, serpents (snakes), four-legged animals that lay eggs, and fishes.

The bloodless animals were classified as cephalopods (such as the octopus); crustaceans; insects (which included the spiders, scorpions, and centipedes, in addition to what we now define as insects); shelled animals (snails, clams, oysters, starfish, sea urchins, etc.); and "zoophytes, or "plant-animals," which looked like plants (such as coral, sponges, etc).

Your Task

Using one set of your group's wildlife species cards; design a poster that groups the 24 animals according to Aristotle's classification system.

Part II: Linnaeus

Carl Linnaeus was born in 1707, the son of a Swedish Lutheran minister. Linnaeus shared his father's interest in plants and loved nature deeply. His religious beliefs led him to natural theology, a philosophy that taught that it is possible to understand God's wisdom by studying His creation. The study of nature would reveal the Divine Order of God's creation, and as a naturalist it was Linnaeus' task to construct a "natural classification" that would reveal this order in the universe.

Linnaeus's search for a natural system for the classification of living things led him to group organisms based on shared ***characters***—identifiable features, traits or characteristics. He combined his groups into a hierarchy of subsequently more inclusive, higher taxonomic groups. Very similar species were grouped together in a genus; similar genera were grouped into orders, and so on. Linnaeus' first hierarchy of taxonomic groups included species, genus, order, class, and kingdom. The highest taxa, the kingdom, contained groups that shared the most general characteristics.

What's In A Name?

For centuries species had been given long, Latin names that described them. For example, the common European honey bee was called *Apis pubescens thorace subgriseo abdomen fusco pedipus posticus glabris utrimque margin ciliates*, meaning "the bee with a grayish thorax and brown belly, and a hind foot that is smooth on the sides and fuzzy on the margins." Linnaeus simplified this naming system by providing each species with two names or a ***binomial***. The first name of the binomial indicated the ***genus***, or group of very similar organisms, that the species belonged to. The second name was unique to the species. The exclusive two-part name for a species is now referred to as its ***scientific name***. For instance, *Apis mellifera* is the binomial and scientific name for the honey bee.

The scientific name of an organism gives biologists a common way of communicating, no matter what their native language. Regardless whether the researcher is from the United States, China, Spain or Africa, and no matter their alphabet or form of writing, he or she will always use the scientific name in an agreed format in any scientific publication. The first letter of the genus name is always capitalized, and the first letter of the second word is always lowercase. The scientific name is always either underlined or in italics.

Kingdoms, Empires, And Domains

Linnaeus's classification system has been used by biologists for over 200 years, although it has been slowly modified as new discoveries were made. At first, biologists grouped all of the organisms that they knew into two kingdoms—plants and animals. Even microorganisms were grouped into these kingdoms, depending on their color and appearance.

During the 1800's, Ernst Haeckel proposed putting microorganisms in a separate kingdom, the protists. This three-kingdom system was then expanded to four in the early 1900's, when scientists began to distinguish between bacteria and other microorganisms. The new kingdom for bacteria was called Monera.

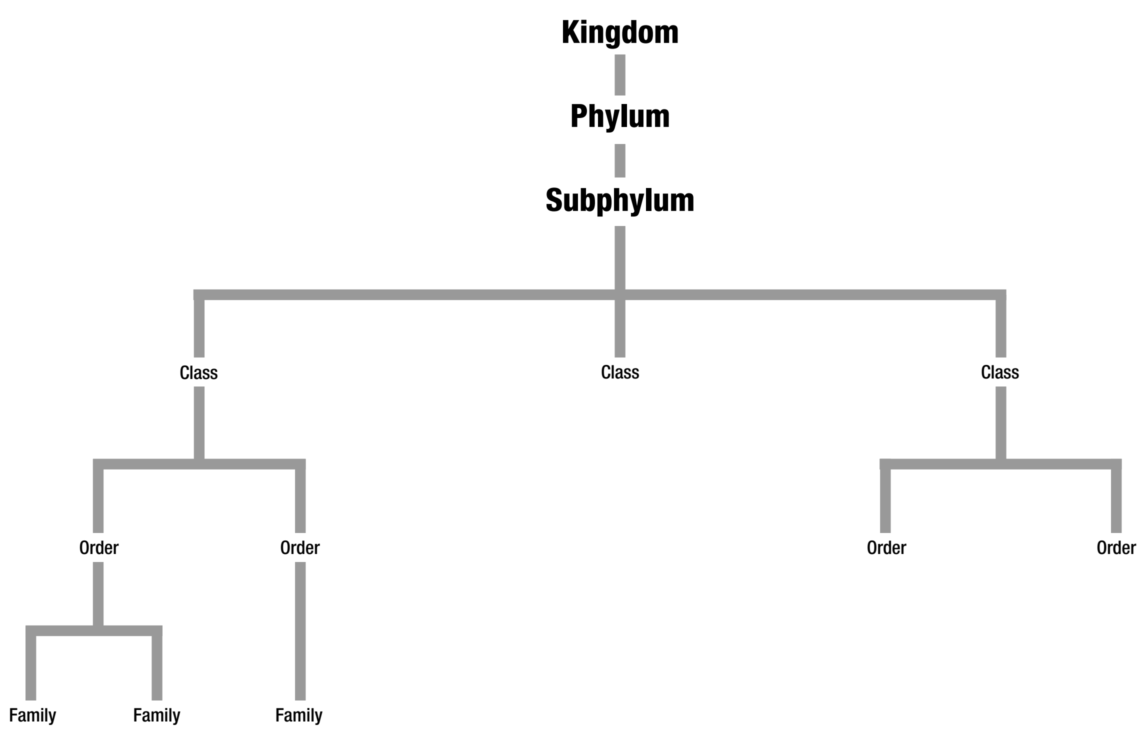
The current ***five-kingdom classification system*** (Monera, Protista, Plantae, Fungi, Animalia) found in most high school biology textbooks today was not proposed until 1969. Robert Whittaker proposed that organisms be grouped into kingdoms on the basis of three characteristics: cell structure (prokaryotic cells which have no nucleus or eukaryotic cells that have a nucleus), body structure (single-celled or multicellular) and manner of getting energy or nourishment (photosynthesis, absorption, or ingestion).

Recently, two other methods of classifying organisms have been suggested. Your textbook may talk about these. The late Ernst Mayr, a prominent biologist at Harvard, supported a ***two-empire classification system*** based on cell structure. The two empires are called Empire Prokarya or Prokaryotae (***prokaryotes***—organisms lacking nucleated cells) and Empire Eukarya or Eukaryotae (***eukaryotes***—organisms having nucleated cells).

Another noted biologist, Carl Woese, promotes a ***three-domain classification system***. He groups organisms on the basis of the genetic makeup of their ribosomal RNA (rRNA). Just as every species—and individual—has a unique DNA sequence, each species and individual has a unique rRNA sequence. When he analyzed each organism's rRNA, Woese discovered that bacteria fall into two genetically distinct groups, which he calls Bacteria and Archaea, that are as different from each other as they are from eukaryotic organisms. Woese divides Earth's organisms into three domains: Bacteria, Archaea, and Eukarya.

Your Task

Using your biology textbook and other resources, research the names of the taxonomic groups of the 24 wildlife species. Then, using a second set of your group's species cards, design a poster that groups the animals in a Five-Kingdom classification system. Your poster may look a bit like a company's organizational chart, because all the animals share characters that group them in the same kingdom, phylum, and subphylum. The chart may look a bit like this:



Lesson 3: Taxonomy Through The Ages

You will first need to research the classical taxonomic groups of the 24 species:

Colorado Wildlife Species	Classical Taxonomic Classification For Each Species The Following Groups Are Identical: Kingdom: Animalia Phylum: Chordata Subphylum: Vertebrata
Black-footed ferret	Class: Order: Family: Name: *Mustela nigripes*
Lynx	Class: Order: Family: Name: *Lynx lynx*
Mule deer	Class: Order: Family: Name: *Odocoileus hemionus*
American elk	Class: Order: Family: Name: *Cervus elaphus*
White-tailed deer	Class: Order: Family: Name: *Odocoileus virginianus*
Bison	Class: Order: Family: Name: *Bison bison*
Pronghorn	Class: Order: Family: Name: *Antilocapra americana*
Black-tailed prairie dog	Class: Order: Family: Name: *Cynomys ludovicianus*
Red fox	Class: Order: Family: Name: *Vulpes vulpes*

Colorado Wildlife Species	Classical Taxonomic Classification For Each Species The Following Groups Are Identical: Kingdom: Animalia Phylum: Chordata Subphylum: Vertebrata
Moose	Class: Order: Family: Name: *Alces alces*
Mountain lion	Class: Order: Family: Name: *Felis concolor*
Bighorn sheep	Class: Order: Family: Name: *Ovis canadensis*
Mountain goat	Class: Order: Family: Name: *Oreamnos americanus*
Burrowing owl	Class: Order: Family: Name: *Athene cunicularia*
Sandhill crane	Class: Order: Family: Name: *Grus canadensis*
Wood frog	Class: Order: Family: Name: *Rana sylvatica*
Boreal toad	Class: Order: Family: Name: *Bufo boreas*
Tiger salamander	Class: Order: Family: Name: *Ambystoma tigrinum*

Colorado Wildlife Species	Classical Taxonomic Classification For Each Species The Following Groups Are Identical: Kingdom: Animalia Phylum: Chordata Subphylum: Vertebrata
Western rattlesnake	Class: Order: Family: Name: *Crotalus viridis*
Western box turtle/ Ornate box turtle	Class: Order: Family: Name: *Terrapene ornata*
Triploid checkered whiptail	Class: Order: Family: Name: *Cnemidophorus neotesselatus*
Gunnison sage grouse	Class: Order: Family: Name: *Centrocercus minimus*
Rainbow trout	Class: Order: Family: Name: *Oncorhynchus mykiss*
Little brown bat	Class: Order: Family: Name: *Myotis lucifugus*

Part III: Evolution Theory, Genetics, And Biotechnology

There are periods in human history in which discoveries and new ideas of all kinds seem to emerge out of nowhere. If one looks more closely, new ideas usually developed as result of combining old ideas in a unique way. Our newest and most useful taxonomic methods—those that utilize DNA and RNA analysis, computers, and all sorts of biotechnology—had their start in the 1800s. Those ideas had their birth thousands of years before, with the start of agriculture.

Building A Better Burger

Since the dawn of agriculture, humans have been trying to alter plants and animals to give them traits that were more desirable—a process known as ***selection***. First, people found ways to domesticate these species. They gathered edible grasses and planted them near their homes. They penned and herded wild goats, sheep and cattle so that they would not have to spend days looking for something to eat.

These early agriculturists noticed that offspring seemed to have traits that were similar to parents. Although it was a complete mystery as to how it happened, early ranchers found that if they bred the two woolliest sheep, the offspring would be pretty woolly. If farmers wanted more grain, they would cross plants with the biggest and most abundant seed heads. Over time, this led to bigger and better food crops, well-fed people, and enough free time in the day to devote to academic pursuits.

Figuring Out Fossils

In the late 1600s, scientist Robert Hooke—best known for his discovery of the cell—proposed that fossils were the remains of once-living organisms. His hypothesis sounded absurd to most people of his time. In the seventeenth century, nearly everyone thought that fossils were formed and grew within the Earth. They thought there was a shaping force that could create stones that looked like living things.

Hooke was the first person to examine fossils with a microscope. He noted close similarities between the structures of petrified wood and fossil shells on the one hand, and living wood and living mollusk shells on the other. Hooke believed that the features he could see in fossils were similar to those found in living organisms. He concluded that dead plants and animals could be turned to stone by being submerged in water rich in dissolved minerals. Over time, the minerals which were deposited throughout the body of the organism would replace each cell.

As Hooke continued to study fossils and compare them with living organisms, he concluded that many fossils represented organisms that no longer existed on Earth and that fossils could be used to understand the history of life.

> *"There have been many other Species of Creatures in former Ages, of which we can find none at present; and that 'tis not unlikely also but that there may be divers new kinds now, which have not been from the beginning."*

This was an incredibly radical thought at the time. A century later, two other scientists developed theories that would not only support Hooke's ideas, but change our understanding of living organisms, update Linnaeus's taxonomic hierarchy, and group organisms in completely new ways.

Lyell And Darwin

Charles Lyell (1797–1875) was the leading British geologist of his era. He studied the ***strata***—layers—of the earth and realized that each differed in the number, type and proportion of marine shells (fossils). Each layer represented a different era of Earth's history. He found evidence for the then-controversial hypothesis of ***uniformitarianism***, the idea that the earth was shaped entirely by slow-moving forces acting over a very long period of time. He assumed that the kinds of activities which affected the earth in the past must have been exactly like those in operation in the present (such as erosion, sediment deposition, volcanic action, earthquakes, etc.).

Lyell's ideas influenced a close personal friend of his, Charles Darwin. Comparing living organisms to fossils, Darwin (1809–1882) hypothesized that populations of organisms could change over time. Just as farmers and ranchers could slowly improve their crops and livestock over time, he proposed that wild organisms could slowly change by a process he called natural selection. ***Natural selection*** is often referred to as *survival of the fittest*. Life is a constant struggle for survival, thought Darwin, and more individuals are produced in a population than will be able to survive and reproduce. Those individuals who possess characteristics that allow them to adapt to their environment are more likely to survive and pass on these adaptive traits to their offspring. Over time, an increasing proportion of a population will possess the adaptive traits.

The Gene Connection

Later research showed how physical traits could be passed on to future generations. In 1865, Gregor Mendel's experimented on peas and demonstrated that traits could be passed to offspring proportionally in discrete units—later named ***genes***. In 1902, a British physician named Archibald Garrod observed that the disease alkaptonuria is passed from one generation to the next in the same proportion as the features of Mendel's peas. Garrod had discovered the first disease recognized to have a genetic cause!

Meanwhile, in 1882, Walter Flemming was able to stain chromosomes and observe the process of cell division. In 1911, while studying fruit flies, Thomas Hunt Morgan found that chromosomes carry genes. By 1952, Alfred Hershey and Martha Chase discovered that genes are made of DNA and the following year, Francis Crick and James Watson described the double helix structure of DNA. The genetic code was cracked in 1968, when Marshall Nirenberg and others figured out that the order of the four nitrogen bases in DNA (A, G, T, and C) determines the amino acid sequence of proteins.

The combined research clearly demonstrated that DNA coded for all the characteristics possessed by an organism. Anytime the order of the nitrogen bases found in a strand of DNA changed, the changes were passed on to offspring. The changes in traits that the DNA coded for would be inherited by future generations! It seemed likely that ***the more traits species had in common, the more similar their genetic code and the more "related" they were.***

The New Taxonomy

According to this idea, organisms that are more similar to one another than they are to other organisms have descended from a more recent common ancestor. Taxonomists are now actively constructing a new "natural system" for the classification of organisms based upon the evolutionary relationships of taxa. ***Systematics***, a large field of biology that deals with the diversity of life, combines taxonomy and ***phylogenetics***, the study of the pattern of events that led to the diversity of life.

The method of analysis that most biologists use to reconstruct evolutionary relationships of organisms is called ***cladistics***. Cladistics can be used to hypothesize the order in which different groups of organisms evolved. Organisms that share important characters are placed together into taxonomic groups called ***clades***, that branch from a single "twig." With respect to two different groups or clades, a character is defined as an ***ancestral character*** if it evolved in a common ancestor of both groups. For example, all of the 24 animals that you have been classifying have a backbone or vertebra. A backbone is an ancestral character. A trait that evolves in one group and not another is called a ***derived character***. All the birds, mammals, reptiles and amphibians have four limbs and fish do not. Having four limbs is a derived character that evolved later. However, when comparing birds with the other four-limbed organisms, four limbs becomes the ancestral trait. Having forelimbs (front limbs) developed into feathered wings becomes the new derived character.

After looking at the various characters that different groups share, scientists create ***cladograms***, branching diagrams that represent a hypothesis about the order in which organisms evolved.

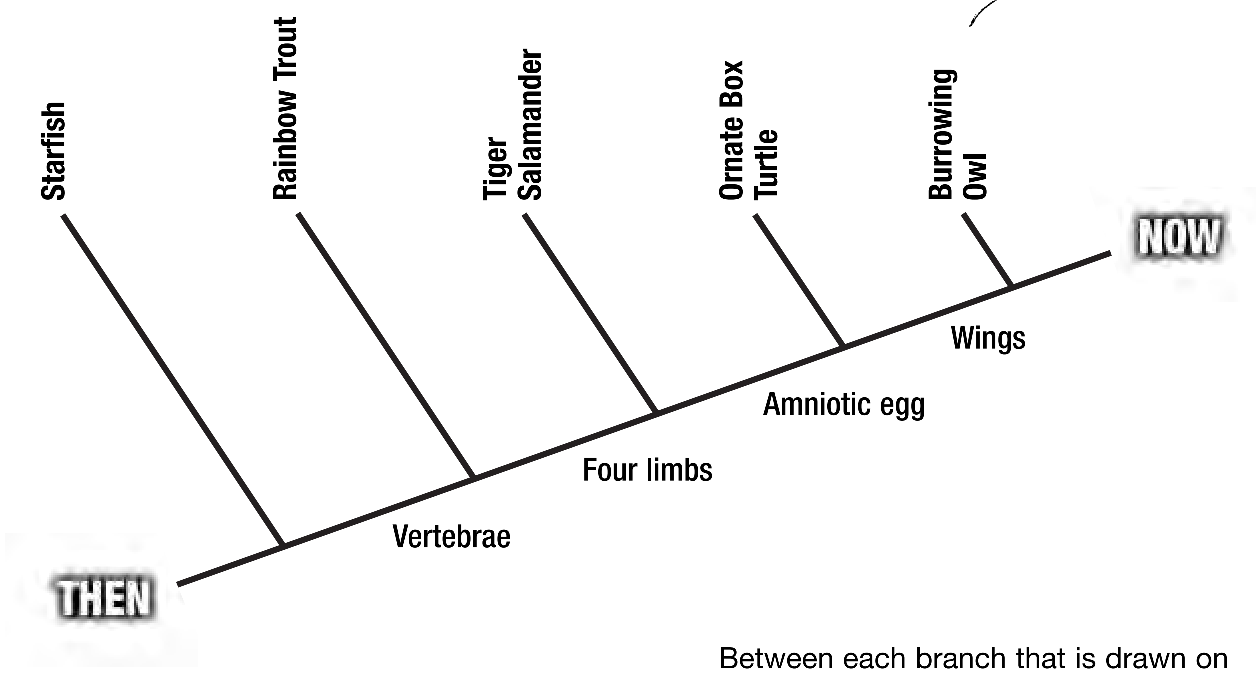
Cladograms convey comparative information about relationships. Organisms that are grouped more closely on a cladogram share a more recent common ancestor than those farther apart. Because the analysis is comparative, cladistic analysis deliberately includes an organism that is only distantly related to the other organisms. This distantly related organism is called an ***out-group***. The out-group serves as a base line for comparison with the other organisms being evaluated, the ***in-group***.

Construction A Cladogram

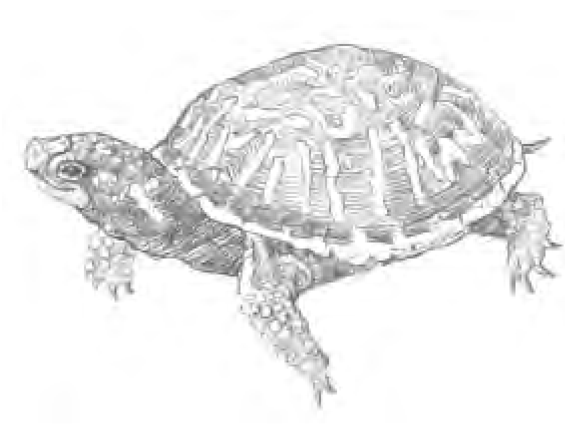
The first step in constructing a cladogram involves analyzing characters in a data table. The table below will be used to record whether characters are present or absent in several vertebrate species you have been studying. A non-vertebrate, or animal that doesn't have a backbone, will represent the out-group for our comparison. Notice that the all the traits in the column for the out-group are marked with a 0, which means that the animal does not have the character. If the organism has the new derived character, the column is marked with a 1.

Vertebrate Cladistic Analysis CHARACTER (Character Present = 1) (Character Absent = 0)	Starfish (Out-group)	Rainbow Trout	Tiger Salamander	Ornate Box Turtle	Burrowing Owl
Vertebrae or backbone	0	1	1	1	1
Four limbs	0	0	1	1	1
Embryo surrounded by water and enclosed within specialized membranes (amniotic egg)	0	0	0	1	1
Forelimbs function as wings	0	0	0	0	1

The second step is to draw a diagonal line. The bottom of the line represents the remote past. The top of the line is represents a more recent time. Each branch that is drawn from the diagonal line will represent a ***clade*** (group of organisms). Now, starting with a diagonal line to represent evolutionary time, the out-group (starfish) is placed on the lowest, “oldest” branch. All the in-group organisms will be found on the upper or more recent branches.

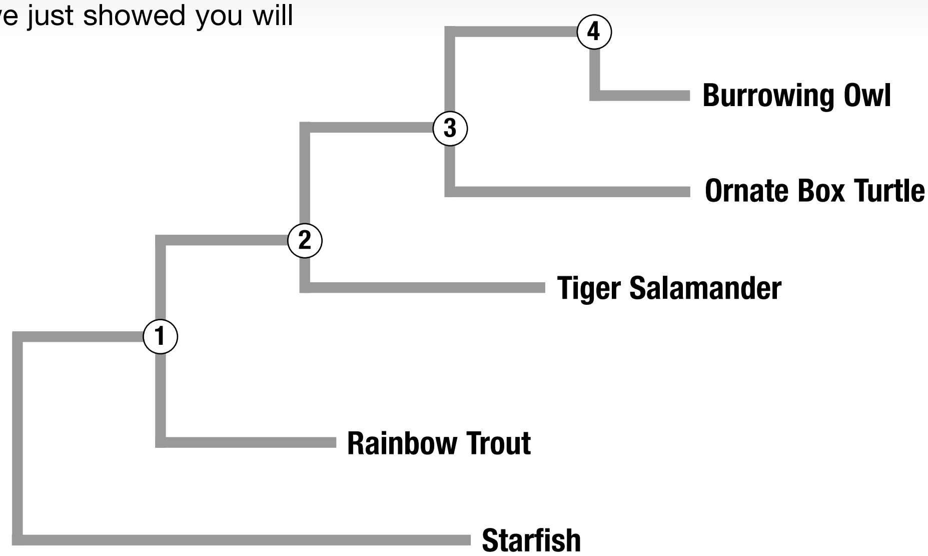


Between each branch that is drawn on the cladogram, a derived feature is listed. Just past the first branch, the most common derived character—having a backbone—is listed. Between the second and third branch, the next most common derived character—four limbs is listed, and so on. The clade that has the least common derived character, which is thought to be the character that most recently occurred, occupies the upper branch.

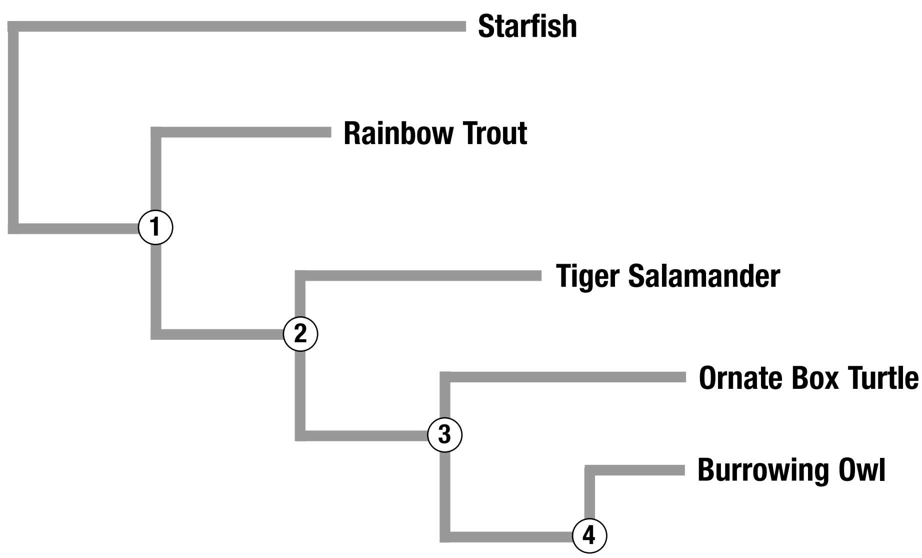


Please—Don't Let This Confuse You!

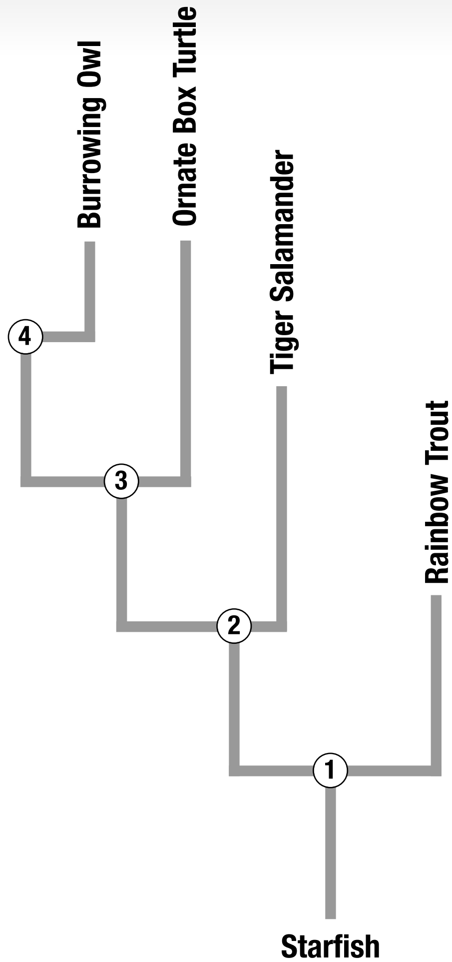
Cladistic analysis is a bit of a new thing and scientists haven't agreed on a format of presentation. So, sometimes a cladogram that represents the very same thing as the one we just showed you will look like this:

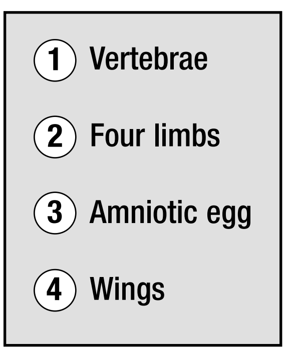


Or this:



Or this:





The reason we are showing you this now is because you will see all of these formats in magazines or newspapers and also in books, and some of the activities you will be doing. Think of this as a stretching exercise for your brain. It's important to have a flexible body and mind!

Lesson 4

Duration

One 45-minute class period

Vocabulary

*Ancestral characters**
Artiodactyls
Brachydont
Bunodont
Canines
Cannon bone
Carpals
*Character**
*Clades**
*Cladist**
*Cladistics**
*Cladogram**
*Derived characters**
Diastema
Digitigrade
Digits
Herbivorous
*Homologous structures**
Hypsodont
Incisors
*In-group**
Mesaxonic
Metacarpals
Metatarsals
Metapodials
Molars
*Monophyletic group**
*Out-group**
Paraxonic
Perissodactyls
*Phylogeny**
Plantigrade
Premolars
Ruminants
Selenodont
Stance
Tarsals
*Ungulate**
Unguligrade

Educator's Overview

Understanding Ungulate Phylogeny

Summary

Students use cladistics to determine the evolutionary history of nine groups of ungulates.

Learning Objectives

After completing this activity, students will be able to:

- Define cladistics and describe its use
- Read a cladogram and describe the information that it illustrates
- Sort through various characters of limb structure, tooth structure and dentition, form of stomach and type of horn and decide which characters are ancestral and which are derived
- Construct a cladogram that demonstrates the phylogeny of nine groups of ungulates
- Describe how cladistics is used to classify organisms into groups

Background

Systematics, a large field of biology that deals with the diversity of life, combines ***taxonomy*** and ***phylogenetics***, the study of the pattern of events that have led to the distribution and diversity of life. ***Cladistics*** is a system of analysis used by biologists to reconstruct the pattern of events that led to the distribution and diversity of life, both living and extinct. It was founded by Willi Hennig, a German entomologist in 1950, and in the past few decades has become the most commonly used method to examine evolutionary relationships of organisms.

Cladists, biologists who use cladistics, use the appearance of what they believe to be derived or newly evolved traits to assemble organisms into groupings—***taxa***—that appear to represent the evolutionary history of the species. All members of each natural group are thought to be ***monophyletic***, to have characteristics in common because they evolved from a common ancestor. These monophyletic taxa are called ***clades***. After looking at the various characters that different clades share, cladists create ***cladograms***, branching diagrams that represent a hypothesis about the order in which organisms evolved. They can then test their hypotheses about species relationships through DNA and rRNA sequencing, computer modeling and other techniques.

Cladistic hypotheses about the relationships of organisms can also be used to predict traits or characteristics of the organisms. For example, if biologists are searching for particular genes or biological compounds to improve crop yield or produce medicines, cladistics can help narrow the range of organisms that need to be examined. Cladistics can also be used to determine the genetic differences between different populations for species conservation plans or help predict resistance or vulnerability to disease in certain organisms.

Teaching Strategies

1. Thoroughly read the student materials for *Understanding Ungulate Phylogeny*.

2. Copy and post a list of the starred (*) vocabulary words in a highly visible place. These are the only words that students should be held accountable for defining.

3. Divide the class into groups of two to four students.

4. You may wish to have students read and complete *Understanding Ungulate Phylogeny* on their own. However, it is recommended that you review what cladograms portray and how they are constructed with your students. This review takes another look at the cladogram from Lesson 3, *Taxonomy through the Ages*. First review the data table construction with students. Emphasize that organisms that possess a trait receive a (1) in the table. If they lack that trait they receive a (0). Make sure that students notice that as new derived traits appear, all of the organisms "downstream" from this change also receive this new character from their ancestors.

5. After reviewing the vertebrate cladogram, students use these same procedures to generate a character table and cladogram for ungulates, hoofed mammals.

6. Students must first look at the *Table of Ungulate Characters* and answer some analysis questions. These questions will help students look at different characters in a way that will help them do their cladistic analysis.

7. The table *Ungulate Cladistic Analysis* is started for students and includes the one character that defines Artiodactyls, a type of ungulate. The character is paraxonic symmetry—having the symmetry of the foot pass between the third and fourth digit. Notice that when characters are assigned to the out-group (rhinos), the out-group possesses none of the characters of Artiodactyls. Having a group that possesses all (0) scores provides a place to "root" the phylogenetic tree or cladogram. Encourage students to assign characters to the table in a dichotomous fashion. That is, each character listed should include all of the remaining species with (1) scores except one.

8. After students complete this assignment, you may wish to have students share and defend their cladograms. Some students may complain that there are not enough characters listed in the table to completely—or easily—sort the species. You can recommend further research or discuss the difficulty in constructing cladograms. Remind students that cladograms represent testable hypotheses of

Materials and Preparation

- *Student Reading and Activity Pages from Lesson 3,* Taxonomy through the Ages*—retained by each student*
- *Student Reading and Activity Pages* Understanding Ungulate Phylogeny*—one per student*
- *Important vocabulary words, those with an *, posted in a visible place*

evolutionary relationships. Cladograms are just ideas that scientists have that they can test with other types of technology.

Assessment

Students' preparation and defense of their cladograms represent an assessment for this activity.

Extension

Pose the following situation to students: A protein called a prion is thought to be responsible for the group of diseases called transmissible spongiform encephalopathies (TSEs). The prion protein is a normal protein that has been found in most eukaryotic cells from yeast to humans. An abnormally shaped prion protein is associated with these deadly neurological diseases. Evidence indicates that abnormally shaped prion proteins can influence normal prion molecules to assume the same abnormal shape. Evidence also shows that the abnormal prions that cause TSEs have appeared to be of different "strains" that can affect the prions of some species, but not others. The relatedness of certain species may influence the frequency of transmission of prion diseases from one species to another.

The artiodactyl family Bovidae currently contains gazelles, sheep, musk oxen, goats, cattle and bison. Scrapie, the prion disease in sheep, has been recognized since the 18th century. It is believed that the prion disease in cattle, bovine spongiform encephalopathy (BSE), may have appeared after cattle were fed meat and bone meal containing sheep meat with scrapie in the 1950s. How could a biologist use a cladogram to help design a testable hypothesis regarding transmission of scrapie to cattle and other ungulate species? What types of technology would be necessary to test this type of hypothesis? ***Cladograms are used to hypothesize the evolutionary relatedness of species. The artiodactyls in the same clade should be the most similar and might have a greater potential to transmit disease between species. Biologists would need to extract prion protein from the species thought most closely related and do DNA or RNA sequencing to check to see if the prions were indeed similar.***

Key: Analysis Questions

1. How does the number of toes differ between the rhinoceros and other ungulate groups in the table? ***Rhinos have three (an odd number of) toes while the other ungulates have two or four toes. Also, rhinos are mesaxonic and all others are paraxonic. Therefore, rhinos are perisso-dactyls and all others are artiodactyls.***

2. Which character is ancestral in the "Stomach" column, and which seems to be most recently derived? ***A simple, 1-chambered "gut" is ancestral (it's a character of the out-group, the rhino), while the complex 4-chambered, rumi-nating "gut" is the most recently derived.***

3. Which families could be regarded as "true ruminants"? ***According to the table, "true ruminants" with complex 4-chambered, ruminating "gut" would include Antilocapridae (pronghorn), Giraffidae (giraffe), Bovidae (sheep, musk ox, cattle, goat, bison), and Cervidae (deer, elk, reindeer).***

4. Place the families in order according to increasing complexity of the stomach. ***Rhino (Rhinocerotidae), pigs (Suidae), hippo (Hippopotamidae), camel (Camelidae), mouse deer (Tragulidae), pronghorn (Antilocarpidae), giraffe (Giraffidae), cattle (Bovidae), deer (Cervidae) in any order.***

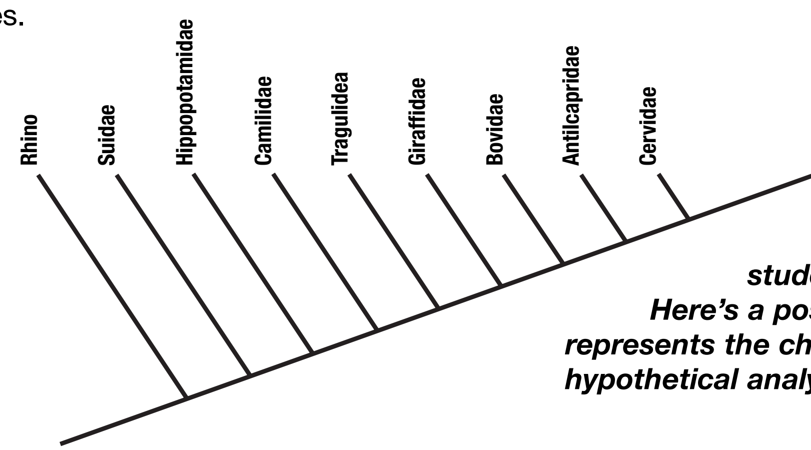
5. What other structures do those families with the most complex stomachs share? ***They share the characters: paraxonic, cannon bone, unguligrade, no upper incisors, long diastema, and bony horns or antlers.***

6. Below is a table "Ungulate Cladistic Analysis." The characters that you choose for your table should separate one family or group from those that remain. To get you started, the first character has been placed in the table for you. If quite a few characteristics separate the remaining members choose only one of those on your table. Choose the character that you believe provides the greatest advantage for survival. ***Tables will vary depending on the characters chosen. The data that fill the table should have a pattern similar to Character Table 1 with lines exchanged according to the species list. Any table that a student can defensibly demonstrate dichotomous characters separating clades is acceptable. Here's an example of a beginning of a possible table:***

8. Would a cladogram based upon DNA sequence data be similar to the one that you just constructed? ***Probably.*** Explain why or why not. ***DNA carries the code for proteins that make structures, so any changes in DNA could also change structures coded by DNA.***

Ungulate Cladistic Analysis — CHARACTERS	Rhino (Out-group)	Suidae	Hippopotamidae	Camilidae	Tragulidea	Giraffidae	Bovidae	Antilcapridae	Cervidae
Paraxonic	0	1	1	1	1	1	1	1	1
3 or 4 Chambered Gut	0	0	1	1	1	1	1	1	1
Ruminating Gut	0	0	0	1	1	1	1	1	1
Completely Fused Cannon Bone	0	0	0	0	1	1	1	1	1
Bony Horns or Antlers	0	0	0	0	0	1	1	1	1
Hypsodont Cheek Teeth	0	0	0	0	0	0	1	1	1
Horn Sheath or Antlers Shed Annually	0	0	0	0	0	0	0	1	1
Antlers	0	0	0	0	0	0	0	0	1

7. Use the data from the character table to construct a cladogram of Artiodactyl ungulates.



Depending upon the characters chosen in their analysis table, student cladograms will vary. Here's a possible cladogram that represents the characters chosen in the hypothetical analysis table above.

Lesson 4

Student Pages

Understanding Ungulate Phylogeny

Wow! The title of this lesson may seem a bit intimidating. Resist the urge to raise your hand and ask for a pass to the restroom, the nurse, or whatever. This really isn't going to be too difficult. Keep in mind that scientists have a language of their own. They are not trying to confuse anyone. Just the opposite, scientists use all these crazy sounding big words to communicate accurately. Usually, many scientific terms are built from words of "dead" languages—like Latin. Since no one speaks Latin anymore, the meaning of Latin words does not change. If scientists just used plain ol' American, there's a chance they could be misunderstood. In "living" languages, the meaning of words can change over time. For example, think of how your grandparents might have defined the words "tight," "hit," or "cool" when they were your age. How many different meanings can you think of for these three simple words? Then, there are those brand new words, like "blog" or "podcast." You can see why these funky scientific terms are necessary.

Which Came First?

To speed things up, all the tough words in this lesson are going to be translated for you. Let's start with the title. If you recall Lesson 3—and you probably remember that lesson as clearly as you remember what you had for breakfast this morning—the word ***phylogeny*** means an organism's evolutionary history. An ***ungulate*** is a hoofed mammal. So, in this lesson, you will be trying to figure out which came first, the camel or the pig? Or was it the giraffe or the cow? Or possibly, could it have been the elk or the hippopotamus?

In order to answer these questions, you need to use cladistics. Your razor-sharp memory may recollect from the last lesson that ***cladistics*** is a method of analysis that biologists use to reconstruct the evolutionary history of organisms. That is, biologists use cladistics to reconstruct the pattern of events that have led to the diversity of life, both living and extinct. You will need to sort through all the various ***characters*** (physical features) of these hoofed animals and determine which features are older (***ancestral***) and which are more recent (***derived***).

Another Big Word And A Quick Review

A basic assumption of cladistics is that *the greater the number of* ***shared derived characters*** *between two species or groups, the more recent their common ancestor and* ***the more closely they are related.*** In other words, the more similar two organisms are, the more closely related they are. Organs and body parts that are alike in structure and origin are said to be ***homologous structures***. For example, the front legs of an elephant, the wings of a bird, the flippers on a sea lion, and the arms of a human are all homologous to each other. Each represents a version of forelimbs. When different organisms share a large number of homologous structures, it is considered strong evidence that they are related to each other. These related organisms are thought to have had a common ancestor at some time in the past.

Let's re-examine the cladogram of the vertebrates found in Lesson 3 to be sure you understand how cladograms are made. A ***cladogram*** is a diagram that represents a hypothesis of the sequence in which new species evolved. Ancestral traits are found among more groups of organisms. Fewer groups of organisms share derived traits that appeared more recently.

Notice the first branching point of the cladogram. The organism that represents the first branch is one that doesn't share the common ancestral characteristic—it is the ***out-group***. The starfish does not have a backbone, the commonly shared ancestral trait. Each group of organisms that represent the branches that follow has a backbone—they are part of the ***in-group***.

Now this next statement is really important so this author is going to put it in ***BOLD ITALICS*** so that you will know just how important it is.

As further new characters appear, each descendant group or clade possesses the new derived character AND all of the ancestral characters of its ancestors.

In other words, the tiger salamander has the new derived character—four limbs—and a backbone. The ornate box turtle has the new derived character—an amniotic egg—and four limbs and a backbone. You get the picture.

Not All Features Are Created Equal

When you compare all of the characters that each ungulate has, keep in mind that not all features are equally important in determining evolutionary relationships. If every single animal shares a feature, it may not be all that useful for tracing ancestry. For example, a two-opening gut (with a mouth at one end and an anus at the other) is an ancestral character. Nearly all animals have a two-opening gut—from cockroaches to fish to humans. This feature cannot tell us much about the relatedness of these species.

The features that are most helpful in figuring out a species' ancestry are newer modifications of older traits—***derived characters***. For example, many animals have ***digits*** (fingers or toes) on their forelimbs, but only humans, apes and monkeys have opposable thumbs. No other animals have this feature. ***Cladists*** (biologists who practice cladistics) try to identify branching points where characteristics like this first appear to determine species' family trees or lines of descent. Then they group the species—humans, apes, and monkeys—which share the derived character of opposable thumbs into a ***clade***—a group believed related by common origin. Clades are ***monophyletic groups***, meaning they have one (mono) common ancestor.

Lots Of Big Words And One Guarantee

First, the bad news—there's a ton of big scientific words in this next part. The good news is that these words are not ones you need to memorize. Your teacher has signed a statement guaranteeing that

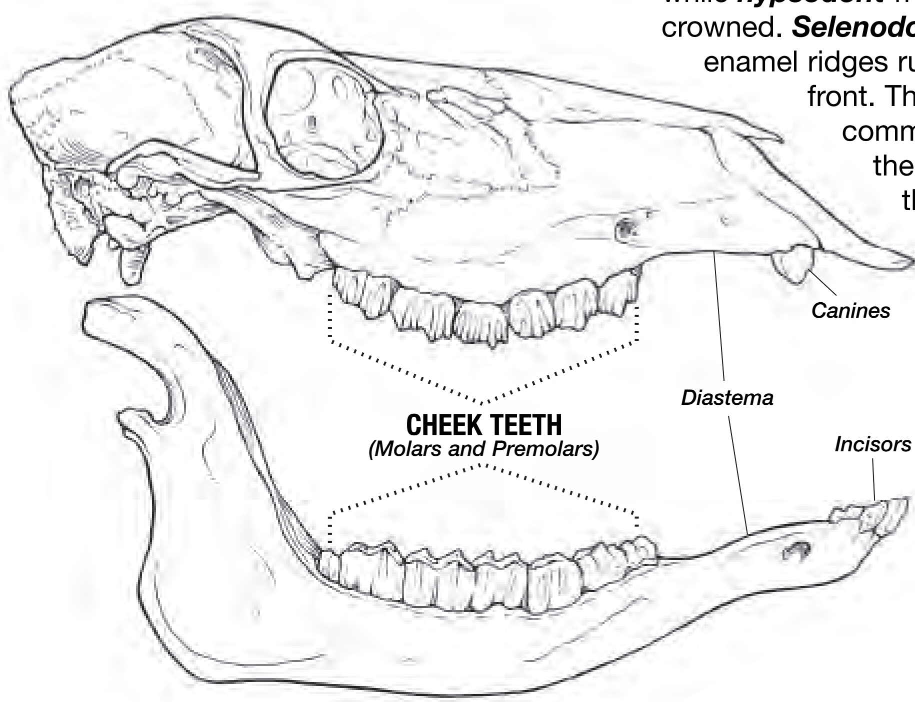
you will not be tested on the meanings of these words. The scientific names of all the ungulate characters are just explained so that you can fill out a table and draw a cladogram. Of course, if you want to impress your friends and relatives by actually learning these words, go right ahead.

Starting At The Top

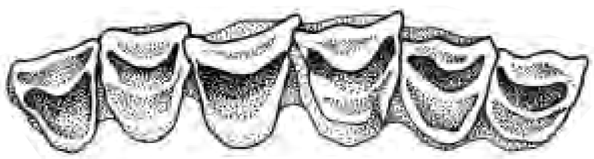
Mammals require a greater amount of food than most other animals to support a higher body temperature and provide energy for the development and growth of young. Adaptations that increase efficiency in finding, eating, and digesting food are important for survival. Ungulates are no exception. Most have specialized stomachs and teeth, adaptations that allow them to extract the most energy from their food source.

Ungulates are ***herbivorous***—plant eaters. While most animals lack the digestive enzymes needed to break down the large amounts of cellulose found in plants, some ungulates have modified guts with multiple chambers which allow them to get the most nutrition from their food. The first chamber acts as a fermentation vat where microorganisms break down the plant fibers and cellulose. This partially digested food is regurgitated back into the mouth, chewed again, re-swallowed into the second chamber of the gut, and then passed to the third and fourth gut sections which further digest the food. Ungulates that possess these complex "stomachs" are called ***ruminants***.

Teeth also are important in digestion. Although all vertebrates except turtles and birds have teeth, the teeth of mammals are the most specialized. Tooth structure is important for studying mammalian phylogeny and the process and pattern of evolution. ***Premolars*** and ***molars*** are cheek teeth and come in various sizes and shapes to help ruminants grind their food. Premolars are usually simpler and smaller than the molars at the rear of the mouth. ***Brachydont*** molars are low-crowned, while ***hypsodont*** molars are high crowned. ***Selenodont*** molars have hard enamel ridges running from back to front. This type of molar is common in grazers because these hard ridges increase the number and size of cutting surfaces in the mouth. Animals with a more varied diet usually have ***bunodont*** teeth that are squarish with low rounded cusps, like human molars.



Incisors are typically found at the front of the mouth and are used for grasping, picking up, or biting off food. The incisors may be followed by a toothless gap called a ***diastema***. ***Canines*** are most often used for stabbing and holding prey. Males typically have larger canines than females in species that use their canine teeth as weapons for social displays or fighting. Herbivorous species that do not capture prey may have smaller canines or lack them altogether.

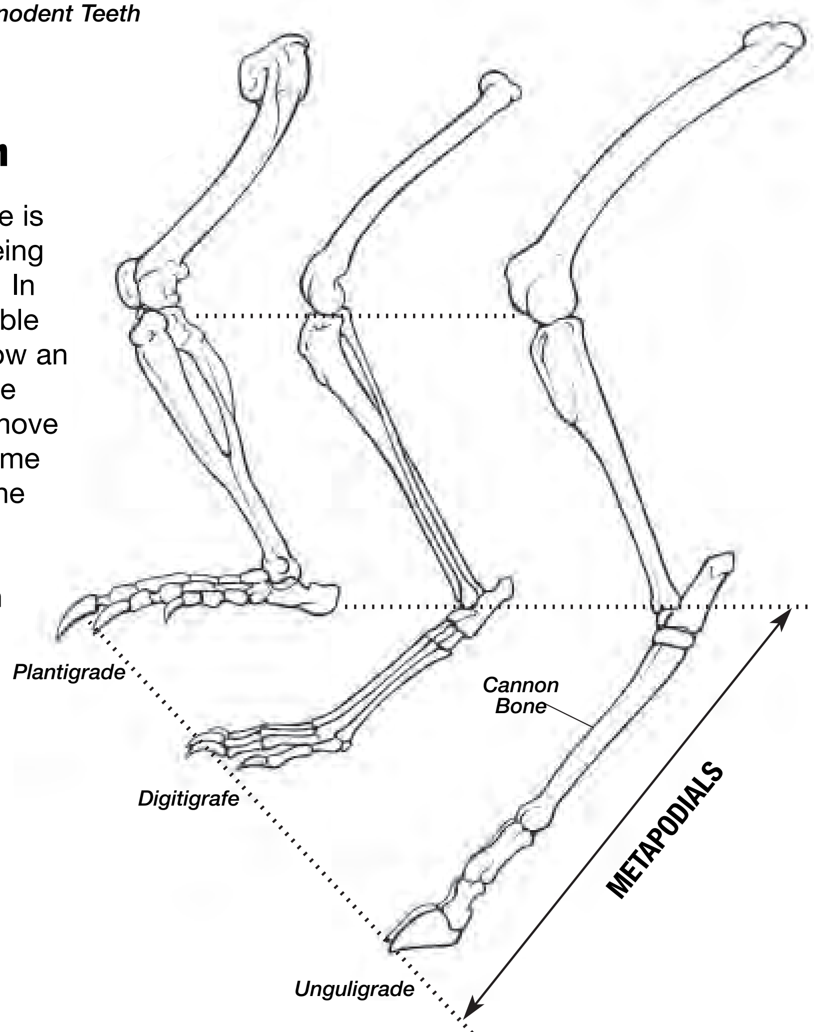


Selenodent Teeth

Like us humans, the earliest mammals had five digits on each limb. Digits are numbered 1 (thumb, big toe) to 5 ("little" finger). The bones in our fingers (***carpals***) and toes (***tarsals***) are attached to the bones in our hand (***metacarpals***) and foot (***metatarsals***). Metacarpals and metatarsals are also called ***metapodials***. In ungulates, the 3rd and 4th metapodials may be fused to form a single, stronger ***cannon bone***. Walking on tiptoes, lengthening metapodials or reducing their numbers, and reducing the number of digits are adaptations for increasing stride length and speed while reducing effort and increasing endurance in locomotion.

Moving To The Bottom

Another important feature is the ability to escape from being eaten by some other animal. In other words, it helps to be able to run really fast. ***Stance***, how an animal stands, can determine how quickly an animal can move while walking or running. Some species like humans place the full length of the foot on the ground during their stride (***plantigrade***), some walk on the length of their digits like dogs (***digitigrade***), and others walk on their tiptoes like deer (***unguligrade***). An unguligrade stance helps to increase stride length and speed. Hoofs hardened with the protein keratin help ungulates walk with their full weight on their toes.



The number of digits or toes divides ungulates into two orders, Perissodactyla and Artiodactyla. ***Perissodactyls*** are odd-toed ungulates having either one or three weight bearing toes. Perissodactyls are ***mesaxonic***, the line of symmetry passes through their center toe—which is enlarged and bears most of the weight. ***Artiodactyls*** are even-toed ungulates with two or four toes. Artiodactyl have lost the first digit on each limb making them ***paraxonic***—the line of symmetry passes between the two centermost toes and bears the body's weight.

The Ungulate Cladogram

Use the information in the Table of Ungulate Structures to answer the following questions. The answers to the questions may help you decide which characters are ancestral and derived. Just like a real cladist, you will need to determine which characters are shared among the greatest number of groups. Then, construct a cladogram for the eight families of ungulates. The rhinoceros (Family Rhinocerotidae) will be the out-group. Rhinos have three toes on each foot and are considered perissodactyls. Scientists believe that rhinos shared a common ancestor with ancestral artio-dactyls some 83 million years ago.

Analysis Questions

1. How does the number of toes differ between the rhinoceros and other ungulate groups in the table?

2. Which character is ancestral in the "Stomach" column, and which seems to be most recently derived?

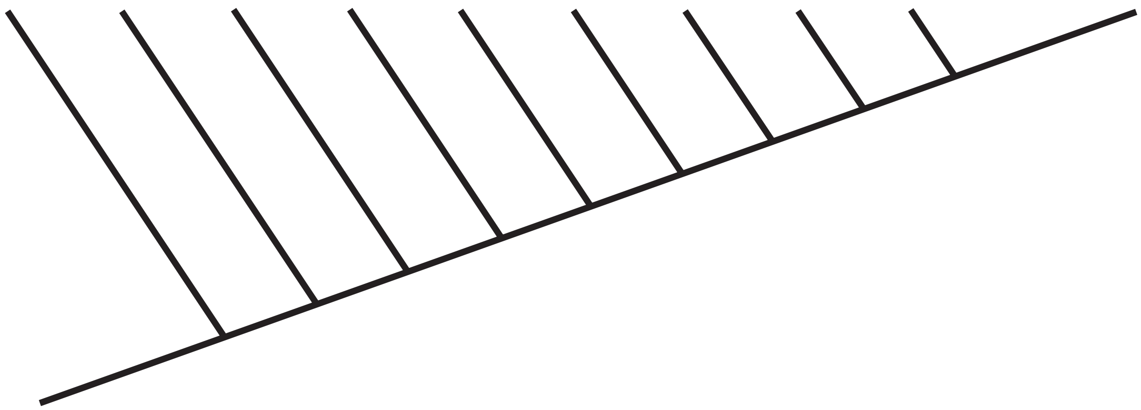
4. Place the families in order according to increasing complexity of the stomach.

5. What other structures do those families with the most complex stomachs share?

6. Below is a table "Ungulate Cladistic Analysis." The characters that you choose for your table should separate one family or group from those that remain. To get you started, the first character has been placed in the table for you. If quite a few characteristics separate the remaining members choose only one of those on your table. Choose the character that you believe provides the greatest advantage for survival.

Ungulate Cladistic Analysis CHARACTERS	Rhino (Out-group)								
Paraxonic	0								

7. Use the data from the character table to construct a cladogram of Artiodactyl ungulates.



8. Would a cladogram based upon DNA sequence data be similar to the one that you just constructed? ________________

Explain why or why not.

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TABLE OF UNGULATE CHARACTERS

Family (members)	Rhinocerotidae (rhinoceros) [Out-group]	Camelidae (camels, llamas)	Hippopotamidae (hippopotamus)	Antilocapridae (pronghorn antelope)	Giraffidae (giraffe, okapis)	Tragulidae (mouse deer, chevrotain)	Bovidae (gazelle, sheep, musk ox, goat, cattle, bison)	Suidae (pigs, hogs)	Cervidae (deer, rein-deer, elk)
Number of Toes	3	4	4	2	2	4	4	4	4
Foot Structure/ Symmetry	Mesaxonic	Paraxonic	Paraxonic	Paraxonic	Paraxonic	Paraxonic	Paraxonic	Paraxonic	Paraxonic
3rd and 4th Metopodials Fused into Cannon Bone?	No	Yes, Partially fused y-shaped	No	Yes	Yes	Yes	Yes	No	Yes
Stride	Digitigrade	Digitigrade	Digitigrade	Unguligrade	Unguligrade	Unguligrade	Unguligrade	Unguligrade	Unguligrade
Upper Incisors	No	Yes	Yes	No	No	No	No	Yes	No
Upper Canines	No	Yes	Yes	No	No	Yes	No	Yes	No
Lower Incisors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lower Canines	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes
Cheek Teeth	Mostly Brachydont	Selenodont	Brachydont & Bunodont	Hypsodont & Selenodont	Brachydont & Selenodont	Selenodont	Hypsodont & Selenodont	Brachydont & Bunodont	Hypsodont & Selenodont
Diastema Length	Short	Long	Short	Long	Long	Long	Long	Short	Long
Gut	Simple 1-chambered; nonruminating	3-chambered; ruminating	3-chambered; nonruminating	4-chambered; ruminating	4-chambered; ruminating	3-chambered ruminating; a 4th chamber is poorly developed	4-chambered; ruminating	2-chambered; nonruminating	4-chambered; ruminating
Horns with Bony Core or Antlers?	Horns of keratin (same stuff as human hair and fingernails), no boney core	No	No	Keratin horn sheath is shed annually	Keratin horn sheath with boney core, not shed	No	Keratin horn sheath with boney core, not shed	No	Antlers, shed annually

Lesson 5

Educator's Overview

The Pocket Gopher Cladogram Conundrum

Summary

Using the principle of parsimony, students use morphological characteristics and differences in DNA sequences to determine the most likely cladogram to represent the phylogenetic (evolutionary) relationship of four closely related species of pocket gopher.

Duration

One or two 45-minute class periods

Vocabulary

Analogous character

Ancestral character

Character state

Convergent evolution

Derived character

Evolutionary systematics

Homologous character

Parsimony

Phylogenetic tree

Phylogeny

Learning Objectives

After completing this activity, students will be able to:

- State the principle of parsimony and describe how it is applied in cladistic analysis.
- Choose six characters that may be important to the survival of pocket gophers and use these characters to construct a character table for four species of pocket gopher.
- Evaluate three hypothetical cladograms based on morphological characters and select the one that most likely represents the phylogeny of four species of pocket gophers using the principal of parsimony.
- Distinguish between a cladogram and a phylogenetic tree.
- Evaluate three hypothetical cladograms based on DNA sequences and select the one that most likely represents the phylogeny of four species of pocket gophers using the principal of parsimony.

Background

Cladistic analysis is based on the assumption that life arose on Earth only once. All the diversity of life that now exists on Earth is thought to have been produced through the reproduction of existing organisms. In other words, just as your students had to have been born from parents, and they have had to have had parents (grandparents), all organisms have ancestors. If the evolutionary history, or ***phylogeny***, of an organism is traced back, it connects through shared ancestors to lineages of other organisms.

That all life is connected in an immense phylogenetic tree is one of the most significant discoveries of the past 150 years. Often, evolutionary relationships between species are difficult to figure out. This lesson discusses how the principle of ***parsimony***—that any hypothesis that requires fewer assumptions is a more defensible hypothesis—is used to determine which cladogram hypothesis most likely represents the phylogeny of any group of organisms.

Teaching Strategies

1. Thoroughly read the student materials for *The Pocket Gopher Cladogram Conundrum*.

2. Divide the class into groups of two to four students.

3. Give each student a copy of the *The Pocket Gopher Cladogram Conundrum*, Pocket Gophers of Colorado, and Characters of Colorado Pocket Gophers.

4. Introduce the idea of parsimony—that the hypothesis with the least assumptions is usually the easiest to defend. You can tell students this is the "KISS" rule (Keep It Simple, Silly) of science.

5. You may wish to work through the example of parsimony given in the student pages as a class. You may need to review the form of the cladogram—that each branch represents a different lineage.

6. When you are convinced that students understand parsimony and how to apply the principal to evaluate conflicting cladograms, have students work in small groups to complete the activity.

7. After student groups have completed the activity, ask groups to present their data table and show how they used the principal of parsimony to decide which of the three hypothetical cladograms best represent pocket gopher phylogeny based on the characters that they selected. Allow the rest of the class to ask questions and comment on the choices.

Assessment

Student ability to evaluate three hypothetical cladograms based on physical characters and DNA sequences, select the one that most likely represents the phylogeny of four species of pocket gophers, and defend their selection using the principle of parsimony serves as an assessment for this activity.

Extension

Student groups can exchange papers and try to follow the logic of other groups. They can comment on the selection of characters. Students can then compare the class results and discuss whether any particular cladogram was most useful in representing the evolutionary relationships of pocket gophers.

Key

1. Look at the table *Characters of Colorado Pocket Gophers* again. Looking at the characters that have been provided and the characters you observed, choose six characters that you believe might have the most impact on the day to day survival and reproduction of the four species of pocket gopher. Explain why you believe the six characters that you selected would help a pocket gopher adapt to its environment. ***Answers will vary.***

Materials and Preparation

- *Student Reading and Activity Pages for* The Pocket Gopher Cladogram Conundrum—*one photocopy per student*
- *Student Page* Pocket Gophers of Colorado—*one photocopy per student*
- *Student Page* Characters of Colorado Pocket Gophers—*one photocopy per student*

2. Place the six characters in the table below and indicate the "state" for the character for each species. ***Answers will vary.***

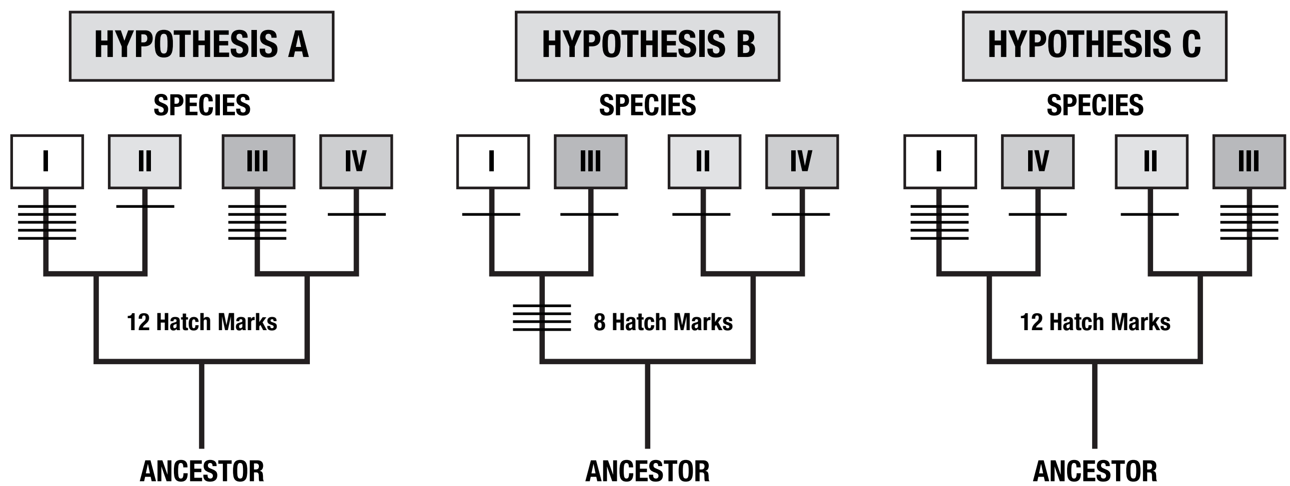
3. Now look at the three hypothetical cladograms again. Taking one character from your table at a time, determine where a character state change would have to occur to produce each species. Make a hatch mark at each position on each hypothetical cladogram to indicate every character state change. ***Answers will vary.***

4. Which hypothesis most likely explains the phylogenetic history of these pocket gopher species using the six characters that you selected? Explain your reasoning. ***Answers will vary.***

5. What other types of characters, besides external appearance, could be used to construct a data table and a cladogram? *(Hint: Think about Lesson 2,* Birds of a Feather?*)* ***Answers will vary but may include internal anatomical features, embryological similarities and differences, DNA, rRNA, or protein sequence data, and behavioral differences.***

6. Which cladogram most likely explains the evolutionary relationships of these gopher species? ***B*** Explain your answer. ***Using the concept of parsimony, this hypothesis produces the gopher species with the least number of changes (8 hatch marks) based upon DNA differences.***

Cladograms Based Upon DNA Sequences



7. Is it possible to have character data support a different hypothesis than the DNA data? ***Yes.*** Explain your answer. ***The hypothesis supported may depend upon which characters or DNA sequences are used.***

8. Once the most likely cladogram has been determined for related species, this information could be used to make predictions about species. For instance, if a disease strikes gopher species I but not gopher species III, what would you predict about the resistance of gopher species II and IV to this same disease? ***Gopher species I and IV are closely related, so species IV is also likely***

to be affected by the disease. Gopher species II and III are more closely related, so species II is most likely to be resistant to the disease.

9. How are morphological characters and DNA sequence data related? ***DNA codes for the different characters of an organism.***

10. The scientific names of the four gopher species are given below.

Species I—northern pocket gopher (*Thomomys talpoides*)
Species II—plains pocket gopher (*Geomys bursarius*)
Species III—Botta's pocket gopher (*Thomomys bottae*)
Species IV—yellow-faced pocket gopher (*Pappogeomys castanops*)

What do the scientific names of these pocket gopher species imply regarding their phylogenetic relationships? ***Species I and III belong to the same genus (Thomomys), so they must be more closely related to each other.***

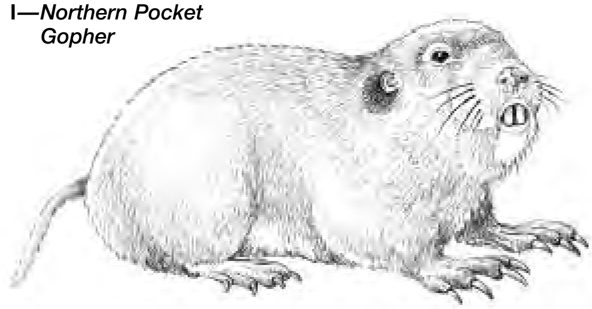
11. As more DNA sequences are accumulated, researchers gain better understanding of the phylogenetic relationships of organisms and may reassign the classification groups that organisms have previously been assigned. Which classification groups are more likely to be changed, a general grouping (like kingdom or phylum), a specific grouping (like genus or species), or an intermediate grouping (like orders or families) as DNA data on species are evaluated? ***Any answer with support should be accepted because reassignment of classification categories is occurring at all taxonomic levels.***

Notes

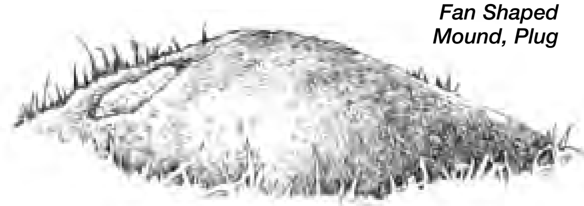
Student Page

Pocket Gophers Of Colorado

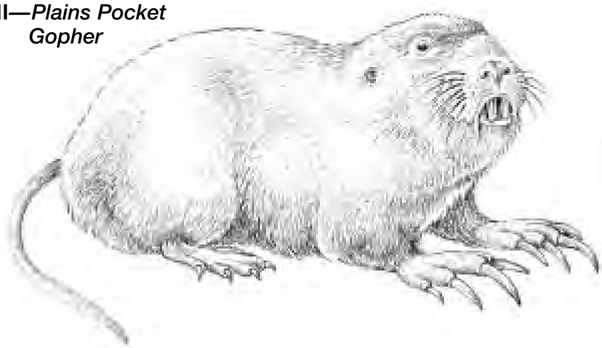
I—*Northern Pocket Gopher*



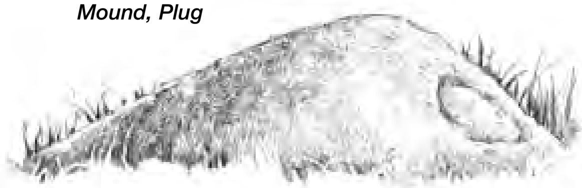
Fan Shaped Mound, Plug



II—*Plains Pocket Gopher*

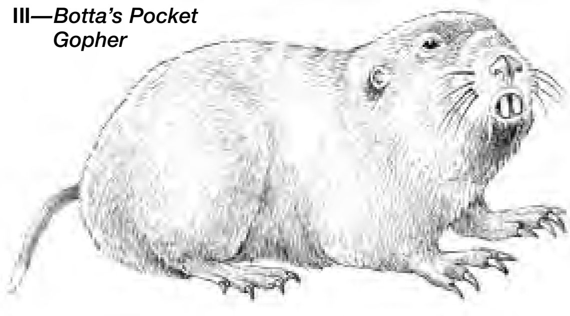


High, Fan Shaped Mound, Plug

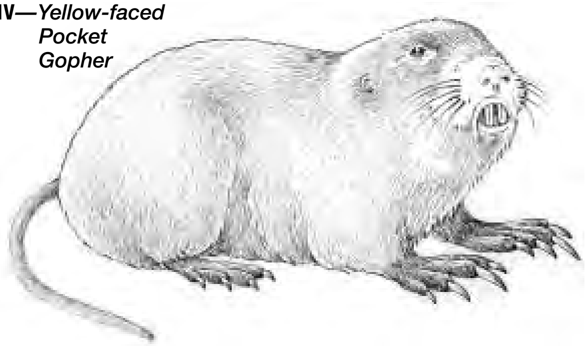


Mound Beneath Bushes, Large, Fan Shaped Mound, Plug

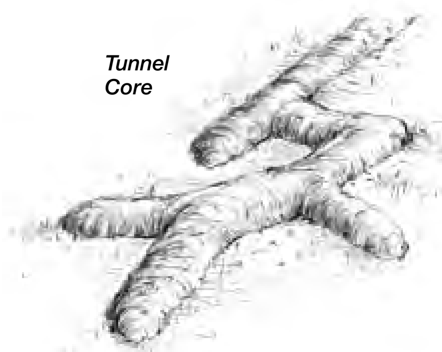
III—*Botta's Pocket Gopher*



IV—*Yellow-faced Pocket Gopher*



Tunnel Core



Student Page

Characters Of Colorado Pocket Gophers

Characters Of Colorado Pocket Gophers	I—Northern Pocket Gopher	II—Plains Pocket Gopher	III—Botta's Pocket Gopher	IV—Yellow-faced Pocket Gopher
Total Length	165–250 mm	180–300 mm	200–260 mm	245–300 mm
Tail Length	45–75 mm	50–90 mm	60–85 mm	68–80 mm
Hindfoot Length	25–31 mm	30–36 mm	28–33 mm	34–40 mm
Ear Length	5–7 mm	3–5 mm	5–7 mm	<7 mm
Weight	100–150 grams	170–330 grams	110–215 grams	160–350 grams
Body Color (Dorsal or Back)	Dark brown or yellowish brown to grayish yellow; black patch behind ears	Pale brown to yellowish-brown	Yellowish to reddish brown	Reddish brown
Body Color (Ventral or Belly)	Whitish	Slightly paler than dorsal	Slightly paler than dorsal	Buffy
Foot Color	Whitish	White	Whitish	Blackish
Frontal Grooves on Incisors	None	2	None	1
Mammae	10	6	8	6
Shape of Entrance Mound	Fan shaped mound, plug	High fan shaped mound, plug	Fan shaped mound, plug	Mound beneath bushes, large, fan shaped, plug
Tunnel Cores?	Yes	No	Yes	No
Eye Size Observations:				
Limb and Claw: Observations:				
Other Observations:				

Student Pages

The Pocket Gopher Cladogram Conundrum

co•nun•drum (k -n n'dr m) *n*. [Orig. unknown.] **1.** A riddle in which a fanciful question is answered by a pun. **2. a.** A problem with no satisfactory solution. **b.** A complicated problem.

Webster's II New College Dictionary, ©1995 Houghton Mifflin Company

In case you are wondering what this lesson is about, look at Webster's definition "2.b." for conundrum. Life can be a challenge, and it is certainly a challenge to figure out life—the diversity of life. As tricky as it might be to sort out evolutionary relationships of organisms that have very different features, such as hippopotamuses and giraffes, it really gets difficult when the animals look nearly alike. Usually, a biologist has to start out with several predictions—hypotheses—and then choose the best one based on the most evidence.

Constructing a cladogram is the first step in figuring out an organism's phylogeny. Every cladogram represents a hypothesis—a possible answer to the questions "How are these organisms related?" and "How might this group of taxa have evolved from a single common ancestor?" When relationships of very similar species are in question, biologists put together many different cladograms and then look at morphological and genetic evidence to form an argument for or against each hypothesis.

First Steps

To put together and sort through several hypothetical cladograms for a group of similar organisms, cladists construct different possible cladograms using the steps you are already familiar with. *First, they determine some observable characters (traits) and note their "states."* A ***character state*** is one of two or more possible forms for that character. For example, for a character "wings," the possible states may be "present" and "absent." For the character "number of digits," possible states may be 1, 2, 3, 4, or 5.

The next step is to determine which character states are ancestral and which are derived. Usually, this is done by comparing the group of organisms (in-group) with a more distantly related organism, the out-group. If the character has only two states, then the task of distinguishing ancestral and derived character states is fairly simple: The character state which is in the out-group is ***ancestral*** and the one found only in the in-group is ***derived***. For example, if the organism in the out-group does not have wings, and all the organisms in the in-group do have wings, then wings are the derived character state.

It can be a little more difficult to determine which character state is ancestral or derived when there are many possible states. Let's consider the character "digit" as an example. On the following page is a group of mammals listed with the number of digits for each:

Mammal	Number of Digits (fingers or digits)
Human	5
Horse	1
Cow	4
Rhinoceros	3
Giraffe	2

If scientists compare this group of mammals with some out-group of terrestrial vertebrates—maybe crocodiles, turtles, or frogs—they can see that animals in these out-groups also have 5 digits on each limbs, so “5 digits” must be the ancestral character state.

More To Think About

This brings up a problem, and it is not just which character state—1, 2, 3, or 4—comes next. Clearly, humans have more in common with horses and giraffes than they do with crocodiles and frogs. Humans have retained the ancestral character of “5 digits” while the other mammals in this list have not. This character may not be very valuable for constructing a cladogram for these species.

Cladistics assumes that organisms that are more similar to one another than they are to other organisms are more closely related. However, inferring relationships from similarities can be misleading. Not all ***homologous characters***—those inherited from a common ancestor—look similar. In Lesson 4, the various forelimbs of vertebrates, such as wings, flippers, arms, and legs, were examples of homologous features that did not look alike.

Also, just because characters or features look similar does not mean they are homologous. The flippers of whales and dolphins look like and function like the pectoral fins of sharks. These body parts resemble each other because whales, dolphins, and sharks live in the same environment and all need to be effective swimmers to obtain food and survive. The paddle-like flippers of whales and dolphins are highly modified hand bones, with five finger bones. The shark’s pectoral fins are supported by cartilage. Another example would be the wings of a bird or the wings of an insect. Both enable flight, but the structure and origin of the two kinds of wings differ. Through the process called ***convergent evolution***, similarities evolve in organisms not closely related to one another, usually because they live in similar habitat and have a similar way of life. Similarities that arise through convergent evolution are called ***analogous characters***.

This takes us to the third step. *To accomplish the task of creating plausible cladograms, cladists must use good judgment.* Good judgments are based on asking good questions. Are characters chosen well? Should other or additional characters be considered? Could a supposed shared derived character (similarity inherited from a common ancestor) be the result of independent evolutionary development (convergent evolution)?

Last Steps

After the cladist has finally decided which characters to use, he or she moves on to *the fourth step; building the data table of characters.* When the data leads to several possible cladograms, scientists choose the most “parsimonious” cladogram. *Using parsimony to evaluate conflicting cladograms is the fifth and final step.*

The rule of ***parsimony*** is that any hypothesis that requires fewer assumptions is a more defensible hypothesis. What this means is that the cladogram that had the least number of changes in character states is the most logical. In other words, the best cladogram is the one that minimizes the number of times a feature must be assumed to have arisen or disappeared.

Speaking of assumptions, this author thinks you may need to see an example of choosing between cladograms using parsimony to make sense of this. So, we'll get to that pretty soon. First, you need to know a thing or two about pocket gophers.

Colorado's Pocket Gophers

You should have in your possession two important pages: ***Pocket Gophers of Colorado*** and ***Characters of Colorado Pocket Gophers***. Take a look at the pictures on the page: Pocket Gophers of Colorado. The pictures show Colorado's four species of pocket gopher and some evidence that one could find that they live in a certain habitat. These rat-sized rodents are named for the external, fur-lined storage pouches on each cheek. Pocket gophers are well-suited for life underground. Rarely seen, they excavate extensive underground tunnel systems with numerous forks and special side branches for stockpiling food, nesting, and storing feces. They have short tails, tiny eyes, dinky ears, and strong front legs with claws for digging. Their lips close behind their ever-growing incisors, so gophers can dig with their teeth without getting a mouthful of soil.

As a pocket gopher digs, it pushes soil behind itself. When enough loose material accumulates, the gopher turns around and shoves the dirt up to the surface with its chin and forefeet. The expelled dirt forms large fan-shaped mounds. Pocket gophers plug the opening to these mounds so that weasels and snakes cannot get in and hunt them underground.

Pocket gophers tunnel to get food, mainly green vegetation and roots. Usually, they eat in their burrows, often pulling entire plants underground. When they feed at the surface, pocket gophers clip off vegetation around the burrow as far as they can reach without losing physical contact with the tunnel opening.

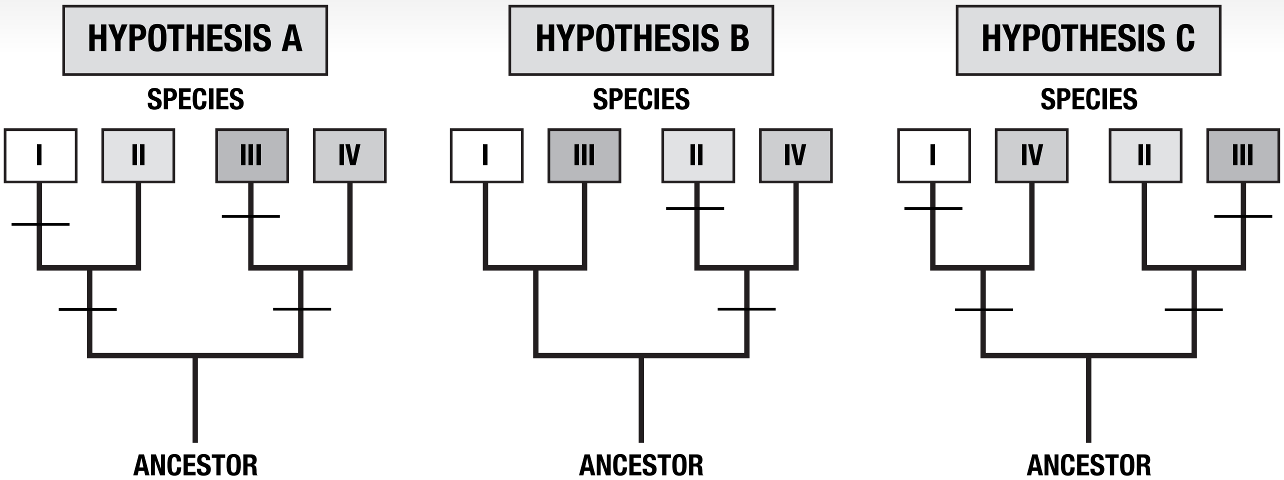
Now take a look at the page: ***Characters of Colorado Pocket Gophers***. In addition to the characters listed on the table, all four species of pocket gopher share these characters: rodent shape, external fur-lined cheek pouch, short hairless tail, long claws on toes, four toes on forelimbs, five toes on hind limbs and 20 teeth. These characters were probably shared by some ancestor that all four species have in common.

Your Task

Please use the last three rows of the table to fill in characters that you observe by looking at the illustrations of the four species of pocket gopher.

Getting in the Groove

Using the principle of parsimony, let's evaluate three possible pocket gopher cladograms using only one character "Frontal Grooves on Incisors." For this example, we will say that the ancestral character is "no frontal grooves." Each time the character state must be changed on the proposed cladogram, we will make a hatch mark on the branch on the cladogram where the change occurs.



In Hypothesis A cladogram, there would need to be a change that caused grooves to form on the incisors where the two new lineages occur. The branch to species I and II would need to show the development of two frontal grooves and the branch to species II and IV would need to show the development of one frontal groove. So, both branches would have a hatch mark. Then, since species I has no frontal groove, there would need to be another change in character state showing the loss of the two frontal grooves where that species branches off. That change would also be indicated with a hatch mark. A similar change would also happen on the branch to species III, showing the loss of one frontal groove. Altogether, for the character “Frontal Grooves on Incisors,” there would be four changes in character state for Hypothesis A. Hypothesis C would also show four changes in character state, designated by four hatch marks.

In Hypothesis B cladogram, assuming the ancestor had no frontal grooves on its incisors, there would be one change in character state on the branch to species II and IV, which each have frontal grooves. Then, because the branch to species II would need to indicate a change from one frontal groove to two frontal grooves, there would be another hatch mark on that branch. Hypothesis B has two character state changes, indicated by two hatch marks.

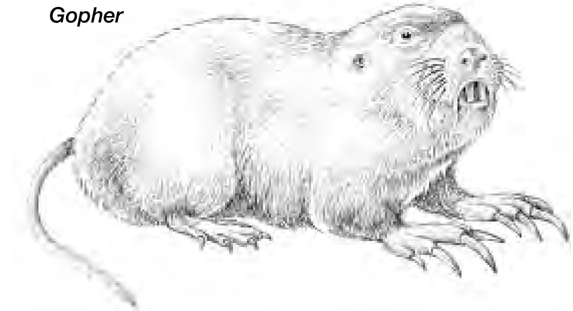
According to the principal of parsimony, Hypothesis B most likely indicates the true ***phylogeny***—evolutionary relationship—of the four species of pocket gopher *if only the one character was considered*. Of course, cladograms are rarely constructed soley on the basis of just one character.

Now It's Your Turn

1. Look at the table ***Characters of Colorado Pocket Gophers*** again. Looking at the characters that have been provided and the characters you observed, choose six characters that you believe might have the most impact on the day to day survival and reproduction of the four species of pocket gopher. Explain why you believe the six characters that you selected would help a pocket gopher adapt to its environment.

I—*Northern Pocket Gopher*

II—*Plains Pocket Gopher*



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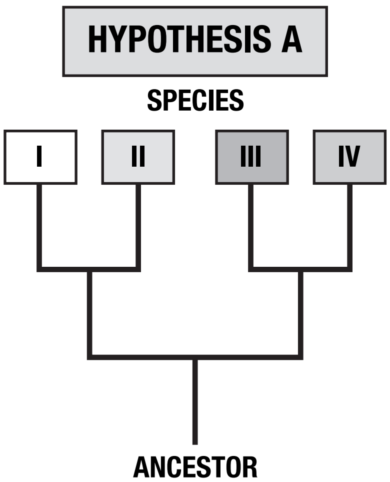
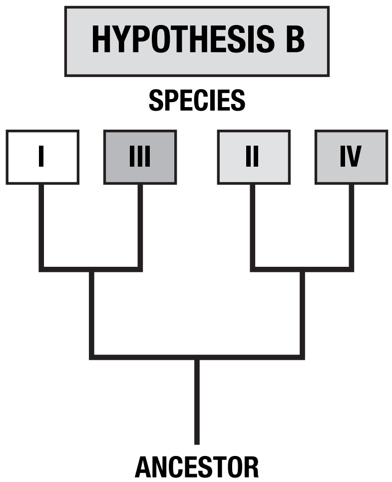
2. Place the six characters in the table below and indicate the "state" for the character for each species.

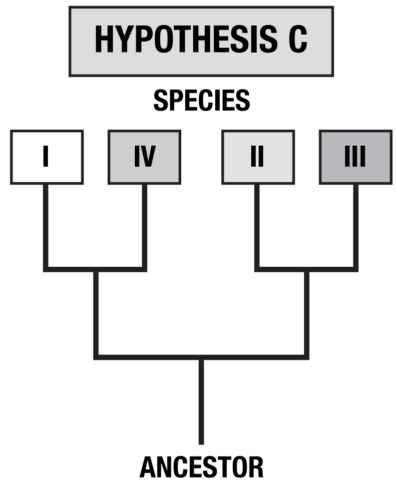
Pocket Gopher Characters

Character	Gopher Species			
	I	II	III	IV

3. Now look at the three hypothetical cladograms again. Taking one character from your table at a time, determine where a character state change would have to occur to produce each species. Make a hatch mark at each position on each hypothetical cladogram to indicate every character state change.







4. Which hypothesis most likely explains the phylogenetic history of these pocket gopher species using the six characters that you selected? Explain your reasoning.

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5. What other types of characters, besides external appearance, could be used to construct a data table and a cladogram? *(Hint: Think about Lesson 2,* Birds of a Feather?*)*

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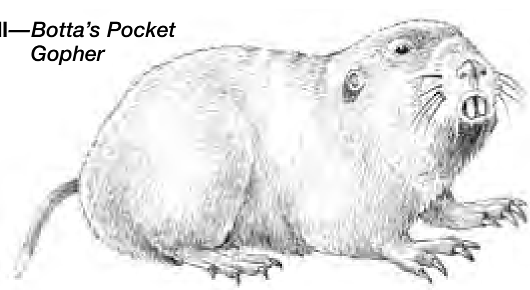
III—*Botta's Pocket Gopher*



IV—*Yellow-faced Pocket Gopher*

Cladogram Or Phylogenetic Tree?

In practice, when cladograms are constructed, many hundreds of characters have to considered, and computers are needed to sort out which organisms go on each branch. An advantage of cladistics is that it is a very objective analytical technique. If a data table containing the same set of character data is fed into and analyzed repeatedly by different computers, the computers will construct identical cladograms each time. Cladistic analysis simply indicates if a character exists or not, and then determines the sequence or order in which derived characters arose.

A disadvantage of cladistics is that it does not consider the importance of any one character. Equal weight is given to all the characters used and some of them may be fairly insignificant. In contrast, when biologists use ***evolutionary systematics***, they weight or give more importance to some derived characters over others. *This is what you just did when you selected six characters that you thought would be more important to the survival and reproduction of pocket gophers!* As another example, a biologist using evolutionary systematics principles would probably consider the character "giving birth to live young" more important than "fur color" when considering the evolutionary relationships of placental mammals and monotremes (i.e. duck-billed platypus).

The branching diagram that is constructed when a scientist uses subjective judgment when deciding which characters to weight the most heavily are called ***phylogenetic trees***. A phylogenetic tree and a cladogram are similar in that each represents a hypothesis of evolutionary history, but phylogenetic trees show both the best judgment and the biases that the scientist may have.

Cladograms Based Upon DNA Sequences

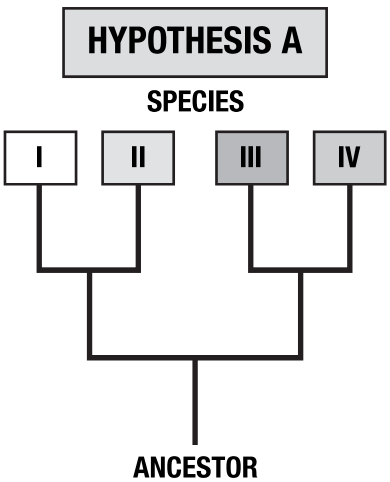
It can be very difficult to sort out evolutionary relationships of similar species based on physical characters alone. It is not always obvious which traits are the most important. Molecular biological technologies have been very helpful in determining phylogeny. We can now compare the sequences of DNA, RNA or proteins which are more representative of fundamental genetic relationships than are many superficial physical characters.

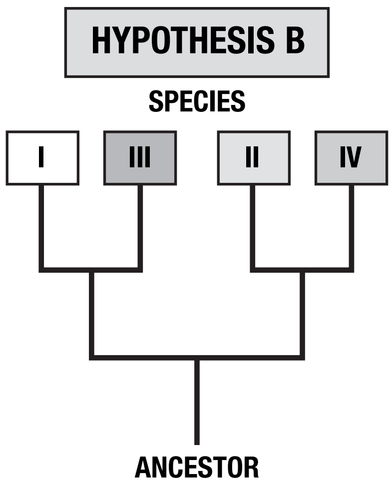
How are molecular cladograms constructed? First, the biologists need to decide which molecule to compare. While cladists can compare sequence portions of cellular DNA or the mitochondrial DNA, they usually sequence ribosomal RNA (rRNA). All living cells must make proteins and so all cells have ribosomes. The rRNA molecule is usually not as large as the entire DNA molecule.

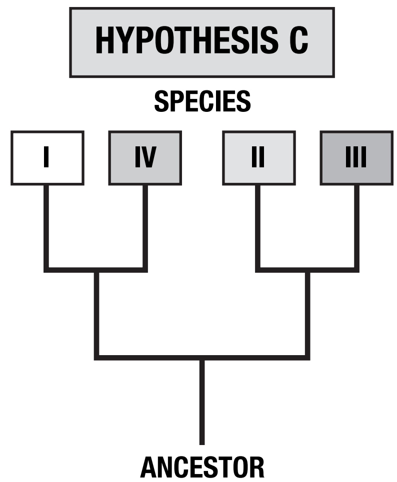
After DNA or rRNA sequences are determined for each organism, the sequences are aligned and compared. This task is usually done by computers that can sort through the differences and construct cladograms. Closely related species will have fewer differences in the DNA or RNA sequences than species that are more distantly related.

The following table shows differences in DNA sequences for the gopher species at different locations for the same gene. Use this information the same way that you used physical characters to determine which hypothetical cladogram best describes the most likely evolutionary history for these gophers. Taking one DNA difference at a time, place a hatch mark (/) at each position on each hypothetical cladogram where a change or mutation would have to occur in order to produce the four gopher species.

Gopher DNA Sequence Differences								
Pocket Gopher Species	Site of DNA Change 1	2	3	4	5	6	7	8
I	A	C	C	G	G	C	G	C
II	A	T	G	A	A	C	A	G
III	A	C	G	G	G	T	G	C
IV	G	T	G	G	A	C	A	G







6. Which cladogram most likely explains the evolutionary relationships of these gopher species? _____. Explain your answer.

7. Is it possible to have character data support a different hypothesis than the DNA data? _____. Explain your answer.

8. Once the most likely cladogram has been determined for related species, this information could be used to make predictions about species. For instance, if a disease strikes gopher species I but not gopher species III, what would you predict about the resistance of gopher species II and IV to this same disease?

9. How are morphological characters and DNA sequence data related?

10. The scientific names of the four gopher species are given below.

Species I—northern pocket gopher (*Thomomys talpoides*)
Species II—plains pocket gopher (*Geomys bursarius*)
Species III—Botta's pocket gopher (*Thomomys bottae*)
Species IV—yellow-faced pocket gopher (*Pappogeomys castanops*)

What do the scientific names of these pocket gopher species imply regarding their phylogenetic relationships?

11. As more DNA sequences are accumulated, researchers gain better understanding of the phylogenetic relationships of organisms and may reassign the classification groups that organisms have previously been assigned. Which classification groups are more likely to be changed, a general grouping (like kingdom or phylum), a specific grouping (like genus or species), or an intermediate grouping (like orders or families) as DNA data on species are evaluated?

Notes

Lesson 6

Educator's Overview

Déjà Vu

Summary

Students read and analyze a recent study completed by the University of Colorado for the Colorado Division of Wildlife to determine if a particular population of pocket gophers is a subspecies in need of special protection, or just a variation of a very common species.

Duration

One 45-minute class period

Vocabulary

Candidate species

Divergence

Genetic Drift

Home Range

Niche

Peer review

Speciation

Species of special concern

Subspecies

Learning Objectives

After completing this activity, students will be able to:

- Describe the application of cladistics to a current wildlife management issue.
- Review and evaluate a research paper and describe its significance.
- Provide examples of how peer review improves scientific inquiry.

Background

Speciation occurs when a descendant population can no longer interbreed with the ancestor population. Species undergo different selective pressures in different environments. Small, isolated populations of species may, over time, develop noticeably different physical features in response to their environment than similar populations elsewhere. Are these changes indicative of a significant modification of the species? Do differences in appearance indicate the presence of a subspecies or new species? How small or big of a change is significant. These questions are important ones for biologists who are trying to quantify and maintain species diversity.

Cladistics has been especially useful as a tool for scientists working with these questions. This activity ties together all the concepts found in ***The Species Question***, and demonstrates how cladistics is used to address current wildlife issues in Colorado.

Teaching Strategies

1. Thoroughly read the student materials for *Déjà Vu*.

2. Give each student the reading packet, *Déjà Vu*.

3. After giving students sufficient time to read the packet, review the need for a legal definition of species. ***Wildlife managers and others must make decisions and take actions to maintain healthy populations of organisms and their habitat. In order to avoid confusion and possibly court battles, they need to agree on what populations need protection.***

4. Ask students to describe how taxonomy and cladistic analysis contribute to wildlife conservation. ***Cladistic analysis makes it possible to evaluate the morphological and genetic differences between various wildlife populations. This helps identify populations that are unique and in need of protection.***

5. Peer review is essential to the process of scientific inquiry. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between the methods and procedures used; the historical body of scientific knowledge; and the findings. The importance of peer review to the scientific "way of knowing" can never be overemphasized. Please use this web site to show students examples of peer review:

http://mountain-prairie.fws.gov/preble/PEER/PEERindex.htm

Assessment

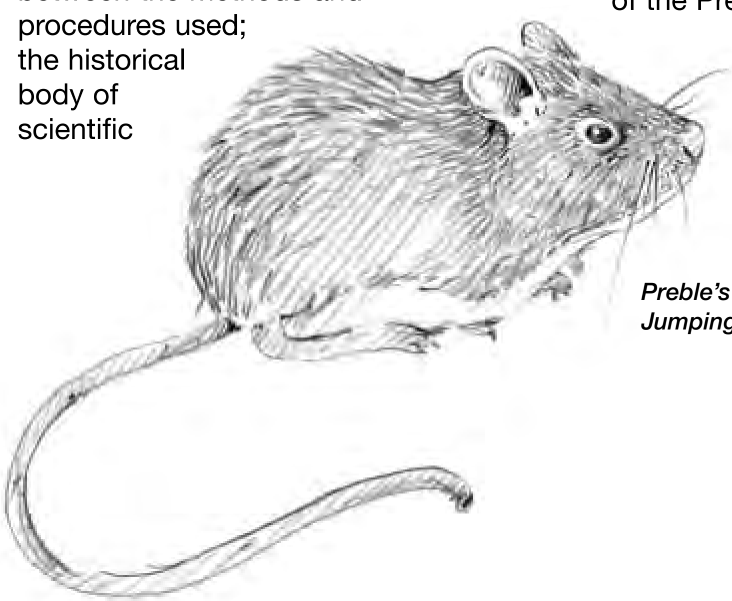
Ask students to write a short paper which describes the relevance of taxonomy and systematics to wildlife management.

Extension

Divide the class into groups of three and ask each group to review and comment on one of the scientific studies concerning the genetic uniqueness of Preble's meadow jumping mouse at:

http://mountain-prairie.fws.gov/preble/

Student groups should look at the study and the peer review of the study. If time allows, students can debate both sides of the Preble's argument.



Preble's Meadow Jumping Mouse

Materials and Preparation

- *Student Reading Pages* Déjà Vu—*one photocopy per student*
- *Access to the library and the internet*

Key

1. To which pocket gopher species did the three subspecies listed in the study (*T.t rostalis, T.t. retrosus*, and *T.t. macrotis*) belong? ***Thomomys talpoides***

2. The authors of the report state that the subspecies *T. t. macrotis* was named on morphological grounds. What does that mean? ***Scientists based the classification of T. t. macrotis on physical characteristics which could be observed.***

3. When was the taxonomy of Colorado pocket gophers last revised? What new technology has been developed since that time to assist taxonomists in determining the taxonomy and phylogeny of pocket gophers? ***The taxonomy was last revised in 1915. Since then, computers and molecular biology techniques have been developed that allow biologists to compare DNA and RNA sequences.***

4. How many mtDNA samples were taken for analysis for the subspecies report? ***24***

5. Why were museum specimens used? ***If the subspecies was indeed threatened or endangered, it would not be reasonable to trap more animals out of the population for testing.***

6. How long are the mtDNA sequences being tested? ***296 bases***

7. What species was chosen to represent the out-group? Why is an out-group used? ***The thirteen-lined ground squirrel was chosen to represent the out-group. An out-group is not closely related to the animals being studied and is used to compare the differences between the animals.***

Notes

Student Pages

Déjà Vu

Caution: Much of what you are about to read will sound eerily familiar. You may have the feeling that you have read these lines before. Rest assured that nothing paranormal is happening—bits and pieces of the last five lessons are being repeated to so that you will see the BIG PICTURE and will understand how all of these ideas connect with wildlife conservation. The BIG PICTURE joins together three smaller pictures from past lessons.

Small Picture #1

In Lesson 1, you learned that the Colorado Division of Wildlife (DOW) is the state agency responsible for protecting and managing Colorado's wildlife and habitat. The biologists at the DOW abide by both state and federal wildlife laws. One of the most significant of all of the laws is the Endangered Species Act (ESA) of 1973. Both the state and federal government maintain a list of threatened and endangered species and also a list of species at risk of becoming threatened or endangered. At the state level, these are ***species of special concern***. At the federal level, these species are often ***candidate species*** for possible listing.

Species on the State of Colorado's threatened and endangered list are managed by the DOW. When a species is placed on the federal threatened or endangered species list, the federal government, through the U.S. Fish and Wildlife Service, supersedes the state's authority to manage that species.

Wildlife on either the state or federal lists requires more intensive management. Some management techniques to prevent the extinction of species or subspecies have considerable social and economic impacts. The ESA may limit land use or human activities in habitat considered important to threatened or endangered species. For this reason, it is important that listing decisions are made with the best available scientific information.

In order to be consistent and accurate, wildlife managers use a legal definition of species for decisions to list certain populations as threatened or endangered. The four characteristics of populations that would be used to consider the population unique include:

1. Usually ***do not interbreed*** with other populations;
2. Have ***different appearance, behavior, or ecological niche*** than other populations;
3. Have notably ***different DNA (genetic material that determines inherited characteristics)***; and
4. Represent a ***unique evolutionary lineage and contain the potential for a unique evolutionary future***.

In Lesson 2, you discovered that two populations of sage grouse that biologists once thought belonged to the same species were really two different species. There was undeniable evidence that the two populations did not interbreed, differed in appearance, behavior and niche, and had different DNA. Lesson 2 did not address the fourth requirement that each population represent a unique evolutionary lineage—this one will!

Small Picture #2

In Lesson 3, you learned that ideas and methods about classifying species and figuring out species relationships to one another have changed over time. Classification schemes change for a number of reasons. First is that, over time, people develop different world views, they have new ideas. Some ***new ideas*** take thousands of years to develop.

A second reason taxonomic classifications change is that scientists have ***new data***. Consider the sage grouse example. Biologists began collecting more physical and behavioral data about the birds. In addition, a new technology, DNA and RNA sequencing, provided new sources of character information or data to compare. This information made it clear that the two populations of birds were very different from each other. ***New information reveals new similarities and differences among groups that may cause taxonomists to revise a group's classification.***

Another reason that classification schemes change is that biologists find ***new species***. Over time, humans have explored more of Earth's environments. Often, unique organisms are found in deep ocean vents, high alpine tundra, caves and other newly searched places. As previously unknown species are discovered, classifications also change to include them.

Small Picture #3

In Lessons 4 and 5, you developed a basic understanding of cladistics and how this system of analysis helps biologists understand the evolutionary relationships of all living things. Each branch of a cladogram represents a unique lineage of organisms that share unique traits or characters. Cladistic analysis allows wildlife biologists to address the fourth part of the legal species definition, that the population represent a ***unique evolutionary lineage and contain the potential for a unique evolutionary future***.

Speciation

When biologists speak of a population containing the potential for a unique evolutionary future, they mean that the population may be genetically unique enough to be undergoing ***speciation***, the process by which new species form. Species formation occurs in stages and is a very slow process.

Separate populations of a single species can live in different types of environments. In each of these environments, there are different "selective" pressures, conditions that challenge the survival of the population. Often, various populations of species overlap and interact and continue to exchange genes by breeding. However, some populations can become isolated from other populations of their species. Over time, animals that are able to survive and reproduce pass their characteristics to young that are genetically better adapted to the unique environment that they live in. Genetic differences between the groups accumulate slowly over time, a process called ***divergence***, or ***genetic drift***. Over time, populations of the same species that have notable genetic difference because of adaptations to certain living conditions become what biologists call ***subspecies***. The members of the newly formed subspecies have taken the first step toward speciation. Eventually, the subspecies may become so different that they can no longer interbreed successfully with other populations. Biologists then consider then different species.

Back To Pocket Gophers

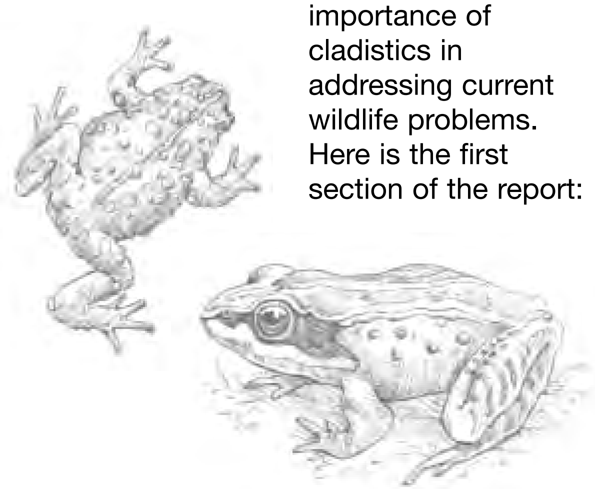
Pocket gophers are one group of animals that seem particularly susceptible to genetic drift. They have very small ***home ranges***—the area where they live and travel. Often, pocket gophers live their entire lives in one burrow system that occupies less than half an acre. Pocket gophers live solitary lives, except briefly during the breeding season. They are very territorial and carefully avoid encounters with each other. When they do meet, they fight ferociously. For these reasons, pocket gophers adapt to their local environment over many generations, and seem to diverge into subspecies and species more quickly than other kinds of mammals.

Like every wildlife species, people have varying "situational" viewpoints about pocket gophers. In their natural environment, pocket gopher burrowing is viewed as beneficial. They increase soil aeration and water infiltration, and boost soil fertility. Pocket gopher burrows also provide hibernation sites and summer retreats for salamanders, frogs, and toads.

In other situations, pocket gophers are viewed as pests. Pocket gophers love alfalfa and can be destructive to crops and trees—girdling or clopping stems and pruning roots. They can decimate a prized flower garden. Many homeowners and agricultural producers both past and present have worked on eradicating gophers from their property.

In March of 2003, two conservation groups filed an emergency Endangered Species Act listing petition for the Douglas County pocket gopher (*Thomomys talpoides macrotis*), seeking to list the pocket gopher as endangered. Their claim was that uncontrolled sprawl in Douglas County had brought the pocket gopher to the brink of extinction, that its habitat had been paved over for parking lots, car dealerships, and other developments. The pocket gopher of concern was thought to survive in only five populations in Douglas County.

If the pocket gopher was listed as endangered, the decision would have a huge economic impact on Douglas County. As the state agency responsible for wildlife management, the DOW enlisted geneticists at the University of Colorado to explore the classification of these pocket gophers to determine if they were indeed a unique subspecies needed special protection. A portion of the final report of the scientists demonstrates the use and importance of cladistics in addressing current wildlife problems. Here is the first section of the report:



Final Report

Genetic relationships among subspecies of Thomomys talpoides: T. t. macrotis, T. t. rostralis, T. t. retrorsus

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The northern pocket gopher, *Thomomys talpoides*, is a polytypic species with numerous described subspecies, nine of them within Colorado (Armstrong, 1972). *T. t. macrotis* is ascribed a range in Douglas, Elbert and Arapahoe Counties. The geographic distribution of *macrotis* is small, and it is geographically isolated from *T. t. rostralis*, which occupies the mountains to the west, and *T. t. retrorsus*, which occupies the Palmer Divide to the south and east.

T. t. macrotis was named on morphological grounds by F. W. Miller in 1930. The subspecies was characterized by generally larger size and paler, more grayish color than adjacent populations. However, there has been no taxonomic revision of *Thomomys talpoides* since 1915, and prior to this study, no genetic data have been collected to evaluate the phylogenetic relationships among the subspecies. Human population growth and development in the greater Denver area make this a propitious time to evaluate the subspecific designation of *macrotis*. Recently, the Colorado-based Center for Native Ecosystems and Arizona's Forest Guardians filed a petition with the U. S. Department of the Interior to list *T. t. macrotis* as threatened or endangered.

1. To which pocket gopher species did the three subspecies listed in the study (*T.t rostalis, T.t. retrosus*, and *T.t. macrotis*) belong?

____

2. The authors of the report state that the subspecies *T. t. macrotis* was named on morphological grounds. What does that mean?

____

3. When was the taxonomy of Colorado pocket gophers last revised? What new technology has been developed since that time to assist taxonomists in determining the taxonomy and phylogeny of pocket gophers?

____

It is nearly impossible to rely on physical traits to classify subspecies. In order to have defensible evidence to make management decisions about *T. t. macrotis*, the researchers decided that mitochondrial DNA sequencing was necessary.

We proposed to use mitochondrial DNA (mtDNA) to examine the variation within and among these three subspecies. Specifically, we proposed to examine the following questions:

1) Is *T. t. macrotis* genetically distinct from *T. t rostralis*, and *T. t. retrorsus*?
2) What is the magnitude of the genetic differences among these subspecies?
3) Given the genetic differences among other recognized subspecies of the northern pocket gopher, is there sufficient justification for subspecific status of *T. t. macrotis*?

Here is the procedure the researchers used:

We obtained DNA samples by clipping small pieces of skin from dried museum samples. The samples were taken from the CU's University Museum and the Denver Museum of Nature and Science.

Specimen sampled for a molecular systematic study of three subspecies in *Thomomys talpoides*.

T. t.rostralis

D5833 Jefferson County, Brookvale, Evergreen
D7627 Park County, 19km N, 11km E Salida; Herring Creek
D9022 Park County, 1mi W of Porcupine Cave, 9100ft
D9023 Park County, 1mi W of Porcupine Cave, 9100ft
D10466 Jefferson County, Connifer, 10647 Snowy Trail
5073 Boulder County, Long Canon, Green Mountain
11376 Larimer County, Rist Canyon 17.5mi NW Ft Collins T8N, R71W, sec26
13991 Clear Creek County, Headwater Clear Creek
14284 Grand County, Steelman Creek

T.t.macrotis
D4428 Douglas County, D'Arcy ranch; 2mi N Parker
17010 Russelville Rd .5mi SE Reed Hollow
17012 Douglas County, Along road to McArthur Ranch T6S, R67W, sec19
17013 Douglas County, Along road to McArthur Ranch T6S, R67W, sec19
17015 Douglas County, Willow Creek at County Line Rd T6S, R67W, sec4
17016 County Line Rd 2mi W of Willow Creek
17017 Douglas County, E of Grand View Estates T6S, R67W, sec12

T.t.retrorsus
17005 El Paso County, 2mi E of I-25 on Palmer Divide Rd
17006 Douglas County, E of upper E Cherry Creek T10S, R65W, sec28
17007 Douglas County, Palmer Gulch Rd 3.25 mi E I-25, roadside ditch
17008 Douglas County, Lake Gulch T9S, R66W, sec4
17009 Douglas County, E of upper E Cherry Creek T10S, R65W, sec33
17011 Douglas County, McMurdo Gulch Rd, .3mi W Cherry Creek T7S, R66W, sec27
17019 Douglas County, E Cherry Creek T10S, R65W, sec9
17020 Douglas County, E Cherry Creek T10S, R65W, sec9

Note: D indicates samples from the Denver Museum of Nature and Science.

We obtained mitochondrial cytochrome oxidase I (COI) sequences from seven *T. t. macrotis*, nine *T. t. rostralis*, and eight *T. t. retrorsus*, and these sequences are being submitted to GenBank. The sequences are 296 base pairs long, and 40 of the nucleotide sites are variable.

4. How many mtDNA samples were taken for analysis for the subspecies report?

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5. Why were museum specimens used?

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6. How long are the mtDNA sequences being tested?

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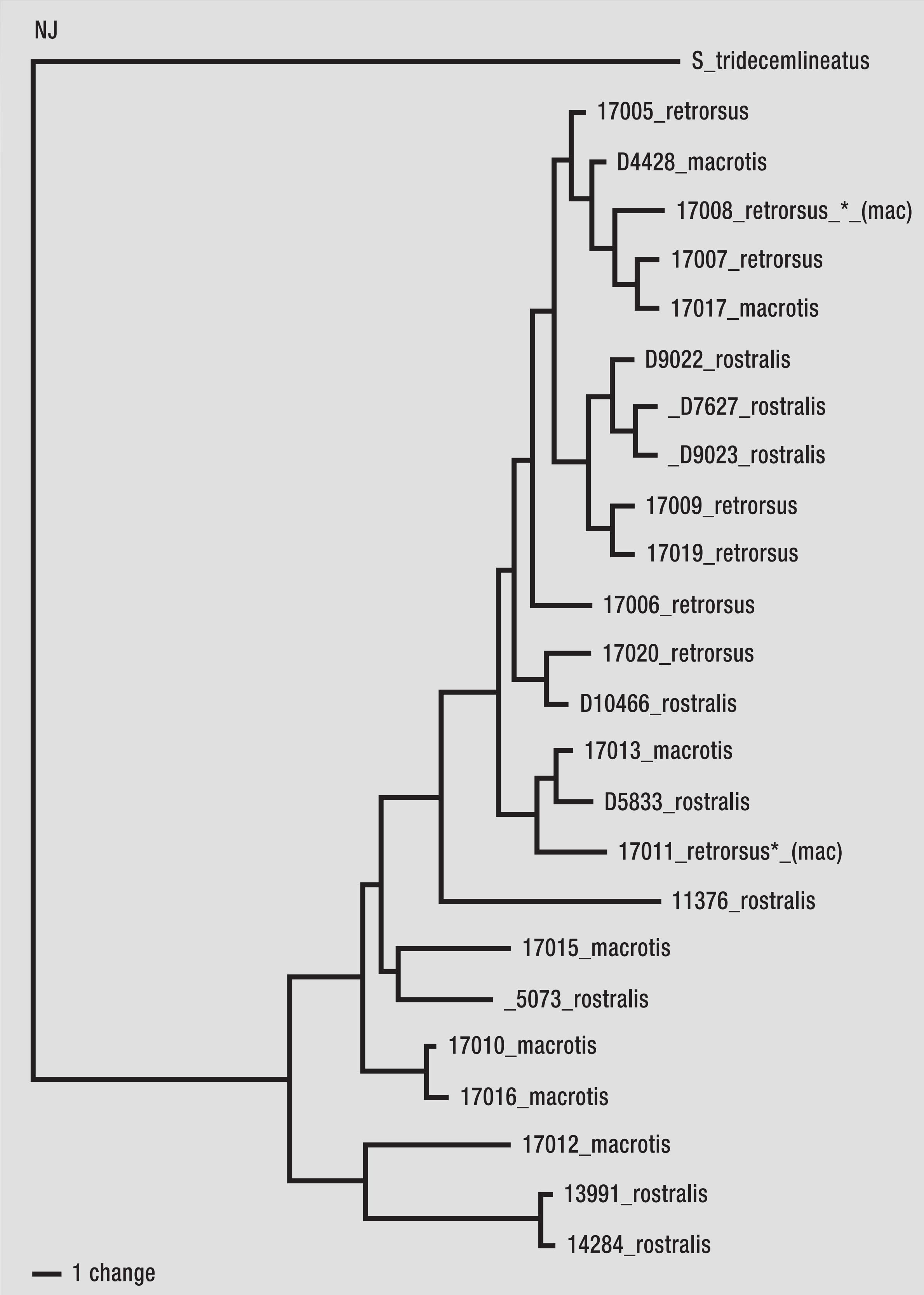
Imagine the task of constructing all the possible cladograms comparing this may DNA sequences! This would boggle the best of minds, so the scientists used a computer to sort the mtDNA bases and produce a cladogram:

A neighbor joining tree of mtDNA sequences from *Thomomys talpoides rostralis*, *T. t. macrotis*, and *T. t. retrorsus*, with *Spermophilus tridecemlineatus* as an out-group. A neighbor joining tree summarizes the relationships among the 24 COI sequences, using the thirteen-lined ground squirrel as an out-group. The data are based on 296 bases from the mitochondrial gene for cytochrome oxidase I. (Specimens marked with an asterisk might have been identified incorrectly).


NJ
S_tridecemlineatus
17005_retrorsus
D4428_macrotis
17008_retrorsus_*_(mac)
17007_retrorsus
17017_macrotis
D9022_rostralis
_D7627_rostralis
_D9023_rostralis
17009_retrorsus
17019_retrorsus
17006_retrorsus
17020_retrorsus
D10466_rostralis
17013_macrotis
D5833_rostralis
17011_retrorsus*_(mac)
11376_rostralis
17015_macrotis
_5073_rostralis
17010_macrotis
17016_macrotis
17012_macrotis
13991_rostralis
14284_rostralis
1 change

The results of the research were as follows:

The mtDNA sequences do not form three groups corresponding to subspecies, but are all intermixed, with no evidence of subspecific groups at all. That is, the mtDNA do not support the subspecific appellations in the literature. The three recognized subspecies have geographically distinct ranges, and differ morphologically, but their mitochondrial lineages have apparently not had sufficient time for lineage sorting and/or selection to develop reciprocal monophyly.

We can now repeat the questions that we proposed to address, and provide answers (**in bold**).

1) Is *T. t. macrotis* genetically distinct from *T. t rostralis*, and *T. t. retrorsus*?
   No
2) What is the magnitude of the genetic differences among these subspecies?
   There are no discernible groups, the subspecies are intermixed in the tree. There are no diagnostic differences among the three subspecies.
3) Given the genetic differences among other recognized subspecies of the northern pocket gopher, is there sufficient justification for subspecific status of *T. t. macrotis*?
   MtDNA sequences do not support the subspecific designations of T. t. rostralis, T. t. retrorsus, and T. t. macrotis.

7. What species was chosen to represent the out-group? Why is an out-group used?

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The scientists found "no discernable groups"—they did not find enough genetic differences to classify *T.t. macrotis* as a subspecies. How did their findings affect the petition to list this species as threatened or endangered? The U.S. Fish and Wildlife Service reviewed the petition to list the pocket gopher in Douglas County, Colorado, and, with this information, concluded that listing the Douglas County pocket gopher was not necessary. The negative finding was published in the Feb. 14, 2006; *Federal Register*, pages 7,715–7,720 and you may read the entire decision at this web site:

http://a257.g.akamaitech.net/7/257/2422/01jan20061800/edocket.access.gpo.gov/2006/06-1288.htm

Back to the Future

Species questions are important. If species are threatened or endangered, steps must be taken to protect them. At the same time, if a population only appears to be unique and is not, agencies would not want to devote scarce time and resources to management efforts for it.

Sometimes it is difficult to determine what the status of a particular group of animals is. As this booklet of lessons is being published, there is lots of scientific debate about the status of a little mouse. Preble's meadow jumping mouse (*Zapus hudsonius preblei*) is a small rodent approximately 9-inches in length with large hind feet adapted for jumping. Its long, bicolor tail accounts for 60 percent of its length and it has a distinct dark stripe down the middle of its back that is bordered on either side by gray to orange-brown fur.

This shy, mostly nocturnal mouse lives in some of the most desired real estate in the west. It prefers heavily vegetated streamside and adjacent upland habitat along the foothills of the Front Range, from southeastern Wyoming south to Colorado Springs, Colorado. This area has undergone rapid residential, commercial, agricultural, and industrial development, to the detriment of the mouse.

On May 13, 1998, Preble's meadow jumping mouse was designated as threatened by the U.S. Fish and Wildlife Service in its entire range. Many people's livelihoods were affected by this decision and it was just a matter of time before more studies were done on the mouse.

Genetic research conducted by Dr. Rob Roy Ramey, formerly of the Denver Museum of Nature and Science, questioned the uniqueness of the mouse. On February 2, 2005, based on Ramey's study, the U.S. Fish and Wildlife Service (USFWS) issued a 12-Month Finding on a petition to delist the Preble's and proposed to remove the mouse from the Federal list of threatened and endangered species.

Seeking to use the best science possible in making a final decision, the Service later commissioned Dr. Tim King of the U.S. Geological Survey (USGS) to do an independent genetic analysis of several meadow jumping mouse subspecies. The USGS study results, provided to the Service on January 25, 2006, raised significant questions about the conclusions drawn by Dr. Ramey in his study.

Because of the complexity of this issue, the Service extended for six months its proposal to delist the Preble's meadow jumping mouse. A six-month extension in making final determinations on listing or delisting proposals ***is allowed under the Endangered Species Act in situations where there is substantial disagreement regarding the sufficiency or accuracy of the available data***.

Since Dr. Rob Roy Ramey and Dr. Tim King disagreed on whether the Preble's meadow jumping mouse constituted a valid subspecies, the studies were placed on the USFWS Web site for public comment and peer review. ***Peer review*** is a process of subjecting a scientist's work or ideas to the scrutiny of others who are experts in the field. Peer review is an essential component of the science process, and all scientists typically recognize that cherished data, analyses and interpretation may ultimately be overturned by new information. The Service also convened an expert panel of scientists to analyze, assess, and weigh the reasons why the conclusions of King differed from the conclusions of Ramey. All of the genetic studies, peer reviews, public comments, and results of the panel can be found at the U.S. Fish and Wildlife Service web site:

http://mountain-prairie.fws.gov/preble

You can follow the decision-making process as it occurs by visiting this Web site. What will the outcome be? Will there be scientific consensus to make a decision? Is Preble's meadow jumping mouse a valid subspecies? A decision may be made by the time you read this, or maybe more studies will be needed. In any case, the decision about Preble's meadow jumping mouse is sure to make a few headlines!

Notes

Glossary

Analogous character: physical traits similar in form or function, in two or more organisms that are not closely related, that evolved through convergent evolution

Ancestor: any organism, population, or species from which some other organism, population, or species is descended by reproduction

Ancestral character: a trait or characteristic that many clades have in common and that was present in an ancestor of the clades

Artiodactyls: even-toed ungulates with two or four toes

Avian: bird

Binomial: two names, the scientific name of an organism, the first name indicates the genus and the second the unique species name

Biodiversity: biological diversity, including the variety of species, the genetic differences within species, and the variety of ecosystems.

Brachydont: low-crowned molars

Bunodont: squarish molars with low rounded cusps

Candidate species: federal designation for species that are at risk of becoming threatened or endangered

Canines: dog-like species OR sharp teeth used to stab and hold prey

Cannon bone: in ungulates, the 3rd and 4th metapodials may be fused to form a single, stronger bone

Carpal: measurement form the wrist bone of the wing to the tip of the longest primary feather

Character: identifiable feature, trait or characteristic

Character state: one or two or more possible forms of a particular character or trait

Clade: a group of organisms which includes the most recent common ancestor of all of its members and all of the descendants of that most recent common ancestor, a monophyletic group

Cladist: a biologist who uses cladistics to reconstruct the common ancestry relationships among organisms

Cladistics: a method of analysis that attempts to classify organisms by common ancestry

Cladogram: a branching diagram, resulting from a cladistic analysis, that represents a hypothesis about the order in which organisms evolved

Classification system: a method of grouping organisms

Five kingdom classification system: groups species on the basis of cell structure, body structure, and manner of getting energy or nourishment into five kingdoms—Monera, Protista, Plantae, Fungi, Animalia

Three domain classification system: groups organisms on the basis of the genetic makeup of their ribosomal RNA into three domains—Bacteria, Arcaea, and Eukarya

Two-empire classification system: groups organisms based on cell structure into two empires—Prokarya or Eukarya

Clone: an organism produced by asexual reproduction that is genetically identical to its parent

Convergent evolution: the independent evolution of similar structures in distantly related organisms, usually because they live in similar habitat and have a similar way of life

Culmen: straight-line measurement from the base to the tip of the upper beak

Derived character: a unique characteristic or trait of a particular group of organisms

Diastema: toothless gap between incisors and premolars

Digits: fingers or toes

Digitigrade: a foot posture in which the digits are in contact with the ground when walking or running, but not the sole or heel of the foot

Distinct Population Segment: a category used by the Endangered Species Act (ESA) to denote populations that must be protected under the act; constitutes a legal definition of species

Divergence: genetic drift, genetic differences between populations that accumulate slowly over time

DNA (Deoxyribonucleic Acid): the material that contains the information that determines inherited characteristics

Endangered: at risk of becoming extinct throughout all or a significant portion of its range

Endangered Species Act (ESA): a federal law passed in 1973 that seeks to prevent plants and animals from becoming extinct in the United States

Eukaryote: an organism made up of cells that have a nucleus enclosed by a membrane

Evolutionary systematics: modifying the process of cladistics by placing more “weight” or importance on certain derived characters

Game: wildlife species that people can legally hunt, fish, or take

Gene: a segment of DNA that is located in a chromosome and codes for a specific hereditary trait

Gene Sequencing: determining the order of the DNA bases in a gene

Genetic drift: divergence, genetic differences between populations that accumulate slowly over time

Genus: a group of similar species

Herbivorous: eats plants

Home range: an area where an animal lives and travels in the scope of its normal activities

Homologous characters or structures: organs and body parts which are alike in structure and origin

Hybrid: the fertile or infertile offspring of normally reproductively isolated populations

Hypsodont: high-crowned molars

Incisors: teeth at the front of the mouth

In-group: in a cladistic analysis, the groups of organisms which are hypothesized to be closely related to each other

Lek: strutting grounds for breeding sage grouse

Marine: ocean

Mesaxonic: type of foot structure where the line of symmetry passes through the center digit (toe), which is enlarged and bears most of the weight

Metacarpals: hand bones that connect to the fingers

Metapodials: metacarpals (hand bones) and metatarsals (feet bones)

Metatarsals: foot bones that connect to the toes

Molars: cheek teeth located at the rear of the mouth behind the premolars

Molt: drop and replace feathers

Monophyletic group: members of a group which have characteristics in common because they evolved from a common ancestor

Morphological: physical form and structure

Morphological trait or character: physical feature of an organism

Natural selection: sometimes referred to as “survival of the fittest,” the process by which individuals that are better adapted to their environment survive and reproduce more successfully than less well-adapted individuals and pass their traits to their offspring, gradually changing the characteristics of the population

Niche: the ecological role of an organism, the set of resources it consumes and habitats it occupies

Out-group: in a cladistic analysis, a group which is not closely related to the groups of organisms being studied and which is used for comparison

Reproductive isolation: populations of organisms that cannot breed and reproduce due to some barrier or factor

Paraxonic: type of foot structure where the line of symmetry passes between the two centermost toes, which bear the body's weight

Parsimony: refers to a rule used to choose among possible cladograms, which states that the cladogram implying the least number of changes in character states is the best

Peer review: a process of subjecting an author's scholarly work or ideas to the scrutiny of others who are experts in the field.

Perissodactyls: odd-toed ungulates having either one or three weight-bearing toes

Phylogeny: an organism's evolutionary history

Phylogenetics: the study of the pattern of events that have led to the distribution and diversity of life

Phylogenetic tree: a graphical representation of the interrelationships and evolutionary history of a group of organisms, which includes both the best judgment and biases of the scientist

Plantigrade: a foot posture in which the full length of the foot, including the heel, touches the ground

Premolars: cheek teeth in front of molars

Prokaryote: an organism lacking nucleated cells

Reproductive Isolation: barriers or factors that prevent one population from inter-breeding with another population

Ruminant: ungulate with a complex gut which helps it digest plants

Scientific name: the binomial of a species, the first name indicates the genus and the second the unique species name

Selection: in agriculture, a process of choosing animals or plants to propagate, with the result that the inherited traits of the chosen organisms are enhanced and perpetuated

Selenodont: molars that have hard enamel ridges running from back to front

Speciation: the process by which new species arise

Species concept: a working definition of species

Biological species concept: a group of organisms that is genetically similar enough to breed and produce viable and fertile offspring are considered a species

Ecological species concept: organisms which occupy the same niche are considered a species

Isolation species concept: groups of interbreeding natural populations that are reproductively isolated from other such groups are considered a species

Morphological or Phenetic species concept: organisms with the same physical traits are considered a species

Species of special concern: Colorado's designation for species that are at risk of becoming threatened or endangered

Stance: how an animal stands

Strata: layers of earth

Subspecies: a population of a species whose members have certain physical and hereditary characteristics that distinguish it from other populations of the species

Systematics: the field of biology that deals with the diversity of life

Tarsals: bones in the fingers and toes

Tarsus: measurement from the point where the leg joins the middle toe to the first joint in the leg

Taxa: groups of organisms

Taxon: a group of organisms

Taxonomy: the science of naming and classifying organisms

Terrestrial: land

Threatened: species not in immediate peril of extinction, but likely to become endangered in the near future throughout all or a significant portion of its range

Ungulate: hoofed mammal

Unguligrade: a foot posture in which an animal walks on its tiptoes, often on hooves

Uniformitarianism: the idea that the earth was shaped entirely by slow-moving forces acting over a very long period of time

Wildlife: (Colorado Statutes) all non-domestic mammals, birds, fish, amphibians, reptiles, mollusks, and crustaceans

Wildlife management: the use of scientific knowledge to maintain healthy populations of wildlife and its habitat and preserve biodiversity