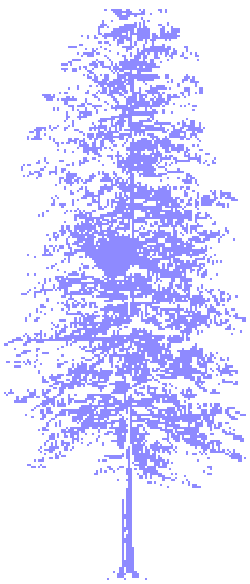
NCSR
Education for a Sustainable Future
www.ncsr.org



Introduction to Mammalogy

Northwest Center for Sustainable Resources (NCSR)
Chemeketa Community College, Salem, Oregon

DUE # 0101498

Funding provided by the National Science Foundation
opinions expressed are those of the authors and not
necessarily those of the foundation

Introduction to Mammalogy

The Northwest Center for Sustainable Resources is an Advanced Technological Education project funded by the National Science Foundation.

Introduction to Mammalogy was developed by Mark Grover, Ph.D. at Feather River College, Quincy, California and was tested and revised at Itasca Community College, Grand Rapids, Minnesota.

Technology education programs in which this course is incorporated are described fully in the Center's report entitled, "Visions for Natural Resource Education and Ecosystem Science for the 21st Century." Copies are available free of charge.

Course materials will also be posted on our website:

www.ncsr.org

Please feel free to comment or provide input.

Wynn W. Cudmore Ph.D., Principal Investigator
Northwest Center for Sustainable Resources
Chemeketa Community College
P. O. Box 14007
Salem, OR 97309
E-Mail: wynn.cudmore@chemeketa.edu
Phone: 503-399-6514

Table of Contents
Introduction to Mammalogy

Introduction to Mammalogy
3 credits–2 hours lecture/3 hours lab

Introduction to Mammalogy is a 3-credit, laboratory/field-based course. It was developed to introduce students in a two-year Wildlife Technology program to the characteristics, evolutionary history, classification, adaptations, ecology, and natural history of mammals.

TEXTS

Feldhamer, G.A., L.C. Drickamer, S.H. Vessey, and J.F. Merritt. 1999. Mammalogy: *Adaptation, Diversity, and Ecology.* WCB McGraw-Hill, Boston, MA. 563 pp.

Burt, W. H. and R. P. Grosseheider. 1980. *Mammals of North American* (Peterson field guide series). Houghlin Mifflin Company, Boston, MA. 290 pp.

SUPPLEMENTAL MATERIAL

Wilson, D.E., F.R. Cole, J.D. Nichols, R. Rudran, and M.S. Foster (eds.). 1996. *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*. Smithsonian Institution Press, Washington D.C. 409 pp.

COURSE DESCRIPTION

This is a comprehensive course in basic mammalogy. Lectures emphasize the characteristics, evolutionary history, classification, adaptations, ecology, and natural history of mammals. Field techniques for the study of mammalian biodiversity and abundance are emphasized in the laboratory. Students design and implement research projects and apply the scientific method to test hypotheses.

COURSE OBJECTIVES

Upon successful completion of this course students will be able to:

1. Understand the significance of the major evolutionary innovations in the ancestors of mammals.
2. Comprehend the benefits and limitations of physiological and neurological adaptations of mammals, particularly as they relate to interactions between mammals and their environment.
3. Appreciate the complex reproductive strategies and social behavior of mammals.
4. Appreciate mammalian diversity, and identify the general traits of major groups of mammals.
5. Identify many of the species of mammals native to the western U.S.
6. Gain a working knowledge of the basic ecology and conservation biology of mammals.
7. Use wildlife survey techniques for identifying sign, evaluating biodiversity, assessing habitat associations, and estimating population densities of mammal species at selected study sites.
8. Conduct very basic quantitative analyses of ecological data.
9. Formulate hypotheses and design a research project to test a hypothesis.
10. Write a research paper that reports the results of a study in a format of a scientific journal.

STUDENT ASSESSMENT

The level of comprehension and mastery of the material by the students will be evaluated through classroom discussions and by monitoring the performance of students in laboratory exercises, exams, and additional duties and assignments.

Grades are based on a point system with an approximate breakdown as follows:

Lab exams (100 points each, 2 exams)	200 points
Lab assignments & reports	100 points
Field notebook	50 points
Research paper	100 points
Midterm exam	100 points
Final exam	100 points
Attendance & participation	50 points

The term's grade is based on a percentage of total points accumulated according to the following schedule:

90-100%	(628-700 points)	A
80-89%	(557-627 points)	B
65-79%	(452-556 points)	C
55-64%	(382-451 points)	D
<55%	(0-381 points)	F

TOPICS

I. General characteristics of modern mammals

II. Mammalian evolution
   A. Origins of mammals
      1. Beginnings: Characteristics of pelycosaurs and other early synapsids
      2. Adaptations: Dentition, jaw structure, and other skeletal traits
      3. Advanced therapsids and the first mammals
   B. Major adaptive radiations
      1. Early lineages and their ecological specializations
      2. Biogeographical influences
      3. Convergence among major groups of mammals

III. General biology of mammals
   A. Mammalian environmental physiology
      1. Thermoregulation
         a. Dealing with cold
         b. Dealing with heat
      2. Torpor, hibernation, & biological timing
   B. The mammalian nervous system
      1. The mammalian brain
      2. Sensory systems in mammals
   C. Mammalian reproductive biology
      1. Comparative strategies of monotremes, marsupials, and eutherians
      2. Reproductive cycles
         a. Hormonal regulation
         b. Delayed fertilization and implantation
         c. Environmental cues

IV. Mammalian biodiversity
   A. Biology of monotremes and marsupials
      1. Classification, characteristics, & biogeography
      2. Natural history & habitat associations
   B. The rise of eutherians
      1. General classification, biodiversity, and biogeography of eutherians
      2. Biology of the sloths, armadillos, anteaters, etc; "life with a low metabolic rate"
   C. Insectivores (shrews and moles): life with a high metabolic rate
   D. Chiroptera (bats)
      1. Classification & characteristics
      2. The biology and physics of echolocation
      3. Biogeography and natural history

E. Primates and related orders
   1. Scandentia (tree shrews)
   2. Dermoptera (colugos or flying lemurs)
   3. Primates
      a. General biology
      b. Evolutionary history
      c. The evolution of hominid primates, including humans
F. Rodentia
   1. Diversity, characteristics, and general biology
   2. Classification, natural history, and habitat associations
G. Lagomorpha
   1. Classification, characteristics, & biogeography
   2. Functional biology & behavior
   3. Natural history & habitat associations
H. Carnivora
   1. Classification, characteristics, & biogeography
   2. Functional biology & behavior
   3. Natural history & habitat associations
I. Artiodactyla
   1. Classification, characteristics, & biogeography
   2. Functional biology & behavior
   3. Natural history & habitat associations
J. Cetacea
   1. Classification, characteristics, & general biology
   2. Natural history & behavior
   3. The biology of sonar
K. Proboscidae, Sirenia, & Hyracoidea
L. Perissodactyla

V. Mammalian social behavior
   A. Reproductive behavior
      1. Mating
      2. Parental Care
   B. Group behavior
      1. Complex social units—packs, herds, and individual roles
         a. Colonies—altruism and kin selection
         b. Mating systems and defense
         c. Pack behavior & cooperative effort
      2. Territoriality

VI. The Ecology of Mammals
- A. Mammalian population biology
  - 1. Population growth
  - 2. Regulation of populations
  - 3. Predator-prey cycles
- B. Mammalian community ecology
- C. Roles of mammals in ecosystems

VII. Conservation biology & endangered mammals
- A. Habitat loss
- B. Exploitation
- C. Theoretical considerations

NOTES FOR INSTRUCTORS

Several of the laboratories described here assume that you have access to local mammal specimens (skulls, skeletons and skins) as well as collection equipment such as livetraps. If these materials are not available at your institution, they can often be loaned from other colleges and universitites, local museums, or state fish and wildlife agencies. Also, before sending students out collecting mammals, be sure to check with state fish and wildlife officials to acquire scientific collecting permits and to clarify restrictions on the capture of protected species.

Laboratory and field activities should be customized for local ecosystems and mammals. Most exercises could be modified by having students develop hypotheses before lab work is started. This would give students some practical experience with the scientific process. Lab exercises could also be combined with computer modeling, a frequently used tool in this type of work. Students should be encouraged to critically analyze how effectively they performed the exercises, and to consider why they came up with the results and conclusions they did.

LABORATORIES & ACTIVITIES

LAB #1 Mammalian skull structure, dentition and skeletal anatomy; Use of a dichotomous key

LAB #2 Mammal classification

LAB #3 Field techniques: Observations, species identification, field notes, and GPS

LAB #4 Measuring and assessing species diversity I: Observations of diurnal animals

LAB #5 Measuring and assessing species diversity II: Trapping small terrestrial mam mals

LAB #6 Measuring and assessing species diversity III: Identifying mammals by their sign

LAB #7 Transect methods for estimating the abundance of mammal populations

LAB #8 Abundance indices: Burrows and deer pellets

ONGOING ASSIGNMENTS

1. Keep a field notebook on observations of wild mammals and mammal sign.

2. Plan a field study that tests a hypothesis concerning the biology of mammals.

3. Write a research paper reporting the results of the field study.

4. Write a detailed lab report, in the format of a scientific journal article, that summarizes the findings of the laboratory exercises that are components of the class biodiversity study.

Mammalian Skull Structure, Dentition, and Skeletal Anatomy

INTRODUCTION

As early mammals evolved to fill a variety of niches, the morphology of the teeth, jaws and postcranial skeleton became increasingly diverse and specialized. The dietary specializations and evolutionary history of the different lineages of mammals are reflected in the structure and arrangement of the teeth and the features of the skull. In fact, the teeth and jaws exhibit more variation than any other feature among mammals. Consequently, mammalogists frequently use skull and tooth characteristics to classify groups of mammals or to identify mammal species.

In this exercise, you will use a dichotomous key to identify mammals based on their skull characteristics. In addition, you will also attempt to discern the type of foods that each species eats based on its dentition and jaw structure. Finally, you will compare the postcranial skeletons of three mammals and determine the relationship between skeletal structure and function.

PROCEDURE

1. Use of a Dichotomous Key & Interpreting Tooth and Jaw Specializations

The term **dichotomous** refers to the fact that each step of the key has two choices, or branches; each of which leads to a different group of species. The key is branching, or bifurcating, and will eventually lead to a terminal branch that identifies your specimen. Each step of the key consists of two separate descriptive summaries of traits for different groups of species. As you follow the key, your specimen will fit the description of one of the two summaries. The number listed after the summary that describes your specimen tells you the next step that you should go to in the key. Eventually, the key will lead to the name of the species or group to which your specimen belongs. A sample dichotomous key is shown on page 10.

A key to the coins of the United States minted after 1976:

1(a).	Consisting entirely of copper	Penny
1(b).	Consisting of nickel, or a mixture of copper and silver	2
2(a).	Eagle present on the back of the coin	3
2(b).	Eagle not present on the back of the coin	6
3(a).	Eagle flying above the surface of the moon	4
3(b).	Eagle not flying above the moon	5
4(a).	Woman's head present on the front of the coin	Susan B. Anthony $
4(b).	Man's head present on the front of the coin	Standard (Eisenhower) "Silver" $
5(a).	Shield covering the breast of the eagle; eagle clutching arrows in its left talons and an olive branch in its right talons	50 cent piece
5(b).	Breast of eagle unshielded; eagle perched on branch	Quarter
6(a).	Neoclassical building (Monticello) on the back of the coin	Nickel
6(b).	Torch with olive branches on each side on the back of the coin	Dime

You will find the skulls to be identified on your table in the laboratory. Each skull is numbered. There is an index to the skulls in the reference collection that reveals the true identity of each of the numbered skulls. Record the index number of each skull in the first column of the attached Skull Identification Sheet. Use the key to determine the order, family, and species (or genus if the key only goes that far) of each mammal skull on your table. Record this information in columns 2 to 4 of the Skull Identification Sheet. Examine the cheekteeth of each specimen and categorize the cheek teeth based on the terms listed under Cheekteeth Terminology in the handout. Record this information in column 5 of the identification sheet. Based on the structure of the teeth and jaw, describe, in column 6 (Diet), what types of foods were eaten by this species.

2. Postcranial Skeletal Structure and Locomotion

The major evolutionary change in the postcranial skeleton of mammals involved a shift from the sprawling stance of their reptilian ancestors to an upright stance in which the limbs were held directly beneath the body. Changes in the shape and position of the bones of the pelvis, the proportions of the shoulder blade, the number of ribs, and the shape of the vertebrae (along with the plane of flexure in the spine) accompanied this shift. In addition some of the wrist and ankle bones became fused, while extensions of the heel bone and the ulna provided additional area for the attachment of muscles that move the limbs in a plane parallel to the body. All of these adaptations improved the biomechanical efficiency of locomotion in mammals by shifting the direction of limb movement to a plane parallel to the longitudinal axis of the body. Mammals were becoming increasingly adept at sustained and rapid running, also known as **cursorial locomotion**.

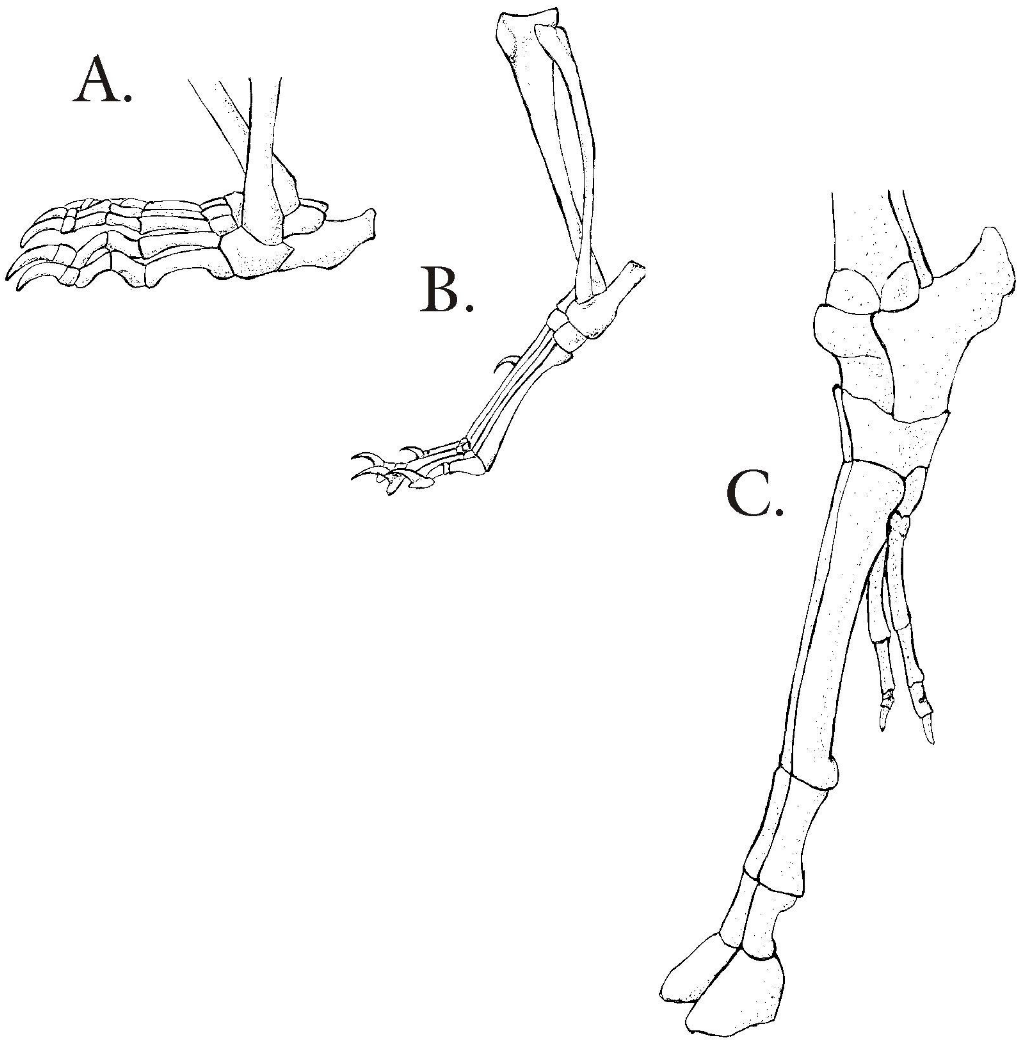
As mammals became increasingly dependent on cursorial locomotion, many groups exhibited a trend towards running on their toes to increase the length of their stride and decrease the surface area of the foot that was in contact with the ground. A stance, or posture, in which the metapodial bone (metacarpals and metatarsals) are elevated and only the toes touch the ground is known as a *digitigrade* stance. The primitive mammalian stance, in which the foot rests flat on the ground, is known as a *plantigrade* stance. Burrowing mammals and mammals with opposable digits tend to retain the plantigrade condition. The digitigrade condition has been taken one step further by mammals that exhibit an *unguligrade* stance (i.e., deer and horses). Ungulates run on the tips of their toes and have only one or two digits in contact with the ground (See Figure 1, page 12)

a. Examine the three skeletons, Skeleton A, Skeleton B, and Skeleton C, provided. Classify each one as plantigrade, digitigrade, or unguligrade.

b. Compare the limb proportions of the three skeletons. Explain the functional significance of the differences you see in the proportions of the limb bones.

c. How are the shoulder and pelvic girdles of the three skeletons different? What might be the functional significance of these differences?

Figure 1. A comparison of the skeletal structure of the lower limbs of mammals with a plantigrade stance (A), digitigrade stance (B), and unguligrade stance (C).



Skull Identification Sheet

Index Number	Order	Family	Species (or Genus)	Type of Cheekteeth	Diet

Index Number	Order	Family	Species (for Genus)	Type of Cheek-teeth	Diet

HANDOUT

Trends in the Evolution of Mammalian Teeth, Jaws, and Postcranial Skeletal Features

Among the earliest terrestrial vertebrates was a group known as the limnoscelids, which lived in the late Carboniferous Period. They had an open suture (slit) between the skull roof and cheek region. The bones bordering the slit were mechanically advantageous sites for the attachment of jaw muscles. The edges of this opening in the temporal region of the skull provided a more secure origin for muscle attachment than a flat surface. Natural selection for stronger jaw musculature favored a larger and larger gap. This was the origin of *Synapsida*, traditionally considered a subclass of the Class Reptilia, which eventually gave rise to mammals. There were three other subclasses of early reptiles (Figure 2, page 20). One subclass, known as Diapsida, developed two temporal openings. This lineage eventually gave rise to dinosaurs, crocodilians, birds, lizards, and snakes. Another subclass, *Euryapsida*, developed a single temporal opening in a position higher on the skull than the temporal opening of synapsids. The Euryapsids included marine reptiles, such as the Plesiosaurs, which are now extinct. The early reptiles that never developed a temporal opening are grouped in the subclass Anapsida. Turtles are the modern representatives of this lineage.

Among the groups of early synapsids were the Eupelycosaurs (sometimes called the sail finned reptiles—for the prominent dorsal crest in some species). The Eupelycosaurs exhibited a variety of dietary and morphological specializations that were important in the evolution of mammal-like traits. For example, a group of stout, robust herbivores known as the casieds developed tooth specializations for herbivory. The largest teeth were in front, and were specialized for snipping vegetation. The posterior teeth had cutting edges formed by many small cusps. A family of carnivorous synapsids, known as the sphenacodonts, had enlarged anterior teeth that were specialized for grasping and killing prey. The condition in which teeth in different regions of the mouth exhibit morphological differences that are related to specialized functions is known as **heterodont dentition**. **Homodont dentition** is the condition in which all of the teeth perform similar functions and resemble one another. Heterodont dentition is one of the key traits contributing to the success of mammals.

The teeth of sphenacodonts were rooted deeply in the maxilla (the large tooth-bearing bone of the upper jaw). An evolutionary trend towards deeper roots was accompanied by an increase in the depth of the maxilla. As maxilla grew downward, the palate (bones that form the roof of the mouth) became arched. An arched palate is advantageous for two reasons: (1) it is mechanically stronger than a flat palate, and (2) it provides space for air to pass over prey held in the mouth, which allows eating and breathing to occur simultaneously. The arching of the palate was the first step toward the separation of the mouth & nasal cavities. Later synapsids developed a secondary palate that formed a partition between the oral and nasal cavities. The formation of the secondary palate, and changes in the structure of the limbs and spine, suggests that synapsids were becoming increasingly active creatures.

The sphenacodonts gave rise to the therapsids—or mammal-like reptiles that flourished from the mid-Permian through the Triassic periods. The therapsids exhibited trends that culminated in the tooth, jaw, middle ear, and skeletal features characteristic of modern mammals. In fact, the distinction between later Therapsids and early mammals is extremely vague.

These partitions are known as **nasal turbinates**. Some of these turbinates, known as the **maxilloturbinals**, function in warming and humidifying inhaled air and in recapturing moisture from exhaled air. These structures are found only in **endothermic animals**. The rapid breathing rates of endothermic animals makes them susceptible to respiratory water loss. The maxilloturbinals minimize respiratory water loss during exhalation and condition the air to minimize stress to the lungs during inhalation. Evidence of mammal-like maxilloturbinals first shows up in fossils of advanced therapsids. This indicates that endothermy was evolving among later therapsids (Hillenius 1994). Some of the other significant evolutionary trends that occurred as the therapsids became increasingly mammal-like are summarized below.

Changes in the Skeleton that Occurred During the Evolution of Mammals from Earlier Synapsids

1. The temporal opening became larger and eventually the attachment site for the jaw muscles moved from the inner surface of the temporal region of the skull to the outer surface of the cranium and the zygomatic arch.

2. Among the bones of the lower jaw, the dentary became larger while the articular and quadrate became smaller until they were incorporated into the structure of the middle ear. A new jaw joint formed between the dentary bone of the lower jaw and the squamosal of the cranium. Fossils of some of the advanced therapsids exhibit a double-jointed jaw, in which both the reptilian and mammalian jaw joints were present. Fossils that exhibit the single dentary-squamosal jaw joint are generally classified as **mammals**.

3. The maxillary and palatine bones of the upper jaw extended back and toward the center of the roof of the mouth to form a secondary palate, which separated the mouth cavity from the nasal cavity. In animals with a secondary palate, the internal nares are at the back of the palate, rather than at the front of the roof of the mouth. This allows them to chew and breathe at the same time. This is also useful for animals that suck milk while they are young.

4. The dentition of the stem reptiles was homodont (all teeth were uniform in size & shape) with little occlusion. Some of the early synapsids developed heterodont dentition, in which different teeth exhibited different specializations in form and function. Tooth specialization became increasingly complex with the therapsids. The teeth began to exhibit precise occlusion (the teeth of the upper and lower jaws fitting together nicely) and chewing efficiency was improved by the advent of complex cheek teeth, including the tribosphenic molar, which was triangular in shape and had multiple cusps.

5. Dentition changed from polydont, in which the teeth were replaced many times during the lifetime of the animal, to diphyodont, in which the teeth were replaced only once (two sets of teeth).

6. There was a shift from one occipital condyle to two occipital condyles in advanced mammal-like reptiles. This made vertical (up and down) movement of the head easier, but decreased lateral (side to side) movement.

7. The limbs rotated from a splayed or "push-up" position, characteristic of the reptilian stance, to a position where they are held directly beneath the body, perpendicular to the ground. Some of the therapsids had hind limbs that were held directly beneath the body, but retained the sprawling reptilian forelimbs. Later therapsids had a mammalian stance, in which all four limbs were held directly beneath the body. This change was accompanied by changes in the pelvis and pectoral girdle. The ilium of the pelvis extended forward and the bones of the pelvis became fused. The scapula, or shoulder blade, of the pectoral girdle expanded upward. This provided an increased area for attachment of dorsal muscles. There was less emphasis on ventral muscles.

8. The ribs of the cervical (neck) and lumbar (lower back) vertebrae were lost, and the number and size of the thoracic ribs was reduced. This, along with changes in the shape of the vertebrae and the scapula, allowed more dorsoventral flexure (up and down movement) of the spine. Think of the dorsoventral movement of the spine of a running dog compared to the lateral movement of the spine of a running lizard.

9. The number of carpal (wrist) and tarsal (ankle) bones was reduced through fusion. This strengthened the wrist and ankle joints. Extensions of the heel bone and the ulna (funny bone) allowed for better muscle attachment for movement of the limbs in a plane parallel to the body.

10. The phalangeal formula (which gives the numbers of bones in each finger & toe) went from the reptilian 2-3-4-4-3 on the front feet and 2-3-4-5-4 on the hind feet to 2-3-3-3-3 on both front and hind feet, which is the formula for most mammals, including you. You can count your own phalanges to prove this fact to yourself. Start with your thumb and finish with your little finger.

Tooth and Jaw Characteristics of Modern Mammals

As early mammals diversified and specialized to fill a variety of niches, the morphology of the teeth, jaws, and postcranial skeleton became increasingly diverse and specialized. The dietary specializations and evolutionary history of the different lineages of mammals are reflected in the structure and arrangement of the teeth and the features of the skull. In fact, the teeth and jaws exhibit more variation than any other feature among mammals. Consequently, mammalogists frequently use skull and tooth characteristics to classify groups of mammals or identify mammal species.

As was noted previously, one of the major evolutionary innovations in mammals was the shift from homodont to heterodont dentition. However, not all modern mammals have heterodont dentition. Some groups, such as the armadillos and toothed whales, have homodont dentition. Homodont dentition has apparently been derived from heterodont dentition among several lineages of fish-eating creatures in the synapsid lineage (including the toothed whales). The monotremes, an order that includes the duck-billed platypus and echidnas, lack teeth altogether as adults (they are **edentate**). Several lineages of mammals that feed on ants and termites are also edendate. Baleen replaces the teeth in the upper jaw in the mysticete whales. The baleen acts as a filtering device to capture small planktonic creatures from the water.

Most mammals exhibit heterodont dentition. The teeth of mammals with heterodont dentition can be classified in four categories: (1) **incisors**, (2) **canines**, (3) **premolars**, and (4) **molars**. The incisors are the anterior teeth that are rooted in the premaxilla of the upper jaw and in the anterior portion of the dentary bones (mandible) of the lower jaw. They usually have a single cusp and a single root. In rodents and lagomorphs the central incisors are specialized for gnawing or cutting, and they grow throughout the life of the animal. The lateral incisors are absent in rodents. Deer (family Cervidae) have lost the upper incisors, but press their lower incisors against a tough region of tissue in the upper jaw to clip vegetation.

The canines are the pair of teeth just behind the incisors. No mammal species has more than one pair of upper canines and one pair of lower canines. Canines usually have a single cusp and a single root (although shrews have an accessory cusp on the upper canines). Among carnivores, the canines are usually long and sharp, and are used to penetrate deeply into their prey to deliver the fatal wound. The upper canines of walruses are modified to form tusks. Pigs have tusks that are derived from the lower canines. Certain Asian deer species that lack antlers also have canines that are modified to form tusks. Many herbivorous mammals lack canines or have canines that are modified to look and function like incisors. For example, deer have *incisiform* lower canines that are indistinguishable from the lower incisors. Species that lack canines, such as the rodents and lagomorphs, frequently have a prominent gap, called a *diastema*, between the incisors and the *cheekteeth*.

The premolars are the teeth between the canines and the molars. They may have multiple cusps or a single cusp, depending on the species and the location in the jaw. Premolars usually have two roots (molars usually have three). In many grazing and browsing mammals the premolars are large and similar in structure to the molars. Among certain carnivores, such as the cats, the premolars are large and specialized for slicing meat, whereas the molars are reduced in number, size, and significance.

The molars are the most posterior teeth in the jaw. They usually have three roots and multiple cusps. There are no deciduous molars (they are not replaced and are not present among the "milk teeth"). The molars and premolars are often grouped together and classified as *cheekteeth* or postcanine teeth. They are typically more complex and specialized than the incisors and canines. A variety of terms have been coined to describe the different types of postcanine teeth. Some of these terms are defined below.

Cheekteeth Terminology

1. Crown height:

   Brachyodont - cheekteeth with low crowns. A common condition among omnivores.
   Hypsodont - cheekteeth with high crowns or ridges. A common condition among grazers and browsers, which eat tough or fibrous plant material.

2. Terms referring to the occlusal surface:

   Bunodont - cheekteeth with rounded cusps that are modified for grinding and crushing; brachyodont cheekteeth usually have bunodont occlusal surfaces.
   Lophodont - cheekteeth with cusps that form lophs (continuous ridges that are shaped like the folds of an accordion). This is the pattern exhibited by elephants, including the extinct woolly mammoth, which had massive lophodont molars.
   Selenodont - cheekteeth with separate crescent-shaped ridges. This is the pattern typically seen in members of the order Artiodactyla (deer, cattle, and their relatives). Lophodont and selenodont teeth are used for grinding tough vegetation.
   Carnassial (sectorial) - specialized cheek teeth that function like scissor blades to slice or shear. A pair of carnassial teeth is present on each side of the jaw in modern mammals in the order Carnivora. They are especially well developed among members of the families Felidae (cats), Canidae (dogs), and Mustelidae (weasels). The carnassial teeth always consist of the last upper premolar and the first lower molar. When carnassial teeth on one side of the jaw are being used, the carnassials on the other side are out of alignment.

Dental Formulae

Mammalogists frequently use **dental formulae** as a type of notation to describe the numbers and locations of teeth in mammal species. Dental formulae express the number of teeth of each category (incisor, canine, premolar, and molar) on one side of the jaw. For each category, beginning with incisors and ending with molars, the number of teeth on one side of the upper jaw is written above a line (or preceding a slash) and the number of corresponding teeth on the lower jaw is written below the line (or after the slash). For example, the dental formula of the mountain lion (*Felis concolor*) is 3/3, 1/1, 3/2, 1/1. It has 3 incisors, 1 canine, 3 premolars, and 1 molar on each half of the upper jaw; and 3 incisors, 1 canine, 2 premolars, and 1 molar on each half of the lower jaw.

Jaw Structure

The morphology of the lower jaw, and the use of the muscle groups associated with the jaws, varies according to the diet of the species. In **carnivorous mammals**, the joint (articulation) between the mandible and the cranium is level with the tooth row. In this position, the temporalis muscle, which originates on the temporal region of the skull and inserts on the coronoid process of the mandible, serves as the major jaw-closing muscle. In herbivorous mammals the mandibular articulation is much higher than the tooth row. Consequently, the masseter muscle, which originates on the zygomatic arch and inserts on the lower posterior part of the mandible, is the major jaw-closing muscle in herbivores (See Figure 3). The masseter muscle allows lateral movement of the lower jaw, which aids in grinding food.

In carnivorous mammals, the part of the cranium that articulates with the mandible (known as the mandibular fossa) is deep and C-shaped in cross-section, and the mandibular condyle is shaped like a cylindrical bar. Consequently, the mandibular condyle of the lower jaw fits tightly within the mandibular fossa of the cranium to form a hinge-like joint that allows very little lateral movement of the lower jaw. Often, the skulls of carnivorous mammals will possess prominent ridges that provide additional area for attachment of the powerful temporalis muscles. The powerful temporalis muscle and firm jaw joint permits a carnivore to firmly grasp struggling prey in its mouth without dislocating its lower jaw.

Figure 2. Skulls of representative members of the early reptilian subclasses Anapsida, Synapsida, Diapsida, and Euryapsida. A. *Eocaptorhinus*, an early anapsid. B. *Dimetrodon*, a synapsid in the family Sphenacodontidae, the lineage that gave rise to mammal-like reptiles.
C. *Euparkeria*, an early diapsid. D. *Elasmosaurus*, a marine reptile in the subclass Euryapsida.

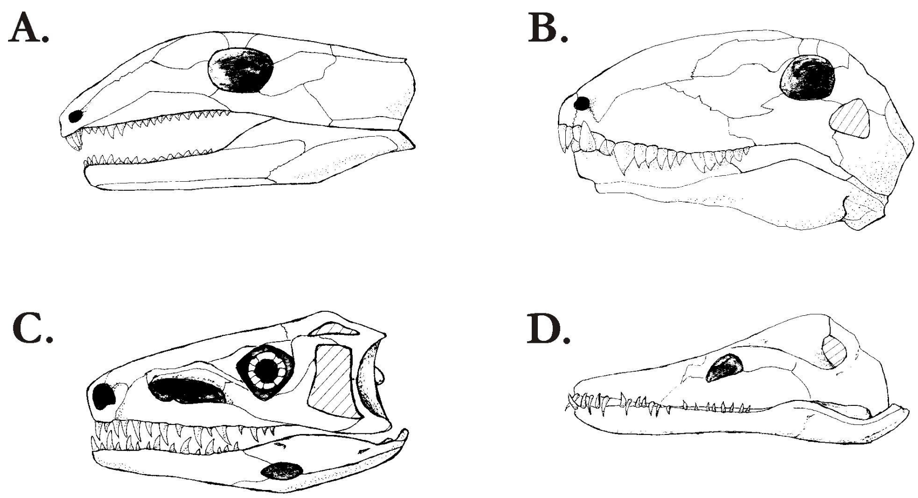
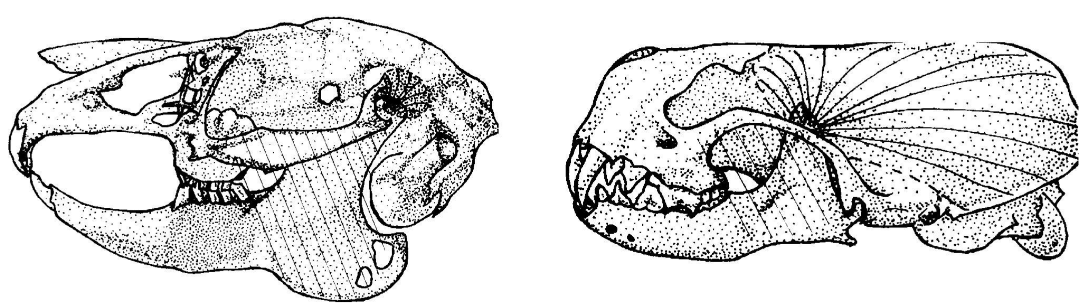


Figure 3. Skulls of a black-tailed jackrabbit (below left) and a long-tailed weasel (below right), illustrating the differences between herbivores and carnivores in the structure of the jaw and the jaw musculature. Stripes indicate the positions and orientation of the masseter and temporalis muscles.



MATERIALS

Dichotomous key (adapted from Ingles, 1967 for Pacific states; see resources below for keys to mammals in other areas)
Skulls of representative mammals
3 complete mammal skeletons (representing various stances as described in lab)

REFERENCES

DeBlase, A.F. and R.E, Martin. 1981. *A manual of mammalogy with keys to families of the world*. Wm. C. Brown Co. Publ., Dubuque, IA 436 pp.

Hamilton, W.J., Jr. and J.O. Whitaker, Jr. 1979. *Mammals of the eastern United States*, 2nd ed. Cornell Univ. Press, Ithaca, NY 346 pp.

Hillenius, W.J. 1994. *Turbinates In Therapsids: Evidence For Late Permian Origins Of Mammalian Endothermy.* Evolution 48:207-229.

Ingles, L.G. 1967. *Mammals of the Pacific States.* Stanford University Press, Stanford, California.

Whitaker, J.O., Jr. 1968. *Keys to vertebrates of the eastern United States*. Burgess Publ. Co., Minneapolis, MN. 256 pp.

Mammal Classification

INTRODUCTION

It is human nature to assign objects to categories. This tendency is especially prevalent in science. Scientists have categorized everything from rocks to clouds according to their similarities and differences. Considering the almost limitless opportunities for classifying living organisms, it should not be surprising that humans have been classifying plant and animal species for as long as human culture has existed. A reliable system of classification was probably indispensable to hunter-gatherer societies that depended on the correct identification of plants that were sources of food or medicine. Surprisingly, the systems of nomenclature and classification employed by many aboriginal peoples is conceptually similar to our current scientific system. The classification of living things played an integral role in agricultural societies as well. An accurate system of classification for assigning species to categories is especially pertinent from a scientific perspective, because it helps us understand both the characteristics of a species, and the evolutionary relationships among species.

Linnean System Of Classification

The system of classification that is used today was developed by a Swedish botanist named Carolus Linneaus. It became established with the publication of the tenth edition of Linneas' *Systema Naturae* in 1758. Although Linneas did not originally envision it this way (he believed that species are fixed and unchanging), the Linnean system of classification reflects to a degree the evolutionary relationships among species. The Linnean system uses a hierarchy of categories to reflect the degree of similarity among species and among groups of species. These categories are species, genus, family, order, class, phylum (equates with division in plants), and kingdom. Genera are groups of related species, families are groups of related genera, orders are groups of related families, etc. For example, the species name of the wolf is *Canis lupus. Canis lupus* is in the genus *Canis*, the family Canidae, the order Carnivora, the class Mammalia, the phylum Chordata, and the kingdom Animalia. The species name always includes the genus name (it is binomial). It is Latin based, and is always underlined or italicized. Often, for convenience, extra categories or divisions are included in the classification scheme. For example, humans (*Homo sapiens*) are in the family Hominidae, which is included in the superfamily Hominoidea (which includes the ape and gibbon families as well), which is included in the suborder Anthropoidea (which also includes the superfamilies of Old World and New World monkeys), which is included in the order Primates (along with all other primates, both living and extinct), which is included in the infraclass Eutheria (along with all other mammals that have a true placenta), which is included in the subclass Metatheria (which also includes the marsupials), which is included in the class Mammalia (which also includes the monotremes), which is included in the subphylum Vertebrata (along with all other vertebrates), which is included in the phylum Chordata (along with all other chordates).

Of all of the categories, subcategories, and supercategories in the Linnean system of classification, the only truly meaningful one is the species category. All other categories are subjectively defined and are designated in a somewhat arbitrary manner. Species are real taxonomic units that exist in nature. The traditional definition of a species, known as the biological species concept, is a group of naturally interbreeding organisms that are similar in appearance, produce fertile offspring, and are reproductively isolated from other groups of organisms (Mayr 1957, 1969). In reality, this definition is too restrictive for some organisms, since individuals of certain species are unisexual and produce clones of themselves instead of reproducing by sexual means. A more appropriate definition of a species, known as the evolutionary species concept, is a lineage of organisms with a unique genetic identity and distinct evolutionary history (Simpson 1961, Wiley 1981). However, since all mammals depend on sexual reproduction, the biological species concept is adequate for mammals. In practice, we usually identify an individual as belonging to a certain species because it looks like other members of that species. Consequently, classification has historically relied heavily on morphological traits. Recently, molecular techniques that reveal the genetic similarity of individuals have assumed a prominent role in classification.

PROCEDURE

You will find that there are specimens (stuffed mammal skins) available for inspection in the lab. Your job is to consult with your classmates to assign these specimens to categories. Don't worry about using the actual Latin names. You can use descriptive names for categories instead. For example, if you were examining a western gray squirrel, you might decide that it should be placed in a category called *squirrel-like mammals with bushy tails*. The squirrel-like mammals with bushy tails might be grouped with another category of mammals called *squirrel-like mammals with thin tails* in a higher category called *squirrel-like mammals*. Continue grouping, classifying, and naming mammals until all of the specimens in the room have been placed in a hierarchical classification system. You will be supplied with *Post-It* ® notes that you can use to label each category.

Once the classification system is complete, record the categories on a piece (or pieces) of paper and list all of the specimens or groups in each category. It might help to draw your classification scheme out, like a phylogeny or evolutionary tree, to organize it. The common name of each of the specimens is written on a piece of paper that has been slipped over the original specimen tag.

After your list is complete, we will examine a copy of a recent classification scheme that includes all of the families represented by our specimens. We will also inspect the "*Tree of Life*" on the worldwide web at www.phylogeny.arizona.edu/tree. The Tree of Life is a huge series of interconnected web sites that contains regularly updated information on the evolutionary

relationships of all living organisms on the planet. It is a work in progress, so information on some groups is missing or fragmentary, but the information that is presented usually represents the latest ideas on the evolutionary relationships of different species and groups of species. Compare your classification scheme to the established system of classification.
Use the new information that you have received to place the specimens in hierarchical groups according to their actual genera, families, suborders, and orders. You may need to rearrange the specimens in some of the groups that you created previously. Label each of the categories of specimens. The names and correct spellings of the families and orders can be found in the Appendix. The genus and species names can be found on tags attached to the specimens. The tags have been concealed beneath paper sleeves that bear the common names. Note instances when specimens had to be rearranged to place them in groups that are in agreement with the current system of classification.

This is a group activity, so be sure that you consult with your classmates. Answer the following questions and turn in your answers before you leave the end of the lab period. Attach your classification to the answers to the questions.

MATERIALS

Museum specimens for classification (mammal skins)
Post-It ® Notes

QUESTIONS

1. What were the major discrepancies between the classification scheme described by the class and the currently recognized classification? How might you account for these differences?

2. A common problem that biologists face when classifying species is that some unrelated species may look similar because they have independently evolved similar traits in response to similar selective pressures. This pattern is known as convergent evolution. Do you see any examples of convergent evolution among our specimens? If so, describe them.

3. Overall, was your method of classification reasonably accurate? Which traits appeared to be the best indicators of the degree to which different species and groups of species are related? Which traits were apparently poor indicators of evolutionary relationships?

APPENDIX

The Orders of Mammals, and Some of the More Familiar Families

This classification is based on Wilson and Reeder (1993) and Feldhamer et al. (1999). The sub-orders of some of the more well-known groups are also listed.

Total numbers for Mammalia:
Orders: 26
Families: 133
Genera: 1117
Species: 4604

Class Mammalia

Subclass Prototheria - egg layers
- Order Monotremata - duck-billed platypus and echidnas (spiny anteaters)

Subclass Theria - live birth
- Infraclass Metatheria - marsupials (young develop in pouch)
  - Order Didelphimorpha
    - Family Didelphidae - New World opossums
  - Order Paucituberculata - shrew opossums (rat opossums)
  - Order Microbiotheria - monito del monte
  - Order Dasyuromorphia - marsupial mice, Tasmanian devil, numbat
  - Order Peramelemorphia - bandicoots and bilbies
  - Order Diprotodontia - koala, wombats, kangaroos, Australian possums, etc.
  - Order Notoryctemorphia - marsupial moles
- Infraclass Eutheria - mammals with true placenta (endocrine function during gestation)
  - Order Insectivora - shrews, moles, hedgehogs, tenrecs, etc.
      - Soricidae - shrews
      - Talpidae - moles and desmans
  - Order Scandentia - tree shrews
  - Order Macroscelididea - elephant shrews
  - Order Dermoptera - flying lemurs or colugos
  - Order Chiroptera - bats
    - Suborder Megachiroptera - old world fruit bats
    - Suborder Microchiroptera - all other bats
      - Phyllostomidae - new world leaf-nosed bats
      - Vespertilionidae - common bats
      - Molossidae - free-tailed bats
  - Order Primates
      - Hominidae - gorillas, chimps, orangutans, human
  - Order Tubulidentata - Aardvark
  - Order Edentata (Xenarthra) - armadillos, sloths, anteaters
  - Order Pholidata - pangolins (scaly anteaters)
  - Order Carnivora

Suborder Feliformia - cats, mongooses, hyenas
Felidae - mountain lion, bobcat, tiger
Suborder Caniformia
Canidae (dog family) - wolves, coyotes, foxes, jackals
Ursidae - bears
Procyonidae - racoon, ring-tail, coati, red panda
Mustelidae - badger, weasels, skunks, & otters
Otariidae - eared seals (fur seals, sea lions)
Phocidae - earless seals (harbor seals, elephant seals)
Odebenidae - walrus
Order Cetacea - whales, dolphins, and porpoises
Suborder Mysticeti - baleen and filter-feeding whales
Suborder Odontoceti - toothed whales
Order Rodentia
Suborder Scuirognathi
Aplodontidae - mountain beaver
Scuiridae - squirrels. marmots, chipmunks, etc.
Castoridae - beavers
Geomyidae - pocket gophers
Heteromyidae - kangaroo rats, kangaroo mice, pocket mice
Muridae- rats, mice, muskrat, voles, & lemmings
(Note: the New World members of this family have traditionally been placed in the family Cricetidae, but have recently been placed in Muridae)
Suborder Hystricomorpha - porcupines, lots of S. Am. rodents
Erethizontidae - porcupines
Order Lagomorpha
Leporidae - rabbits and hares
Ochotonidae - pikas
Order Hyracoidea - hyraxes
Order Proboscidea
Elephantidae - African and Asian elephants
Order Sirenia - manatees and dugongs
Order Perissodactyla - horses, rhinos, and tapirs
Equidae - horses, zebras

Order Artiodactyla - sheep, goats, camels, hippos, pigs, cows
Suborder Suiformes - pigs, warthogs, peccaries, & hippos
Suborder Tylopoda - camels, llama, gunaco, alpaca (all are Camelidae)
Suborder Ruminantia
Cervidae - deer
Antilocapridae - pronghorn
Bovidae - true antelope, sheep, goats, bison, cattle

REFERENCES

Feldhamer, G.A., L.C. Drickamer, S.H. Vessey, and J.F. Merritt. 1999. *Mammalogy: Adaptation, Diversity, and Ecology*. WCB McGraw-Hill, Boston, Massachusetts.

Mayr, E. 1957. Species concepts and definitions. In E. Mayr (ed.). *The Species Problem*. American Association for the Advancement of Science Publication 50:1-22.

Mayr, E. 1969. *Principles of Systematic Zoology*. McGraw-Hill, New York.

Simpson, G.G. 1961. *Principles of Animal Taxonomy*. Columbia University Press, New York.

Wiley, E.O. 1981. *Phylogenetics: The Theory and Practice of Phylogenetic Systematics*. John Wiley and Sons, Inc., New York.

Wilson, D.E., and D.M. Reeder (eds.). 1993. *Mammal Species of the World: A Taxonomic and Geographic Reference*. 2nd edition, Smithsonian Institution Press, Washington D.C.

Field Techniques: Observations, Species Identification, Field Notes and GPS

INTRODUCTION

Observational Techniques

To learn something about the typical habits and behavior of a species of mammal, we must observe individuals of that species carrying out their normal activities under natural circumstances. Observing mammals is not as easy as it sounds. Most mammal species are secretive and nocturnal. To further complicate matters, many species are also small, inconspicuous, or fossorial (living underground). Consequently, they often escape detection by human observers. To overcome this limitation, an appropriate strategy must be employed to locate individuals of a target species and to have the opportunity to observe and positively identify them.

If we simply need to determine whether a particular species is present in a certain area, or utilizes a certain type of habitat, it is not always necessary to directly observe it. Tracks, scat, burrows, or other evidence can confirm its presence. Muddy soil, sand, trails, and streamside habitat are often good places to look for the tracks of mammals. Structures constructed by mammals are often easy to discover, and certain mammal species deposit scat in conspicuous locations. In many instances, it is possible to identify the species of mammal responsible for the sign by recognizing unique characteristics of the sign. We will explore the use of sign in identifying species of mammals in a future lab exercise.

Often, when we need positive identification or observations of activities such as foraging and activity patterns, we must observe mammals directly. For observations to be most effective, the observer should not be detected. One way to avoid detection is to silently approach an individual or group of animals from a downwind angle that offers some concealment. This method works best for observing herds of ungulates or other relatively large mammals that have visual acuity that is not superior to that of humans. Another method that is suitable for observing medium-sized to large species of mammals is to use a blind, or platform in a tree, near a path or a foraging area that individuals of the target species frequently use.

Certain species of mammals can be observed most easily by first locating structures with which they associate, and then waiting in a concealed location for them to appear. For example, the easiest way to observe many burrowing creatures, such as ground squirrels and pocket gophers, is to first locate an active burrow and then wait for an individual to emerge from the burrow. Beavers can be observed as they move to and from lodges. Bats are easily observed at roost sites, or emerging from roosts or cave entrances. In fact, most species of small to medium sized mammals utilize some kind of structure for shelter.

In studies where the main objective is to confirm the presence and/or estimate the relative abundances of mammal species, formal surveys are often conducted. Survey methods vary according to the circumstances and target species. Some popular methods include setting up arrays of live traps (or mist nets if the target species are bats), walking or driving line transects, spotlighting mammals at night, playing tapes of calls and monitoring responses, and setting up bait stations equipped with trip cameras or a medium that records the tracks of mammals that visit the station. While survey methods are useful for identifying habitat associations and relative abundances of species, they only permit brief glimpses of behaviors such as foraging patterns and social interactions. More extensive observations are necessary when detailed information about the activities of a species is required.

FIELD NOTEBOOKS

Field observations of mammal species should be recorded in a field notebook. A field notebook can be any type of notepad suitable for use in field conditions. Ideally it should have bound waterproof pages and a protective cover. Rite-in-the-rain® notebooks and pens are perfect for taking field notes in a variety conditions. Engineering transit books are also good. Observations should be written in waterproof ink or pencil. Waterproof ink is preferable because it doesn't smudge or fade over time.

The type of information recorded in a field notebook will obviously vary, depending on the observer, location, species, and the purpose of the observations. However, the date of the observation, the time, the weather conditions (including the estimated temperature, cloud cover, and wind speed), the location, elevation, a description of the habitat, and the names of other observers present should be recorded in your field notebook, along with your observations.

The current trend among many wildlife agencies and conservation groups is to incorporate field observations of wildlife into Geographic Information System (GIS) databases. Consequently, any information that can be used to pinpoint the location of your observations is especially important. Global Positioning System (GPS) units are frequently used to obtain precise latitude/longitude coordinates, and/or Universal Transverse Mercatur (UTM) coordinates for the location at which the observations were made. An example of the type of field data used in GIS databases is shown in Appendix I.

PROCEDURE

Your assignment for this week is to acquire a field notebook, venture out into the "great outdoors," and practice observing mammals (and/or their sign) and recording your observations in your field notebook. Make sure that you record the essential information mentioned above. You can employ any observational techniques that you would like to use. You may want to try more than one. Bring your field notebook (with the notes in it) to lab next week and you will receive credit for completing this assignment.

You will use your field notebook many times during the course of the semester. You should carry it with you during each of the lab exercises and record pertinent data and observations. This will make it easier for you to keep track of the data from your lab assignments. You will also be required to conduct an independent research project (see Appendix II) that involves observing mammals, and/or mammal sign, and recording your observations in your field notebook. The data from your project will be the basis of a research paper that you will turn in towards the end of the semester. Your field observations will also be included in a GIS database containing all the field observations recorded by members of the class. Consequently, you will want to record accurate and precise descriptions of the locations where you observed mammals. USGS 7.5 minute quadrangle maps will be available from which you will be able to determine the approximate latitude and longitude and the UTM coordinates for each of the locations. A GPS unit will also be available for you to use to determine geographic coordinates of sites.

We will practice using the GPS unit and determining UTM coordinates and determining latitude and longitude from maps before we go out into the field. To contribute to the class GIS database, you will need to enter the relevant data from your field notebook into a Microsoft Excel® spreadsheet file. The spreadsheet should be in the format described in Appendix I. It is unlikely that you will be able to fill in all of the fields in the spreadsheet, but you should fill in all relevant fields for which you have data. IMPORTANT NOTE: After you have entered your field data, save the file.

After we have completed this exercise and collated all information from files, we will incorporate this data into an ArcView® theme that consists of an electronic map of the locations of all observations of mammals that were made by the members of the class during the semester, and the field data associated with the observations.

Because your notebook will be crucial in completing laboratory exercises, creating the class GIS database and in conducting your research project, it is important that your notes include accurate information about the site and detailed accounts of your observations. You will turn in your field notebook to be graded on the last day of lab.

MATERIALS

Notebooks
Arcview® software
USGS 7.5 minute quadrangle maps
GPS unit
Microsoft Excel® spreadsheet software

APPENDIX I.

Example of a format for field data used in a GIS Database

The data sheet is imported into GIS software that uses the X-Y coordinates to link the field data to map locations. This particular example is organized for use with ArcView® GIS software. The data are initially entered in a spreadsheet program, such as Excel or dBase IV, which can be imported directly into ArcView®.

Explanation of items on the Species Locality Data Sheet

The data sheet is organized in columns, with each row representing data for a reported occurrence of a species at a specific locality. An explanation of the data recorded in each column is given below.

RECNUM: The record number for a specific entry on the data sheet. The data are numbered sequentially for use in ArcView.

XCOOR: East - West UTM coordinate for the locality, recorded as accurately and precisely as possible.

YCOOR: North - South UTM coordinate for the locality, recorded as accurately and precisely as possible.

ZONE: The UTM zone for the reported coordinates (i.e. Zone 10)

ELEV (m): The elevation, measured in meters above sea level, of the locality for which the UTM coordinates are given. Unknown elevations may be estimated from the map.

LAT : The latitude of the location in decimal degrees.

LONG: The longitude of the location in decimal degrees.

GENUS: The genus name (first word in the Latin binomial) for the species being reported.

SPECIES: The species name (second word in the Latin binomial) in the scientific name of the species.

SUBSPECIES: The subspecies is recorded if the subspecies designation is applicable and the subspecies is known.

CNAME: The common name of the species.

HABITAT: A general categorization of the habitat at the location of the species occurrence. Include the dominant vegetative community when applicable. (i.e. Ponderosa pine - black oak woodland).

HABCOM: Specific comments about the habitat (geological characteristics, substrate or soil type, slope or aspect, specific comments on the vegetation, etc).

SITE TYPE: Any relevant indicator of the use of the habitat by the species at the location (i.e. active nest, den, roost, winter range).

SITE ID: Any official name, number, or designation given to the site.

DATE: The date of the observation; day, month, and year. For example: 4 July 2001.

TIME: The time of day (24 hour clock) at which the observation occurred. A time range is acceptable.

CONDITIONS: Available information on weather conditions, temperature, visibility, etc. at the time of the observation.

DATATYPE: The type of data recorded (i.e. observation, roadkill, tracks, scat, etc.).

NUMBER: The number of individuals of the species observed at the location. Numbers of individuals at the same locality but belonging to separate demographic categories (i.e. males, females, adults, juveniles, etc.) can be reported separately.

DEMOGR: A summary of available demographic information about the individuals observed. (i.e. 21 adult females; 17 adult males; & 12 juveniles, sex unknown)

CRITTERID: Any band number, radio-transmitter frequency, or other type of ID specific to the individual(s) observed at the site.

BEHAVIOR: The behavior or activity in which the individual(s) of the species was engaged.

COMMENTS: Any additional comments regarding the species occurrence at this locality.

COUNTY: The county in which the observation occurred.

QUADNAME: The name of the USGS 7.5 minute quadrangle map that encompasses the location of the reported species occurrence.

PRECISION: The precision of the UTM coordinates reported for the locality: M = mappable within a 1 m radius, T = mappable within a 10 m radius, F = mappable to within a 50 m radius, H = mappable to within a 100 m radius, V = mappable to within a 500 m radius,
K = mappable to within a 1 km radius, G = general precision (mappable to placename or 7.5' quadrangle only), and U = unmappable. The precision will depend on the method used to determine the UTM coordinates.

DIRECTIONS: Any directions given to pinpoint the location of the species occurrence.

DSOURCE: The source of the data (i.e. field observation, line transect survey etc.)

RRECORD: A ranking of the reliability of the record (especially pertaining to the identification of the species), on a scale of 1 to 5 (1 = unreliable, 5 = highly reliable).

LCONFID: A confidence ranking of the accuracy of the reported location (1= very low confidence, 2 = low confidence, 3 = moderate confidence, 4 = high confidence, 5 = very high confidence)

OBSERVERS: The names and affiliations or addresses of the observers. Affiliations refer to educational institutions and wildlife agencies (i.e. Mount Hough Ranger Station, USFS, Plumas National Forest, Quincy, CA)

ENTDATE: The date at which the data were entered into the database.

ENTNAME: The name of the person who entered the data into the database.

Note: Missing descriptive data are denoted with *na* (which indicates that the data is not available or that the data type is not applicable for that record). Missing numeric data are designated by the 4-digit code "-9999".

APPENDIX II.

Guidelines For Research Paper

The choice of the subject of your research project and paper is completely up to you. The only restriction is that some aspect of the paper will need to include data that you collected in the field and recorded in your field notebook. Ideally, you will do some library research and/or initial field observations, and then determine a question or hypothesis that you would like to address. For example, suppose that you are interested in the dietary habits of black bears. You go to the library and find all of the information that you can locate on what black bears eat. Based on your library research and your personal observations, you suspect that the black bears of Plumas County consume large quantities of berries in the late summer and early fall. To test this hypothesis, you go out into the woods and collect 537 black bear scats from all over Plumas County. You then spend the next several weeks meticulously picking through the scats, by hand, and identifying every single item in each scat. You find lots of manzanita berries, blackberries, grasses, assorted remains of small mammals (including two house cats), ants, numerous insect larvae, and the fragments of three human femur bones (which you suspect belong to a pair of hikers reported as missing in early August). You can use this information to write a good research paper.

Your paper should consist of the following sections:

1. INTRODUCTION

The Introduction does not need to be very long. You just need to give some background information on the subject that you are addressing, and state your objective or hypothesis. Before stating your hypothesis or objective, you might want to explain why you are exploring the subject.

For example, you could summarize your library research by briefly reporting the general findings of several studies that suggest that black bears switch from a diet of green plants and insect larvae to a diet high in fruit during the late summer. Simply explain the most relevant findings of these studies and cite the literature in which the studies are reported. You could then point out that all of these studies were conducted on black bear populations that occupy habitats that are much different than the habitats characteristic of Plumas County. You believe that the black bears in Plumas county will behave pretty much the same way as other black bears. Namely, that they will consume large quantities of fruit. Specifically, you expect that the bear scat will be high in manzanita berries and black berries.

2. METHODS AND MATERIALS

In this section, you need to state what you did to collect your data and test your hypothesis. For example, if you collected bear scat, you would need to mention where the scat was collected, how much was collected at each location, when it was collected, and how it was processed to determine it contents. Your methods section should also mention any special equipment that you used in your study. Much of this information can be taken directly from your field notebook.

3. RESULTS

The Results section is where you report your findings. Present your findings and any analyses that you conducted on your data. As you describe your results, it is helpful to refer to tables and figures where you have summarized your findings or illustrated trends and interesting patterns.

4. DISCUSSION

The Discussion should elaborate on the significance of your findings and how they compare to what other researchers have observed. If you stated a formal hypothesis in your introduction, this is a good place to address how well the hypothesis held up. Also, you should try to explain any unusual findings in the discussion. For example, the presence of human remains in three of the bear scats in our hypothetical study is unusual, and deserves further investigation. You should state your major conclusions at the end of the discussion section.

Note: when a publication is cited in the text, the author(s) last name should be given, followed by the year of the publication. If the citation is at the end of the sentence, the whole thing should be in parentheses. Example: It has been reported that black bears will often attack humans who have recently consumed a combination of granola and yogurt (Zingbuster, 1991). If the citation is part of the sentence, only the year should be enclosed in parentheses. Example: Zingbuster (1991) reported that humans who have recently consumed a meal of yogurt and granola are more likely to be attacked by black bears than are humans fed alternative foods.

5. LITERATURE CITED

The Literature Cited section is a list of all the papers and books that you make reference to in your paper. The name of the author, the year of the publication, the title, and the publication information should be given. For example, a paper from pages 34-41 of volume 50 of the "Journal of Shrew Research" by Mortimer Q. Snerd titled *Unusually high mortality among vagrant shrews migrating across Interstate 15 near Los Angeles,* and written in 1989, should be referenced as follows:

Snerd, M. Q. 1989. *Unusually high mortality among vagrant shrews migrating across Interstate 15 near Los Angeles*. Journal of Shrew Research. 50:34-41.

If the paper had been written by Mortimer Q. Snerd and Cleodis W. Shrodnick, the reference would be:

Snerd, M. Q., and C. W. Shrodnick. 1989. *Unusually high mortality among vagrant shrews migrating across Interstate 15 near Los Angeles*. Journal of Shrew Research. 50:34-41.

If the source was a book entitled *The Biology of Urban Shrews* published by Smedley & Sons of Elko, Nevada, it should be referenced as follows:.

Snerd, M. Q., and C. W. Shrodnick. 1989. *The Biology of Urban Shrew*s. Smedley & Sons, Elko, Nevada.

If you have any questions about the format of the literature cited section, ask your instructor, or use a scientific publication from the library as a guideline. The *Journal of Wildlife Management* and the *Journal of Mammalogy* are good publications to check for the format of the Literature Cited section.

Suggestions for the types of topics appropriate for field observations and a research paper:

- Activity patterns of local ground squirrels: assessed by observing the numbers of active ground squirrels at a particular site during different times of the day.

- A comparison between species of mammals found in coniferous forest habitats and the species found in nearby meadows. This study might be based on observations of mammals, field identification of mammal tracks, and identification of scat at three 1-hectare study plots in meadows and three 1-hectare study plots in forests.

- A comparison of rodent communities in meadows and riparian habitat; assessed by trapping live rodents using Sherman traps along trap lines in both types of habitat.

- A test of the hypothesis that beavers prefer willows to other types of trees and shrubs. This could be tested directly by examining beavers in the act of cutting down trees, or it could be tested by comparing the proportion of willow trees that have been cut by beavers to the proportions of other types of trees that have been cut by beavers in the same area.

Measuring and Assessing Species Diversity I: Observations of Diurnal Mammals

INTRODUCTION

Traditionally, conservation biologists have concentrated their efforts on managing populations of rare or endangered species. However, the problems of ever-accelerating habitat loss, habitat fragmentation, and habitat degradation caused by encroaching human populations have motivated a shift towards attempts to salvage entire ecosystems, rather than single species. Conservation biology at the ecosystem level usually involves management aimed at preserving the biological integrity of an area that is critical to a relatively large number of species, or an area that harbors a high number of rare or unique species. The main objective of this approach is to minimize the loss of biodiversity.

In this exercise, we will survey mammals in three different habitats and compare these communities using various measures of species diversity.

PROCEDURE

We will conduct surveys to document the presence of mammal species in three kinds of habitat. Three study sites have been delineated and marked with orange wire surveying flags at their corners, and flagged at 50 m intervals along their boundaries. The sites are:

1. Riparian habitat
2. Oak/pine woodland
3. Mixed coniferous forest

Three types of surveys will be conducted at each site:

1. A visual survey to detect diurnal mammals.
2. A trapping survey designed to capture small nocturnal mammals.
3. A survey of mammal sign to detect the presence of carnivores and larger nocturnal species.

The protocol for the trapping survey and survey of mammal sign are described in subsequent lab exercises. Instructions for the visual survey and data analysis follow.

Visual Survey

You will be required to conduct a visual survey of mammals on each of the three study sites. Your survey should last exactly 1 hour and should incorporate one or more of the observational techniques mentioned in the *Observations and Field Notes* lab exercise. You should work alone during your survey so that you don't make too much noise and scare away all of the animals before you see them. Class members will be randomly assigned to survey sites by drawing numbers. The site that you survey will depend on the number you draw. You can conduct the survey any time between now and the time that we conduct the survey of mammal sign described in a subsequent lab.

Take your field guide, a pair of binoculars, and a watch for best results. Record your observations in your field notebook. Be sure to note how many individuals of each species you see and record the time of day when each individual is initially observed. You should also record the time when you begin and end your survey. After you complete your survey, record your data on the data sheets provided and hand them in at the lab. The results of all of the surveys will be compiled and distributed to the class.

Data Analysis

Once the visual survey, trapping survey, and survey of mammal sign have all been completed, you will estimate the species diversity at each of the three study sites. Your surveys must be carefully planned so the effort is essentially uniform across sites. In addition, randomly assigning sites will minimize bias due to differences in your techniques or even the level of motivation of the observers. Consequently, a straightforward count of the number of species encountered at each of the study sites can be used to assess differences between the sites, in terms of species diversity.

After data are compiled you will be provided with a summary of the data from all surveys. Each will target a different group of mammal species. By combining the three, we should have a pretty good database for comparing the diversity of terrestrial species of mammals at our study sites. However, for the purposes of exploring the use of diversity indices, we will initially ignore the survey of mammal sign. The data from all the surveys will be combined for the final analysis.

Follow the steps outlined below in analyzing and interpreting the data.

1. Inspect the data carefully. You will notice that the data from the visual survey (described above) and the trapping survey include the number of individuals of each species that were encountered on each study site. We will use these data for the first of our analyses of differences in the diversity of mammal species at our three study sites. Combine the data from these two surveys and quantify the species diversity at each of the three study sites using Simpson's Index. Show your results. Which of the sites is most diverse?

2. Repeat the above analysis using the Shannon-Weaver Index. How do your estimates of species diversity using the two different indices compare? Do they give the same qualitative results or do they disagree?

3. Compare the estimates of species diversity from Simpson's Index and the Shannon-Weaver Index to an estimate of diversity based on a simple count of all of the species encountered during the visual and trapping surveys at each site. Which method do you feel is most informative? Which do you feel is most accurate? Why?

4. Include the data from the survey of mammal sign now. This survey should add a number of carnivores and large nocturnal species to the lists of species for each site. Determine the total number of species at each site that were represented in the surveys. This number is an estimate of what has traditionally been referred to as species richness. Because the sampling effort was uniform across sites, we can use this count as an index of species diversity. Compare the species diversity of the sites.

5. How might you explain the differences in the species diversity of the sites?

6. Are there certain types or taxonomic groups of species that are present or absent at one site but not the others? If so, what features of the habitats of the sites might have attributed to this?

7. Which of the sites is most unique in terms of the species of mammals that inhabit it? What do you think contributes to its uniqueness?

MATERIALS

Stake flags
Field notebooks
Binoculars
Stopwatch
Livetraps (see Lab #5)

Record of Species Detected During the Visual Survey

Site		Observer		Date	
Observation Numbers	Time	Species	Numbers of individuals	Location	Habitat

Record of Species Detected During the Visual Survey

Site		Observer		Date	
Observation Numbers	Time	Species	Numbers of individuals	Location	Habitat

REFERENCES

Hurlbert, S. H. 1971. *The Non-Concept of Species Diversity: A Critique and Alternative Parameters.* Ecology 52:577-586.

James, F. C., and S. Rathbun. 1981. *Rarefaction, Relative Abundance, and Diversity of Avian Communities.* Auk 98:785-800.

May, R. M. 1975. *Patterns of Species Abundance and Diversity*. Pages 81-120 *In* M. L. Cody and J. M. Diamond (eds.) Ecology and Evolution of Communities. Belnap Press, Cambridge, Massachusetts.

Rosenzweig, M. L. 1996. *Species Diversity in Space and Time.* Cambridge University Press, Port Chester, New York.

Schluter, D., and R. E. Ricklefs. 1993. *Species Diversity: An Introduction to the Problem*. Pages 1- 10 in R. E. Ricklefs and D. Schluter (eds.) *Species Diversity in Ecological Communities: Historical and Geographic Perspectives*. University of Chicago Press, Chicago, Illinois.

Shannon, C. E., and W. Weaver. 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, Illinois.

Simberloff, D. S. 1979. *Rarefaction as a Distribution-Free Method of Expressing and Estimating Diversity.* Pages 159-176 *In* J. F. Grassle, G. P. Patil, W. K. Smith, and C. Taillie (eds.) *Ecological Diversity in Theory and Practice*. International Cooperative Publishing House, Fairland, Maryland.

Simpson, E. H. 1949. *Measurement of Diversity*. Nature 163:688.

Whittaker, R.H. 1972. Evolution and Measurement of Species Diversity. Taxon 21:213-251.

NOTES FOR INSTRUCTORS

MEASURING DIVERSITY

In this exercise, we study various methods for measuring and assessing species diversity.

A legitimate method of measuring and evaluating biodiversity is necessary for identifying areas critical to the maintenance of biodiversity in a region. The simplest method is to survey areas within the region and tally the number of rare species, or species belonging to a target group (i.e. mammals), to obtain an index of species diversity for each area. Areas with relatively high species diversity are then targeted for conservation efforts. The drawback to this method is that the number of species encountered in a survey of an area will vary according to the time and effort devoted to the survey.

Traditionally, ecologists and wildlife biologists have defined species diversity as consisting of two components: (1) **species richness**, which is the total number of species present, and (2) **evenness**, which measures the extent to which all species in the community are equally abundant. A community with a relatively large number of species, all of which are equally abundant, would be considered diverse by this definition. A community with a large number of species, but with most of the individuals belonging to a single dominant species, would have relatively low species diversity because it would have very low evenness. By contrast, a community with a small number of equally abundant species would have low diversity due to low species richness.

QUANTIFYING SPECIES DIVERSITY

Many indices have been proposed to quantify species diversity. The first, known as **Simpson's Index** (Simpson 1949), calculated the probability that any two individuals sampled at random from a population belong to the same species using the equation:

$$\lambda = \sum_{i=1}^{S} \frac{n_i(n_i-1)}{n(n-1)}$$

where n_i is the number of individuals of the *i*th species, and n is the total number of individuals of all species in the sample. Simpson's Index ranges from 0 (maximum species diversity) to 1 (minimum species diversity).

One of the most popular index of species diversity has been the **Shannon-Weaver Index** (Shannon and Weaver 1949). It measures the uncertainty in predicting whether an individual that is randomly selected from a community will belong to a certain species. It is estimated using the equation:

$$H' = \sum_{i=1}^{s} \left[\left(\frac{n_i}{n} \right) 1n \left(\frac{n_i}{n} \right) \right]$$

where n_i is the number of individuals belonging to the ith species and n is the total number of individuals in the sample. $H' = 0$ when there is only one species in the sample and is maximum when all species are represented by the same number of individuals.

In spite of their popularity, diversity indices are fraught with conceptual ambiguities and technical pitfalls (Hurlbert 1971, Schluter and Rickleffs 1993). The major criticism of diversity indices is that, by combining species richness and measures of evenness, they confound these variables and obscure ecologically important patterns that could be visualized if species richness and relative abundances were examined separately (Simberloff 1979, James and Rathbun 1981). Another problem is that using evenness to compare the diversity of communities composed of dissimilar species is often biologically meaningless. For example, certain species will always be more abundant than others because of life-history differences resulting from differences in body size, reproductive strategy, etc. Thus, it does not make sense to conclude that a community that contains a preponderance of small-bodied species that typically occur at high population densities is more diverse than a community that has a variety of dissimilar species, some of which occur at low population densities because of their size, ecological requirements, or reproductive strategies. Furthermore, abundances of species within samples tend to exhibit consistent patterns (Whittaker 1972, May 1975). Consequently, there is often little to be gained by using a diversity index in place of a simple count of the number of species present in an area (Schluter and Rickleffs 1993). In fact, some ecologists prefer to define species diversity in terms of numbers of species in an area (species richness) only, and ignore evenness (Rosenzweig 1996).

When species diversity is defined in terms of species richness, the survey protocol and the amount of effort that went into the survey become particularly important. If one site has been surveyed intensively, and another site has been surveyed on a superficial level, differences in survey effort could obscure actual differences in species diversity between the sites. Surveys are therefore conducted using a standardized methodology to ensure that the survey area and sampling effort does not vary from site to site. For example, if a survey were conducted consisting of trapping small mammals along a 1000-m transect, and it ran for 200 nights, all surveys at other sites would need to involve 200 trap nights of effort along a 1000-m transect. In this laboratory exercise, we will use a consistent sampling effort in our surveys.

Measuring and Assessing Species Diversity II: Trapping Small Terrestrial Mammals

INTRODUCTION

Many of the methods that are used to conduct inventories of mammals (to determine the species of mammals that occupy a particular type of habitat in a given area) require that individual mammals be captured. Certain methods of estimating abundances of mammal species, such as mark-recapture methods, also require the capture and handling of individual mammals. The capture methods used in inventories and surveys are most effective for small to medium-sized species. Large mammals are usually detected most efficiently using observational techniques, tracks, or other sign.

The type of capture method(s) appropriate for an inventory of mammal species depends on the characteristics of the habitat where the study is being conducted and the sizes and activity levels of the species that are expected to be captured. Three capture devices that are generally applicable to capturing small terrestrial mammals (those < 50 g in mass) are **snap, box** and **pitfall traps**.

In this exercise small mammals will be inventoried using these common trapping methods.

IMPORTANT SAFETY NOTE: *Local public health officials should be consulted before students handle live wild mammals. Specific pathogens such as Hanta virus may be a problem in your particular area. If so, special handling precautions must be taken and some species may need to be avoided entirely.*

PROCEDURE

We will conduct inventories of mammal species in three kinds of habitat. Three study sites have been delineated, marked with orange wire surveying flags at their corners, and flagged at 50-m intervals along their boundaries. The sites are:

1. Riparian habitat
2. Oak/pine woodland
3. Mixed coniferous forest

In this lab exercise, we will conduct the first phase of the inventory, using live traps to capture and identify species of small mammals present at the study sites. The class will separate into three groups, and each group will be responsible for trapping at one of the three study sites. Each group will be given 15 folding **Sherman box traps** and 5 **pitfall traps**. Take along your field guides and field notebooks for identifying the species that you capture and recording the data. The procedure that your group should follow is described below.

1. The first step will be to select the general area within your study site where the trap lines will be placed. The traps should be accessible but concealed well enough so that they are not plainly visible from trails and are not subject to frequent human disturbance. Delineate one or more transects for box traps and locations for pitfall traps. Use a tape measure to measure the length of your transect. Mark the locations at which traps will be placed with flags or ribbons.

2. Once you have marked the locations where the traps will be placed, begin placing and setting the traps. Use a shovel or a post-hole digger for excavating holes for your pitfall traps. The top of each of your pitfall traps should be flush with the soil. Make sure that you cover all of your pitfall traps with a cap or circular piece of plywood when they are not in use. There are sheets of 2-m long x 25-cm high plywood that can be used as a “drift fence” to guide small mammals into the pitfall traps. Each box trap should be placed within 2-m of the flag or ribbon that marks its location along the transect line. Remember that, for maximum effectiveness, box traps should be placed near habitat features such as burrows, logs, tree bases, or runways. You will have access to peanut butter, oats, and sunflower seeds for bait. You can use any type of bait, or combination of bait, that you desire. When you set a trap, bait will need to be placed on the trip pan, and a small amount of bait should be placed just in front of the entrance to the trap to entice unsuspecting mammals to stop and explore the trap. You should place enough bait on the trip pan to provide some extra food for a trapped small mammal to snack on during the night. You don’t need to bait the pitfall traps, but you should place three or four mealworms or earthworms in each pitfall trap on each of the nights that you trap. The pitfall traps are likely to catch shrews, which will rapidly expire if they have to go for more than two or three hours without food.

3. Develop a protocol for your inventory. The trapping effort should include 100 trap nights at each of the study sites. Each group will have access to 20 traps, thus, the trapping will need to be conducted on five different nights. The first night of trapping will take place after the traps are positioned. Your group should meet early the following morning to check the traps, identify any captured mammals, and record the data. The scheduling of the remainder of the trapping nights is up to you and the other members of your group. You will need to coordinate optimal trapping periods, make assignments for setting and baiting traps, and checking the traps early each morning. One or two people should set the traps in the evening and a minimum of two people should check the traps early the following morning for the other four nights of trapping. Make sure that everyone in

the group has at least one opportunity to bait and to check the traps. You will have two weeks to complete the trapping. The box traps should be triggered and the pitfall traps should be covered when not in use. When a small mammal is present in a trap, it should be identified and released as soon as possible. You will have access to a list of species of small mammals found in this area.

4. Draw a diagram of your trapping array and assign each trap a number. Record the species that have been trapped at each trap in your diagram and the date of capture. You should record relevant information about the microhabitat at each of the trap sites; i.e., dominant plant species and structural characteristics such as canopy coverage. Also estimate distances of the trap from important habitat features such as water, tree trunks, burrows, etc.

5. Keep a record of your trapping efforts. Record every capture and indicate the species and sex (if you can determine it) of the animal. Also record the trap number, the type of trap, and the type of bait you used as well. You may use the data sheet provided or use your field notebook.

MATERIALS

15 Sherman box traps
5 pitfall traps constructed from 4 inch PVC pipe
5 small circular pieces of plywood to cover the pitfall traps when they are not in use
10 sheets of 25 cm high by 2 m long plywood (to be used as drift fencing)
A shovel and/or post hole digger
A 100 m long tape measure
Flagging ribbon
Bait, consisting of a mixture of peanut butter, sunflower seeds, and oats
Mealworms (for use in the pitfall traps), earthworms
Field guides and field notebooks

QUESTIONS

1. Which species were captured most effectively with the pitfall traps? For which species did box traps work better? How might you explain these patterns?

2. What species of small terrestrial mammals were not captured that are probably present at one or more of the trapping sites? Why do you think they did not show up in the traps?

3. Compare the number of mammals and the species that were captured on each of the three sites. How might you explain the differences? Were certain species associated with specific habitats or microhabitats?

MAMMAL TRAPPING DATA SHEET

Trapping site (location)______________________________ **Date** ____________________
Site habitat description______________________________ **Time**____________________
Conditions ______________________________________ **Type of trap** ______________

Trap Number	Microhabitat Description	Species	Age-class & Sex	Comments

NOTES FOR INSTRUCTORS

Small Mammal Capture Devices

1. **SNAP TRAPS:** Snap traps are used in inventories of small mammals when the objective is to kill the animals to obtain voucher specimens or specimens for collections. A snap trap usually consists of a trigger pan, supplied with bait and mounted on a flat piece of wood to which a spring loaded metal bale is attached. When a tiny bit of pressure is applied to the trigger pan, the spring is released and the bale snaps down on the animal. The bale kills the animal, usually by cervical dislocation. The most effective snap traps are the *Museum Special Mouse & Rat Traps* manufactured by Woodstream Corporation (Address: 69 North Locust Street, Lititz, PA 17543. Phone: 717-626-2125).

2. **BOX TRAPS:** The use of box traps is the most effective way to capture small terrestrial mammals without harming them. Box traps have a trip pan that causes spring-loaded doors at one or both ends of the trap to close when an animal touches it. For optimal results, bait should be placed on the trip pan. Most small mammals can spend several hours in a box trap without suffering any ill effects, as long as food and bedding are provided. Box traps come in a variety of styles and sizes. The type of trap used should be appropriate for the species that are expected to be captured. Popular U.S. brands include the *Sherman* and *Tomahawk traps*. *Havahart humane traps*, made by Allcock Manufacturing Company, offer a most clever brand name and are gaining in popularity.

Considerations for snap traps and box traps

Bait: Both snap traps and box traps usually require the use of bait. Bait usually consists of grain (such as wheat or oatmeal), seeds, peanut butter, fruit, or a mixture of one or more of the above. For live traps, there should be enough bait to feed a small mammal until the traps are checked. If peanut butter and/or fruit is used as bait, the traps should be washed with soap and water after each use.

Trap arrays: The spatial arrangement of traps within the study area should be dictated by the purpose of the trapping. If the purpose of the trapping is to conduct an inventory, a linear array usually works best. Traps arranged linearly are usually placed within 2 m of points that are uniformly spaced along a transect that spans the study area, near relevant habitat features such as logs, trees, burrows, and runways. The space between the traps should be appropriate for the target species. For small rodents, traps should be spaced anywhere from 10 to 15 m apart and the transect should be at least 150 m long. Ideally, two traps should be placed at each point along the transect to improve the chance of catching less active mammals (Drick hamer 1987, Jones et al. 1996). Square or rectangular arrays of traps should be used when collecting mark-recapture data to be used to estimate abundances of species (Nichols and Pollock 1983). Mark-recapture will be done in a future lab exercise.

Box trap manufacturers:

- Allcock Manufacturing Co., Northwater Street, Ossining, NY 10562 (makers of Havahart humane traps). Phone: 914-979-1366.

- H.B. Sherman Traps, Inc., P.O. Box 20267, Tallahassee, FL 32316 (makers of Sherman folding & non-folding aluminum traps). Phone: 904-575-8727.

- Tomahawk Live Trap Co., P.O. Box 323, Tomahawk, WI 54487 (makers of collapsible or folding live traps for small mammals). Phone: 715-453-3550

3. **PITFALL TRAPS:** The use of pitfall traps is the most efficient way to capture the very smallest mammals (< 10 g), such as shrews. A pitfall trap is an open container placed in a hole in the ground; animals fall into the container and cannot get out. Pitfall traps can be made from cans, buckets, PVC pipe, or any other durable cylindrical or conical object. They should be about 40- to 50-cm deep and 20- to 40-cm in diameter (Nellis et al. 1974, Jones et al. 1996). Somewhat smaller diameter traps can be used for our purposes, but we should probably adhere to the minimum depth of 40 cm. Pitfall traps should be covered when not in use. Covers can be constructed of wood or any other flat rigid material that will prevent the trap from filling with water. Capture rates improve if pitfall traps are used in combination with a drift fence (Kirkland and Sheppard 1994). A drift fence functions as a barrier that directs small mammals into the traps. Ideally, drift fences should be 20 - 30 cm high (Jones et al. 1996). They can be constructed from wood, strips of tin or aluminum, or fiberglass. An array of pitfall traps and drift fence can be anywhere from 2 - 20 m long, with traps spaced a maximum of 5 m apart (Handley and Kalko 1993).

Additional Considerations

Trapping Effort: Trapping effort is usually quantified in terms of *trap nights*. The number of trap nights in a survey is equal to the number of traps multiplied by the duration of trapping. For example, an inventory that consisted of four nights of trapping using 250 box traps has a trapping effort of 1000 trap nights. Jones et al. (1996) recommend a minimum of 500 trap nights for preliminary inventories of small mammals.

One way to assess the appropriate trapping effort for an inventory is to plot a species accumulation curve. This is done by constructing a graph with the cumulative number of species trapped plotted on the y-axis and time plotted on the x-axis. When the curve starts to level off, it is safe to assume that most, or all, of the species present at the site have been detected.

Handling: Small mammals that have been trapped are often handled for purposes of identification and sex determination. Initially, a plastic or cloth bag is placed over the open door of the trap and the trap is shaken to encourage the animal to move from the trap to the bag.

Gloves should always be worn as protection from bites and to reduce the risk of disease tran mission. If additional handling is required, small mammals can be grasped by the nape of the neck using the thumb and forefinger. All of the loose skin on the neck, shoulders, and back should be grasped to restrict movement of the animal.

This is an example of a list that should be made available to students. Insert the list for your locality as an appendix to the lab exercise.

Species of small terrestrial mammals likely to be found in Plumas County, California

Order Insectivora — shrews & moles

Family Soricidae

Sorex vagrans (vagrant shrew)
Sorex palustris (northern water shrew)
Sorex trowbridgii (Trowbridge shrew)

Family Talpidae

Neurotrichus gibbsii (shrew-mole)
Scapanus latimanus (broad-handed mole/California mole)

Note: It is difficult for humans to determine the sex of shrews and moles (I'm sure it's easier for shrews and moles to figure it out). The only reliable method is to count the number of openings in the perineal region: three in breeding females (urinary papilla, vagina, and anus) and two in males (urinary papilla and anus).

Order Rodentia

Family Scuiridae (most are too big for small folding traps. Chipmunks are not too big)

Eutamias amoenus (yellow pine chipmunk)
Eutamias merriami (Merriam's chipmunk)
Eutamias minimus (least chipmunk)
Eutamias townsendii (Townsend's chipmunk)
Eutamias quadramaculatus (long-eared chipmunk)
Eutamias speciosus (lodgepole chipmunk)

Family Geomyidae — pocket gophers

Thomomys monticola (mountain pocket gopher/Sierra pocket gopher)
Thomomys bottae (Botta's pocket gopher)

Family Heteromyidae — kangaroo rats, kangaroo mice, and pocket mice

Perognathus parvus (Great Basin pocket mouse)
Dipodomys californica (California kangaroo rat)
Dipodomys ordii (Ord's kangaroo rat)

Family Muridae

Zapus princeps (western jumping mouse)
Reithrodontomys magalotis (western harvest mouse)
Peromyscus maniculatus (deer mouse)
Peromyscus truei (Pinyon mouse)
Microtus californicus (California vole)
Microtus longicauda (long-tailed vole)
Microtus montanus (montane vole)
Microtus pennsylvanicus (meadow vole)
Neotoma fuscipes (dusky-footed woodrat)
Neotoma cinerea (bushy-tailed woodrat) – likely too big for small Sherman traps.
Mus musculus (house mouse) - an introduced species
Rattus rattus (black rat) - an introduced species

REFERENCES

Drickhamer, L. C. 1987. *Influence of Time of Day on Captures of Two Species of Peromyscus in a New England Deciduous Forest*. Journal of Mammalogy 68:702-703.

Handley, C. O., Jr., and E. K. V. Kalko. 1993. *A Short History of Pitfall Trapping in America, With a Review of Methods Currently Used for Small Mammals*. Virginia Journal of Science 44:19-26.

Jones, C., W. J. McShea, M. J. Conroy, and T. H. Kunz. 1996. *Capturing Small Mammals Pages* 115-156. *In* D. E. Wilson, F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster (eds.), *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*. Smith sonian Institution Press, Washington D.C.

Kirkland, G. L., Jr., and P. K. Sheppard. 1994. *Proposed Standard Protocol for Sampling of Small Mammal Communities*. Pages 277-283. *In* J. F. Merritt, G. L. Kirkland, Jr., and R. K. Rose (eds.), *Advances in the Biology of Shrews*. Special Publications of the Carnegie Museum of Natural History 18. Pittsburg, Pennsylvania.

Nellis, C. H., C. J. Terry, and R. D. Taber. 1974. *A Conical Pitfall Trap for Mammals*. North west Science 48:102-104.

Nichols, J. D., and K. H. Pollock. 1983. *Estimation Methodology in Contemporary Small Mammal Capture-Recapture Studies*. Journal of Mammalogy 64:253-260.

Measuring and Assessing Species Diversity III: Identifying Mammals by Their Sign

INTRODUCTION

Most mammal species are nocturnal, secretive, and able to evade detection by human observers by seeking cover (i.e., retreating to burrows) or fleeing. Consequently, it is usually not practical to rely on visual detection to ascertain whether a particular species of mammal is present in a given area. A more effective strategy is to look for evidence of the presence of the species in the form of structures (burrow entrances, dens, and lodges), signs of foraging activity, scat, or tracks.

Many species leave physical evidence of their presence by constructing shelters or other types of structures. Tree squirrels build nests of leaves and grass, moles and gophers produce earthen mounds while they are burrowing, beavers and muskrats build lodges, beavers build dams, and other species construct burrows and tunnels. Some structures, such as beaver dams, are easy to attribute to a particular species. Others, such as burrows, are often fairly nondescript, but can be ascribed to the activities of a certain species by careful examination of unique and subtle characteristics.

Some species leave signs of their foraging activities. The presence of beavers, rabbits, and mountain beavers can be detected by the stems and branches that they cut while they are foraging. The presence of runways with droppings and grass cuttings indicates that voles have been foraging in the area. Porcupines strip the bark of trees to get at the nutritious cambium layer. Carcasses of prey animals can be used to detect the presence of big carnivores, such as mountain lions. Other species leave behind diggings or wallows. Often, evidence of foraging activity is distinctive, and can be used to detect the presence of a species, or at least to indicate the presence of one or more species belonging to a particular taxonomic group.

Obviously, all species of mammals produce scat. However, not all species deposit scat in locations where it is likely to be discovered. Species that tend to deposit scat on trails or elevated objects can usually be detected based on the presence of their scat. Browsing or grazing mammals that produce large quantities of scat can frequently be identified by their scat as well. However, the scats of many small and/or uncommon mammal species are often sparse, inconspicuous, or concealed. Another limitation of using scat as an indicator of the presence of a species is that closely related species tend to produce scat that are very similar in appearance. For this reason, it is prudent to gather other types of evidence, such as tracks or shed hair, before definitively assigning scat to a particular species. Field guides to animal tracking (i.e., Stokes and Stokes 1986) will usually contain material on identifying species based on their scat. For example, Ingles (1967) contains a brief illustrated appendix on mammal scat for selected mammals of California, Oregon, and Washington in the U.S.

Perhaps the most effective way to detect the presence of a particular species of mammal is by observing its tracks. Mammal tracks are usually present in soft or wet soil that is not covered by leaf litter, grass, or thick herbaceous vegetation. Moist areas of bare soil or mud near streams or ponds, where mammals frequently visit to drink or forage, are ideal places to inspect for mammals tracks. Shallow snow is also ideal for observing and identifying mammal tracks. Field guides for identifying mammal tracks are available (Murie 1974, Brown 1983, Stokes and Stokes 1986). However, it is sometimes necessary to provide a record or reproduction of the track so that the identification of the track can be confirmed. There are several methods of documenting mammal tracks. Some of these methods are described below.

Methods of Documenting Mammal Tracks

Photography. The easiest way to document mammal tracks is to photograph them. Close-up photos provide information about the features of individual tracks. These can be supplemented with additional photos that record information about the spatial pattern of the tracks. A photograph of a single track should include an object of known size, such as a small ruler, so that the size of the track can be visualized. Photographs of tracks should be labeled with the date, site, and the name of the species that made the track (if known).

Casting Tracks. A popular method of preserving and documenting the characteristics of individual mammal tracks is to use a mold and casting material to make a cast of the track. The most commonly used casting material is Plaster of Paris (Murie 1974, Wemmer et al. 1996). The advantages of using Plaster of Paris is that it is cheap, easy to prepare, easy to store, and it sets rapidly. The major disadvantage is that it cannot be used in the snow. It gives off heat while it is setting, and will melt the snow before it sets. Rosin-Paraffin Moulage casting material provides a higher quality cast than Plaster of Paris, and can be used in the snow. However, its preparation is somewhat complex and cumbersome. Descriptions of the Rosin-Paraffin Moulage technique can be found in Kent et al. (1985) and Wemmer et al. (1996).

Preparing casts of tracks using Plaster of Paris. Involves cleaning the track of debris, fitting a casting frame around the track, pouring the plaster of Paris into the track, and allowing the cast to set. The procedure is outlined in detail in the *Procedure* section of this lab exercise. Casts of tracks should be labeled with the name of the species (if known), the track's location, the name of the person who prepared the cast, and the date the cast was poured. If the cast is part of a large collection of casts, it should also be labeled with a catalogue number that can be used for indexing purposes. This information can initially be written in pencil or permanent ink on a waterproof piece of paper that is inserted into the Plaster of Paris near the casting frame. After the cast has been removed from the casting frame, a sharp object can be used to inscribe this information on the bottom (flat side) of the cast (see Wemmer et al. 1996).

Scent Stations and Bait Stations. One strategy for collecting tracks of mammals is to create a circular area of bare soft soil and place bait or an odoriferous substance at the center to attract mammals. This method is used most frequently to obtain tracks of carnivores. Olfactory attractants that have been employed for this purpose include fermented eggs, bobcat urine, and synthetic attractants. Animal remains, fish-based cat food, or dead fish can be used for bait at bait stations. Animals that visit scent or bait stations leave tell-tale tracks in the soft bare earth. Ideally, stations should be arranged along a line transect at 300-500 m intervals. If standardized methods are used, bait or scent stations can be used to determine the relative abundances of species at different locations or habitats (Roughton and Sweeny 1982; Conner et al. 1983).

Track Boards and Track Plates. Boards covered with smoked kymographic paper, or metal track plates covered in soot can be used to record the presence of mammal species (Raphael et al. 1986, Carey and Witt 1991). The Forest Service uses sooted metal track plates to conduct inventories of small carnivores in national forests. The track plates are placed inside elongate wooden boxes that are open at one end. Before being placed in a wooden box, each track plate is initially sooted using an acetylene torch. One end of the plate is left unsooted, and contact paper is attached to this end of the plate. Bait (in the form of a can of cat food or a dead fish) is placed just beyond the contact paper, so that any animal that enters the box will have to walk over the sooted portion of the plate and step on the contact paper, leaving sooty footprints behind, to get to the bait. The contact paper is labeled and filed to document the species detected at each track plate station (D. Arietta, unpubl. manuscript). The greatest limitation of using track plates or track boards is that the mammal must step in the right place for the track to be recorded.

Fluorescent Powder. Fluorescent powder can be placed in pans at bait stations, or mixed with bait, so that it will adhere to the feet of mammals and provide information on the movement and identity of mammals that visit the bait station. When an ultraviolet light is shone on the tracks the fluorescent powder will glow, and the tracks can be viewed and identified (Lemen and Freeman 1985). Fluorescent dyes and hand-held ultraviolet lights used in mammal tracking are now available through standard suppliers of equipment for wildlife research, such as *Forestry Suppliers* in the U.S.

PROCEDURE

As part of your ongoing project to assess the diversity of mammal species at your study sites, you will conduct a survey of mammal sign at the study area that you have been assigned. Your survey will have two components: (1) an initial inventory of mammal sign that will involve walking the trails and searching any streamside habitat in your study area to identify structures; finding evidence of foraging activity, scat, and tracks of mammals; and (2) a bait station, designed to attract carnivores. We will set up a total of six bait stations; two at each study area. We will work in pairs to set up the bait stations.

During your initial inventory, you should record the characteristics, initial identification, and location of mammal sign in your field notebook. You should also record the date, the conditions, and a description of the habitat at the location of the sign. You can use the field guide on animal tracking by Stokes and Stokes (1986) to help you identify sign. Your field guide to the mammals of Western North America, [U.S.] (Burt and Grossenheider 1980) includes illustrations of tracks. If you find a particularly impressive track, you should make a Plaster of Paris cast of it. Follow the directions given for making these casts.

After you complete the initial survey of your study area, select a location that is suitable for a bait station and clear all of the debris from a circular area 5 m in diameter. At some point, you will need to use a GPS unit to obtain the UTM coordinates for the bait station. Make sure that you are 300 m or more from the other bait station at the study area in which you are working. Place about 5 kg of fish in a pile at the center of the circle (you can divide 5 kg by the average weight per fish to obtain the approximate number of fish that you should use. You will be told the average weight per fish in advance). Use a rake to smooth and soften the surface of the soil within the 5-m diameter circle surrounding the bait.

Return to the site the following morning and search the soil for tracks. If there is still bait at the bait station, you should leave the bait out for another night and return the following morning to check for additional tracks. Record the types of tracks you see and the approximate number of each type. Identify the tracks to the best of your ability. You should also record the date, the conditions, and a description of the habitat in the vicinity of the bait station. This information should be recorded in your field notebook. Later, you can use your field notebook to fill in the data sheets provided. Make a Plaster of Paris cast of one of the tracks at your bait station. Turn in the attached data sheets and the cast.

MAKING PLASTER OF PARIS CASTS OF TRACKS

You will need to prepare a selected track for casting by carefully removing twigs, small rock particles, and other debris with a pair of forceps. Then apply a thin coat of talcum powder to prevent the Plaster of Paris from sticking to soil particles. Apply a pinch of talcum powder to the track and blow softly on the track through straw to spread a dusting of talcum powder over the entire track. After you have cleaned and powdered the track, gently press a casting frame partially into the soil around the track. Make sure that there are no spaces between the surface of the soil and the casting frame. The frame should surround the track plus an additional area about 3-4 cm wide beyond the edges of the track (Wemmer et al. 1996). Once the frame is in place, apply a light coating of talcum powder to its inner surface.

IMPORTANT SAFETY NOTE: *Do not inhale—talcum powder can cause lung cancer!*

Mix some Plaster of Paris and water in the mixing container. Do not prepare any more than you will need to fill the casting frame. You can add a small amount of vinegar or salt to increase the setting time. Add water and stir the mixture until it is thin enough to be poured into the casting frame, but not runny—it should have the consistency of pancake batter. Pour the Plaster of Paris into the casting frame immediately—hardening will start to occur quickly. Try to minimize the presence of bubbles in the mixture as you pour. If you are dealing with a large cast, you may want to reinforce it by adding small sticks to the plaster before it sets.

You will need to allow at least 30 minutes for the cast to set. After the cast has set, remove it and transport it to the lab. After about an hour, you can remove the frame from the cast and trim the edges of the cast with a sharp knife. Wait at least 24 hours before you inscribe labels or store the cast. Wrap the cast in tissue paper before storing it.

MATERIALS

Powdered Plaster of Paris in a waterproof container
Mixing container
Water
Stirring stick
Casting frames (cut sections of paper milk cartons will suffice)
Forceps
Talcum powder
Straw
Vinegar (or salt)

REFERENCES

Brown, T., Jr. 1983. *Tom Brown's Field Guide to Nature Observation and Tracking*. Berkeley Books, New York.

Burt, W. H. and R. P. Grossenheider. 1980. *Mammals of North America* (Peterson field guide series). Houghlin Mifflin Company, Boston, Massachusetts.

Carey, A. B., and J. W. Witt. 1991. *Track Counts as Indices to Abundances of Arboreal Rodents*. Journal of Mammalogy 58:688-690.

Conner, M. C., R. F. Labisky, and D. R. Progulske, Jr. 1983. *Scent-Station Indices as Measures of Population Abundance for Bobcats, Raccoons, Gray Foxes, and Opossums*. Wildlife Society Bulletin 11:146-152.

Ingles, L.G. 1967. *Mammals of the Pacific States*. Stanford University Press, Stanford, California.

Kent, D. M., M. P. Harris, G. L. Abegg, and T. H. Kunz. 1985. *A New Moulage Technique for Casting Animal Tracks*. American Biology Teacher 47:432-433.

Lemen, C. A., and P. W. Freeman. 1985. *Tracking Mammals with Flourescent Pigments: A New Technique*. Journal of Mammalogy 66:134-136.

Murie, O. J. 1974. *A Field Guide to Animal Tracks*. Peterson Field Guide Series. 2nd edition. Houghton-Mifflin, Boston, Massachusetts.

Rapheal, M. G., C. A. Taylor, and R. H. Barrett. 1986. *Smoked Aluminum Track Stations Record Flying Squirrel Occurrence.* U.S. Department of Agriculture, Forest Service Research Notes PSW-384:1-3.

Roughton, R. D., and M. W. Sweeny. 1982. *Refinement in Scent-Station Methodology for Assessing Trends in Carnivore Populations*. Journal of Wildlife Management 46:217-229.

Stokes, D, and L. Stokes. 1986. *A Guide to Animal Tracking and Behavior*. Little Brown, Boston, Massachusetts.

Wemmer, C., T. H. Kunz, G. Lundie-Jenkins, and W. J. McShea. 1996. *Mammalian Sign*. Pages 157-176 In D. E. Wilson, F. R. Cole, J. D. Nicholes, R. Rudran, and M. S. Foster (eds.). *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*. Smithsonian Institution Press, Washington, D.C.

DATA SHEET: SIGN DETECTED DURING THE SITE SURVEY

Entry Number	Location	Tyupe of Sign	Species	Date	Time	Conditions	Habitat	Comments

DATA SHEET: BAIT STATION

Station site (location)______________________________**Habitat description**______________________________

Directions to the site ____

UTM coordinates: X-coordinate__________________**Y-coordinate**________________________________

Observers____

Species	Number of tracks	Date	Time	Conditions	Comments

Line Transect Methods of Estimating Abundance

INTRODUCTION

Estimating populations of animal species is one of the most important duties of wildlife biologists. A knowledge of wildlife population densities and population trends is essential for assessing management strategies and conservation needs. Population estimation is also an integral component of both descriptive and experimental research designed to evaluate the influence of specific factors on populations.

Natural History of the Western Gray Squirrel

Western gray squirrels are relatively large diurnal tree squirrels that are generally arboreal but will spend a good deal of time on the ground while gathering acorns and other food items. They feed primarily on acorns, conifer seeds, fungi, berries, and insects (Ingles, 1967; Whitaker, 1980). Western gray squirrels typically nest in tree cavities or large tree nests composed of leaves, bark, and sticks. Adult females give birth to a litter of 3 - 5 sometime between February and June. Typical population densities of western gray squirrels range from 0.25 to 2 squirrels per hectare (Burt and Grossenheider, 1980).

In this field exercise, we will carry out a study that involves surveying populations of the western gray squirrel (*Sciurus griseus*) to determine how the population density of gray squirrels varies according to the proximity of the survey area to a major road. Specifically, we will compare population densities of western gray squirrels at survey sites that are located at different distances from a major highway to determine whether population densities are lowest near the highway. We will also examine the frequency at which gray squirrels are killed by automobiles on the portions of the highway adjacent to our survey sites. The data that we collect will allow us to test two alternative hypotheses:

1. Population densities of gray squirrels are lower in the vicinity of roads than they are in interior forest habitats due to automobile-induced mortality.

2. Population densities of western gray squirrels are not lower in the vicinity of roads because there is a net movement of squirrels from the forest interior to the vicinity of roads that compensates for vehicle-induced mortality.

In other words, we are testing that the forest is a source of gray squirrels and the road is a sink.

3. The null hypothesis, which will be supported if neither of our alternative hypotheses are verified, is that automobiles are not a significant source of mortality among western gray squirrels that inhabit roadside habitats.

Use the handout which describes various survey methods to complete this exercise.

PROCEDURE

Survey protocol

We will work in pairs to conduct surveys of populations of western gray squirrels in the vicinity of the selected highway. Each pair of surveyors will set up and search three 200-m long line transects located at three different distances from the highway. All three transects should run parallel to the highway. One transect should be positioned about 20-m from the highway, another transect should be located at roughly 200 m from the highway, and another transect should be positioned 500 m or more from the highway. You may pick any location along the selected highway for your surveys. However, the location should provide sufficient space to accommodate the three transects and the habitat should be fairly uniform as you travel from 20 to 500 m from the highway. Ideally, you would locate your transects within pine-oak forest, although a coniferous forest will suffice.

When you conduct a transect survey, you should walk slowly and quietly along the transect line with a compass, range finder, and a field notebook. When you spot a gray squirrel, record the perpendicular distance from the transect line to the site where the squirrel was located when you initially sighted it. You can use the range finder to measure the perpendicular distance from the transect line to the location where the animal was first sighted, or you can use the range finder to measure the radial distance from you to the animal when you first see the animal. If you choose the latter option, you will also need to use your compass to determine the sighting angle. Later you will need to convert the radial distances to perpendicular distances by multiplying the radial distance by the sine of the sighting angle. Record your data in the tables provided.

Assessing automobile-induced mortality

You will work in pairs to conduct this phase of the assignment. You and your partner will drive along the highway looking for road killed gray squirrels. You will be assigned a 10-km section that you will search. Your transects will be located somewhere along this area of the highway. The search will require two trips. During the first trip, you should stop near each squirrel carcass that you see and remove it by pushing it off to the side of the road using a long stick, or a similar object. For safety reasons, do not remove dead squirrels from locations that do not allow a full view of traffic coming from both directions. Instead, you should note the exact location of the carcass and make a note that it was left on the road. Two days later, at approximately the same time of day, you will need to drive the highway a second time. This time, the squirrels that you see (unless they were left from the previous trip) will have been hit sometime within the previous two days. Record the total number of squirrels that you see and divide the number by two to calculate the number killed per day.

Density estimates

1. Use the Ramsey and Scott method to estimate the population density of western gray squirrels on each of the transects in your study area. You will need to plot the cumulative number of individuals sighted against distance to estimate w_e. Use your estimate of w_e to calculate the effective area (EAS). Record the population density on each transect in units of squirrels per hectare. Attach your graphs and show your calculations.

2. Truncate the width of your transects to exclude all observations of individuals farther than 20 m from the transect line. Now you can assume that each transect was a strip transect with a fixed width of 20 meters on each side of the transect line. Calculate the population density of western gray squirrel on each of your transects.

DATA SHEETS FOR RECORDING TRANSECT PERPENDICULAR DISTANCES FROM TRANSECT SURVEYS

A. Transect 20 m from highway.

Transect Location ________________________________ Transect Length ____________
Date _________________ Beginning Time ____________ Ending time _____________
Transect angle __________ UTM coordinates at starting point ______________________
Habitat description ____
Temperature ________ Weather Conditions _____________________________________
Observer(s) ____

Sighting #	Species	Radial Distance	Compass Angle	Perpendicular Distance	Comments

Estimated population density:________

B. Transect 200m from highway

Transect Location ______________________________ Transect Length ___________
Date ________________ Beginning Time ___________ Ending time ____________
Transect angle __________ UTM coordinates at starting point _____________________
Habitat description ____
Temperature ________ Weather Conditions __________________________________
Observer(s) ____

Sighting #	Species	Radial Distance	Compass Angle	Perpendicular Distance	Comments

Estimated population density: ___________

C. Transect 500+ m from highway.

Transect Location ______________________________ Transect Length ___________
Date ________________ Beginning Time ___________ Ending time ____________
Transect angle __________ UTM coordinates at starting point ______________________
Habitat description ____
Temperature ________ Weather Conditions ___________________________________
Observer(s) ____

Sighting #	Species	Radial Distance	Compass Angle	Perpendicular Distance	Comments

Estimated population density: ___________

QUESTIONS

1. Do there appear to be significant differences in the populations densities of *Sciurus griseus* on your three transects? If so, how does the estimated population density vary with the proximity of the transect to the highway? How might you explain any trends you see?

2. Do you believe that a transect survey was appropriate? Why or why not? What alternative method might work better for estimating population densities of these squirrels?

3. Compare the estimated densities of *Sciurus griseus* on the truncated strip transects to the density estimates that you obtained using the Ramsey and Scott method on the unbounded line transects. Which method appeared to work better? Does your choice of transect method appear to influence any interpretations about where the population density of the squirrels is highest?

4. How many squirrels per day were killed on the 10-km section of the highway that you searched?

5. Using your mortality data, estimate the number of squirrels killed per kilometer of road per year.

6. How many gray squirrels do you estimate are killed each year over 200 m (the length of one of your transects) of the highway?

7. How many squirrels would you expect to be killed within a 50 m × 200 m (1 hectare) area surrounding the highway during the course of the year? In light of this information, is the population density of squirrels near the highway high enough for the squirrel population to persist near the highway without immigration from the forest interior? Explain.

8. Considering your data, which of our original three hypotheses seems to be most correct? Explain.

CLASS ASSIGNMENT

After you complete this assignment, hand in your data sheets, density estimates, graphs, and the answers to the above questions. Once each member of the class has turned in this information, we will combine the data and conduct an analysis of variance (ANOVA) with a randomized block design to test the hypothesis that squirrel population densities are lower on transects near the road than they are on transects farther from the road. Your instructor will explain the basics of the analysis and perform the calculations for you. Basically, the analysis allows you to remove the influence of variation in locations and observers while determining whether there are statistically significant differences in squirrel population densities at different distances from the highway.

We will also combine the data from the 10-km sections of the highway and determine the number of squirrels killed per year per kilometer of this highway over the entire length of highway that was surveyed. Based on this information, and the population density (number of squirrels per hectare) of gray squirrels on transects near the road, we will be able to estimate the proportion of the roadside population that is killed each year. We will then evaluate the three original hypotheses concerning the effect of automobile-induced mortality on populations of western gray squirrels.

MATERIALS

Compass
Range finder
Field notebooks

HANDOUT

METHODS FOR ESTIMATING ABUNDANCES OF MAMMAL SPECIES

A. Census Methods (Complete Count)

The population size in a survey area can be determined directly by counting every individual within the area. This is a true **census**. All other methods are considered surveys, rather than census methods, because the total number of individuals within the survey area is estimated based on subsamples of the population. To take a census of the population of a species within a given area, three conditions must be met:

1. The entire area must be searched (or the census will be inaccurate).
2. All individuals in the study area must be detected and counted.
3. The population must be closed during the census.

Censuses work well for determining population densities of large organisms that are easy to detect, and organisms that are immobile, such as barnacles and trees. Censuses are rarely possible with mammals because mammals are mobile, usually nocturnal, and often secretive. A census might work well for large mammals, such as African elephants or rhinoceri, that occupy open habitats. However, even large diurnal mammals in open habitats might wander in or out of the census area during the count, thereby violating the third condition necessary for an accurate census. Because of the difficulty in conducting accurate censuses, they are rarely used to estimate abundances of mammal populations.

B. Survey Methods (Incomplete Count)

1. Indirect abundance indices

An indirect abundance index is a count statistic of some type of sign of a species that is correlated with the population density of the species. Indirect indices are useful for animals that are very difficult to observe or capture. Burrows, scat, tracks, calls, or other types of sign can be counted within a survey area, and the abundance of the species within the area can be estimated based on a previously established relationship between the abundance of the sign and the abundance of the species. We will explore abundance indices in the near future.

2. Capture-recapture method

The capture-recapture method involves capturing a sample of individuals from a population, giving each individual a durable and recognizable mark, releasing all of the captured animals. Then a second sample of individuals is captured at a later date. The proportion of marked individuals in the second sample can be used to estimate the total number of individuals in the population. If certain conditions are met, the ratio of the number of recaptured marked individuals to the total number of individuals captured in the second sample will be roughly equal to the ratio of the total number of marked individuals to the total number in the population.

This relationship can be represented by the following formula:

$$\frac{c}{N}=\frac{m}{n}$$

where:

c = the number of animals captured, marked, and released during time 1
n = the total number of individuals captured during time 2
m = the number of marked individuals captured during time 2
N = the total number of individuals

Rearranging this equation to solve for the total population size (N) gives the familiar **Peterson Index**:

$$\widehat{N}=\frac{\mathrm{cn}}{\mathrm{m}}$$

Simple two-sample capture-recapture estimates of abundance require that the following four conditions are met:

a. No immigration or emigration occurs and there are no deaths or births between sampling periods.
b. All individuals are equally likely to be captured and marked individuals distribute themselves evenly within the population.
c. The marks are not lost between sampling periods.
d. Marks do not affect survival. The estimate of abundance will be inaccurate if one or more of the above conditions does not hold.

If there are more than two sampling periods, the conditions for an accurate estimate can be relaxed a bit. There are indices that are based on multiple recaptures, but we will not deal with them now.

3. **Line transects**
The line transect method involves having an observer walk along a straight line of known length within a survey area and count all of the individuals of the target species that can be seen from the transect line. When an animal belonging to the target species is observed, the perpendicular distance from the transect line to the location where the animal is initially observed is recorded. If animals tend to flee when observed, the perpendicular distance from the transect line can be estimated by using a range finder to determine the distance between the observer and the animal, and using a compass to determine the sighting angle between the transect line and the animal (Figure 1).

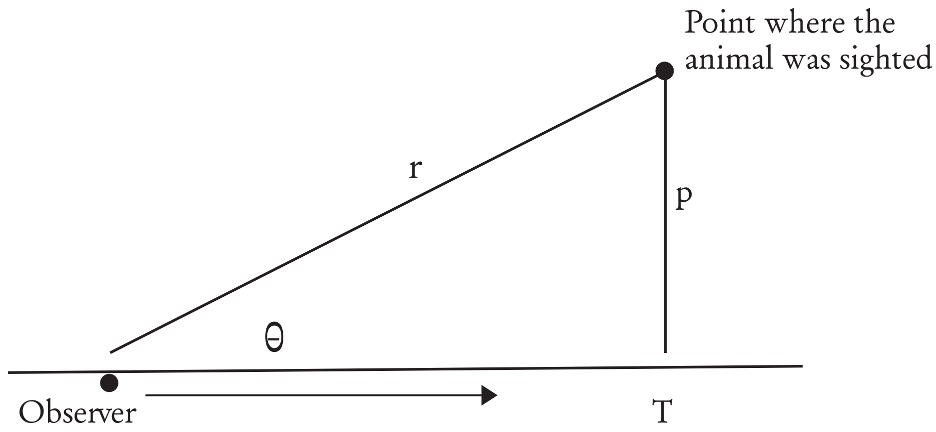


Figure 1. Measurements needed for estimating the perpendicular distance (p) from the point where an animal is initially sighted to the transect line. T is the point on the transect line that is perpendicular to the animal. The radial distance (r) is the linear distance between the observer and animal when the animal was initially sighted. (Modified from Southwood 1996).

Once the radial distance and sighting angle are determined, the perpendicular distance of the animal from the transect line can be calculated using simple trigonometry:

$p = r(\sin\theta)$

One of the assumptions of the line transect method is that all animals that are located directly on the transect line will be detected. The probability of detection decreases as p increases. Consequently, the probability of detection, as a function of perpendicular distance from the transect line, must be taken into account when estimating population densities using a line transect survey. Many mathematical models have been developed for this purpose (see Buckland et al., 1993). The computer programs LINETRAN (Gates, 1980) and DISTANCE (Laake et al. 1991; Buckland et al. 1993) incorporate several of these models into routines for estimating population density based on perpendicular distances or radial distances and sighting angles.

Under ideal conditions, it is sometimes possible to detect all individuals within a certain distance from the transect line. When this is the case, a set transect width (w) in which there is 100% detectability can be chosen before the survey is conducted, and all of the animals that are more distant from the transect line than w can be ignored. The population density of the species in the survey area can then be estimated using the following equation.

$$D = \frac{n}{2wL}$$

where:

D is the estimated population density.
n is the number of individuals counted within the survey area.
w is the distance from the transect line to the outer boundary.
L is the length of the transect.

This type of bounded line transect is called a *strip transect*. The strip transect method is analogous to a complete count, or census, in that *w* is a distance from the transect line in which we assume that all animals present are detected.

In practice, it is rarely possible to safely assume that all individuals of the target species have been detected within a certain distance from the transect line. Consequently, *D* is usually estimated from sightings of animals along an unbounded line transect, and an adjustment is made to account for the decreasing probability of detecting an animal as the perpendicular distance of the animal from the transect line increases. Typically, the distance data are entered into one of the computer programs mentioned above, an appropriate mathematical model is selected, and the computer reveals the estimated population density.

An alternative is to graphically determine a distance from the transect line in which there is a very good chance of detecting any individuals of the target species that are present. One such method, developed by Ramsey and Scott (1981), consists of plotting the cumulative number of individuals sighted from the transect line (plotted on the y-axis) against distance from the transect line (plotted on the x-axis) to determine the effective width of the transect.

The effective width of the transect (w_e) is the perpendicular distance from the transect line beyond which the probability of sighting an animal is significantly lower than the probability of sighting an animal that is directly on the transect line. Remember that for a given distance (p), the cumulative number of individuals sighted at that distance or closer is what is plotted on the graph.

For example, if there were 5 animals sighted at $p = 0$, 6 sighted at $p = 1$, and 4 sighted at $p = 2$, the cumulative number of animals sighted would be 5 at $p = 0$, 11 at $p = 1$, and 15 at $p = 2$. After the cumulative number of individuals sighted is plotted against distance, a line is drawn along the steepest part of the slope. Another line is then drawn which extends from *n*, on the y-axis, and runs perpendicular to the x-axis. The effective width of the transect is the point where this line intersects the line that was drawn along the steepest part of slope (Figure 2).

The effective area surveyed (EAS) can then be determined by the equation EAS = $L2w_e$. The estimated population density can then be calculated using the equation

$D = n/EAS$

Where:

D = the population density of the target species.
n = the number of individuals sighted from the transect line.

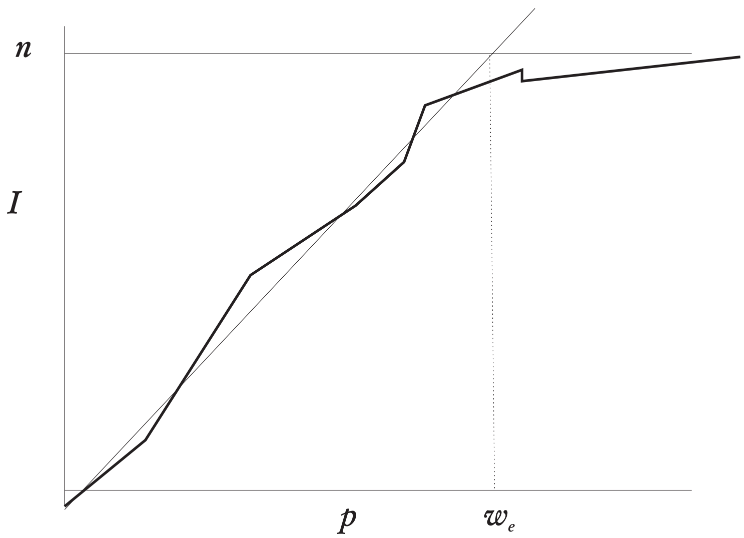


Figure 2. An illustration of the Ramsey and Scott method for graphically estimating the effective width of a transect (w_e) based on perpendicular distances (p) of individuals sighted from the transect line. The cumulative number of individuals sighted (I) is plotted against p, then a straight line is drawn parallel to the steepest part of the slope. Another line is drawn that intersects n (the total number of individuals observed from the transect line) on the Y-axis, and runs parallel to the X-axis. The point where these two lines intersect is used to pinpoint w_e. A vertical line drawn from this point to the X-axis will intersect the X-axis at w_e.

REFERENCES

Buckland, S. T., K. P. Burnham, D. R. Anderson, and J. L. Laake. 1993. *Density Estimation Using Distance Sampling*. Chapman Hall, London, England.

Burt, W. H. and R. P. Grosseheider. 1980. *Mammals of North America.* Peterson Field Guide Series. Houghlin Mifflin Company, Boston, Massachusetts.

Gates, C. E. 1981. *LINETRAN*, a general computer program for analyzing line transect data. Journal of Wildlife Management 44:658-661.

Ingles, L. G. 1967. *Mammals of the Pacific States*. Stanford University Press, Stanford, California.

Laake, J. L., S. T. Buckland, D. R. Anderson, and K. P. Burnham. 1991. *DISTANCE User's Guide.* Colorado State University, Fort Collins, Colorado.

Ramsey, F. L., and J. M. Scott. 1981. *Analysis of Bird Survey Data Using a Modification of Emlen's Method*. Studies in Avian Biology 6:483-487.

Southwell, C. 1996. *Estimation of Population Size and Density when Counts are Incomplete*. Pages 193-210 in D. E. Wilson, F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster.(eds.). *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*. Smithsonian Institution Press. Washington D.C.

Whitaker, J. O., Jr. 1980. *The Audubon Society Field Guide to North American Mammals*. Alfred A. Knopf. New York.

Abundance Indices

INTRODUCTION

An **abundance index** is based on counts of a feature or sign that is indicative of the presence of an animal species, and is correlated with its population density or relative abundance. When a target species is difficult to capture and/or observe, an index of abundance can provide a useful alternative to direct survey methods such as mark-recapture and line transect methods. Abundance indices are also useful for making comparisons of the relative abundance of a species at different locations, particularly when time and resources are limited.

The relationship between an index of abundance and the actual abundance or density of a population is usually assumed to be linear. Consequently, it can be expressed mathematically with the familiar slope-intercept equation, $y = mx + b$. In the statistics of abundance indices, this equation is usually written as

$$Y = \beta_0 + \beta_1 N$$

Where:

Y is the value (count) of the index.
N is the population density or population size.
β_0 is the Y-intercept.
β_1 is the slope.

PROCEDURE

We will conduct two surveys using abundance indices. The first survey will consist of counting the California ground squirrel burrows in a designated site, and relating the number of burrows to the estimated number of ground squirrels determined from our earlier mark-recapture study at the site. The second survey will use pellet group counts on strip transects to estimate the population density of deer at another site. The details of each survey are outlined below.

Determining An Abundance Index For California Ground Squirrels (*Spermophilus beecheyi*)

In a previous lab exercise, you used the mark-recapture method to estimate the number of ground squirrels on a 0.5-hectare survey site. For this exercise, we will revisit our survey site and count the number of burrows. This count will form the basis of an index that we will use to estimate the population density of ground squirrels at another site. To create the index, simply divide the estimated number of squirrels at the site by the number of burrows that we count. The ratio of squirrels to burrows will form the basis of the linear equation that we use to estimate population densities at other sites. Remember that a linear relationship between two variables is described by the equation $Y = \beta_0 + \beta_1 N$.

For the sake of simplicity, we will assume that where there are no ground squirrels there will be no burrows. Thus, β_0 will equal zero and we can drop it from the equation. Therefore, we will be able to solve for β_1 (the slope) using the equation $\beta_1 = Y/N$. We can then plug our value of β_1 into the equation to estimate N for another value of Y at another site. For example, if we counted 42 burrow entrances at our mark-recapture survey site, and our estimate of the population size was 21, then $\beta_1 = 42/21 = 2$. Suppose that we go to a second site and count 30 burrow entrances. Assuming that the relationship between burrow entrances and ground squirrel abundance is the same, we can rearrange the equation $Y = \beta_1 N$ as $N = Y/\beta_1$ and solve for N. In this case, the estimated population size (N) at the second site would be $30/2 = 15$ ground squirrels.

Ideally, we would want to obtain counts of burrow entrances and estimates of ground squirrels abundances at several sites and then perform a statistical procedure known as simple linear regression to solve the equation $Y = \beta_0 + \beta_1 N + \varepsilon$ for β_0 and β_1. In nature, there is rarely ever a perfect linear relationship between two variables. Simple linear regression is a technique for fitting a line to a scatter plot of data in a way that minimizes the deviations (distances) of the data from the line. The term ε represents the deviation of the data from a perfect linear relationship. Because of our limited sample size (1 site), we will estimate β_1 by dividing Y by N, rather than by performing simple linear regression. You will need to follow the steps outlined below.

1. After you count the ground squirrel burrows at our mark-recapture study site, we will designate a further site where there is a cluster of burrows. Count the burrows, and use the procedure outlined above to estimate the number of ground squirrels at the second site (which you can refer to as Site 2). Show your work.

2. Delineate a rectangular boundary around the cluster of burrows at Site 2, and determine the area of the site by multiplying its length by its width. What is the population density (individuals per unit area) of ground squirrels at Site 2?

Estimating Deer Population Densities Based On Pellet Group Counts

We will estimate the population density of deer at a designated study site. We have chosen a site where deer frequently forage an orchard where the grass is mown frequently. The mowing keeps the grass short and prevents fallen leaves from accumulating and covering pellet groups. It also tends to remove or pulverize the deer pellets. Consequently, we can assume that most of the pellet groups that we observe have been deposited since the most recent mowing. The vast majority of the pellet groups at the site have dark and moist pellets and include pellets that are resting upon blades of grass, rather than between the blades. These are fresh pellets that have been deposited since the most recent mowing. Any old pellets that are dry and pale must have escaped the wrath of the lawnmower and can be ignored.

The standard procedure for surveying deer populations using counts of pellet groups involves removing all of the existing pellets from a large strip transect (usually 5 to10-m wide and running linearly across a representative section of a study area) or a series of study plots, and then returning at a later date to count the pellet groups that have been deposited. We will deviate somewhat from this procedure in the interest of time.

To count the pellets, we will need to form a line so that we are spaced apart just far enough that our fingertips touch when our arms are outstretched. We will walk forward slowly, carefully scanning the grass for groups of deer pellets. Each person in the line will be responsible for covering a narrow strip (1.5 - 2 m wide). Keep a mental count of all of the pellet groups that you see. Make sure that you communicate with the person next to you so that you do not both count the same pellet group. We will continue until we have searched the entire area. At the completion of the search, each person will report the number of pellet groups that he or she counted to the record keeper, who will sum the numbers to determine the total number of pellet groups in the orchard.

Under normal circumstances, we would have needed to pick all of the pellets off the grass at the study site at an earlier date, and then counted the new pellet groups to determine the average number of pellet groups produced each day. Instead, we let the lawnmower remove the pellets for us, and we will estimate the number of pellets produced each day by dividing the total number of pellet groups by the number of days since the last mowing. Your instructor will tell you how many days have passed since the grass was mowed. We will make the standard assumption that a typical deer produces an average of 13 pellet groups each day.

Estimate the population density of deer at the site (your instructor will provide information on relating scat counts to density). Remember that population density is the number per unit area, so you will need to take into account the area of the site. Express your estimate of the population density of the deer in terms of numbers of deer per hectare. Show your work.

NOTES FOR INSTRUCTORS

It can be assumed that Y = 0 when N = 0 if the population size is zero-there will be no sign of the species. Consequently, the equation can be reduced to $Y = \beta_1 N$, in theory. However, in practice there is usually a threshold population size in which a few individuals are present but no sign is detectable. The important point is that β_1, the relationship between Y and N, should remain constant. Often this is not the case. Therefore, a pilot survey should be conducted to explore the relationship between Y and N over a range of population densities to determine if the assumption of a constant and linear relationship is valid. If the relationship is positive but variable, an abundance index can still be used for qualitative comparisons of the relative abundance of the species at different sites.

Abundance indices can be categorized as either direct or indirect. A **direct abundance index** is based on numbers of captured or harvested animals. In theory, capture or harvest success should be related to population density, especially if capture effort or hunting pressure is kept constant. **Indirect abundance indices** are based on evidence of an animal's presence, such as counts of tracks, animal calls, scat, scent-station visits, or burrows. Indirect indices are more likely to exhibit a positive linear relationship with abundance than are direct indices (Conroy 1996). The utility of different types of indirect abundance indices is briefly discussed below (see Conroy 1996 for a more thorough treatment).

This activity describes methods for developing abundance indices for ground squirrels and deer. Although they may be easily modified for most medium-sized burrowing mammals and large herbivores, alternative methods described in the resources below must be developed for other types of mammals.

Types of Indirect Abundance Indices

1. **Track counts.** Counting the number of tracks in a defined area provides an index of abundance that can, under ideal conditions, be linearly related to population density. For example, Van Dyke et al. (1986) reported a direct positive relationship between numbers of mountain lion tracks and the abundance of mountain lions. However, variation in habitat attributes and weather can nullify this relationship. Thus, a study in which abundance is inferred from track counts must be designed and conducted in a manner that minimizes variation in factors that influence track counts, but are unrelated to population density.

2. **Scat counts.** Indices based on scat counts are frequently used to estimate abundances of large mammals, such as ungulates. This method has been widely used and refined for cervids (members of the deer family). However, the relationship between counts of fecal pellets and abundance of deer is often unpredictable (Neff 1968, Fuller 1991). Under the right circumstances, scat counts can be fairly reliable abundance indices. For example, Krebs et al. (1987) reported a linear relationship between counts of fecal pellets and mark-recapture estimates of population density for snowshoe hares (*Lepus americanus*). On the other hand, temporal and spatial heterogeneity in weather conditions and decay rates can limit the utility of scat counts for examining trends and spatial variation in populations.

   One way to minimize the influence of decay on scat counts is to remove all of the scat from an area and count all of the new scat produced over a set time period. A common practice among wildlife biologists is to remove all deer pellets from a survey plots or strip transect, and then count the number of pellet groups (clusters) present after a certain number of days or weeks. Cervids tend to produce an average of about 13 pellet groups per day. Thus, the number of pellet groups can reveal roughly how many deer were present, on average, during the time of the survey (Shaw 1985). For example, suppose that 130 pellet groups are present on a 10,000-square meters (1 hectare) survey area that was cleared of pellets 20 days before the count. The number of pellet groups produced by one deer over 20 days is approximately $13 \times 20 = 260$. 130 pellet groups and 260 pellet groups per deer should have been produced. Therefore, the estimated density of deer in the survey area is $130/260 = 0.5$ deer per hectare.

3. **Surveys of structures.** Counts of lodges, nests, burrows, and food caches are sometimes appropriate for abundance indices. A positive linear relationship with population density can be expected for indices based on counts of any structure that is routinely constructed by individuals of the target species (Uhlig 1956, Conroy 1996). However, the relationship should be verified to ensure that the structure is related to population density. For example, Proulx and Gilbert (1984) found that muskrat houses are a good index for muskrat abundance. However, there is only a weak relationship between numbers of beaver lodges and numbers of beavers (Easter-Pilcher 1990). This is because beavers often build dens in stream banks rather than lodges.

Furthermore, they will build lodges in some types of habitat but not in others. Consequently, numbers of beaver lodges are not necessarily related to numbers of beavers.

4. **Scent station surveys.** Surveys involving the use of scent stations can work well for species that mark territorial boundaries. Constructing a scent survey station entails clearing a small area and covering it with a material in which animal tracks will leave a clear impression (i.e., moist sand). Urine, or a synthetic odor designed to attract the target species, is placed in the center of the station. Usually there are many stations, and the proportion of the stations visited is used as the index of abundance (Conroy 1996). Conner et al. (1983) compared abundance indices based on visits to scent stations to estimates of abundance from mark-recapture and radio-telemetry studies. They found that there was a positive relationship between the abundance index and estimated abundance for raccoons, gray foxes, and bobcats, but not opossums. Diefenbach et al. (1994) reported a positive but highly variable relationship between proportions of scent stations visited by bobcats and abundances of bobcats.

5. **Auditory surveys.** Indices based on the number or frequency of calls are often used for loud vocal mammals such as wolves and coyotes or owls. Ultrasonic detection of bat calls is frequently employed to estimate bat abundance. The weakness of auditory surveys is that they are easily influenced by weather conditions, topography, and variation in the activity level of the target species.

REFERENCES

Conner, M. C., R. F. Labinsky, and D. R. Proglske, Jr. 1983. *Scent-Station Indices as Measures of Population Abundance For Bobcats, Raccoons, Gray Foxes, and Opossums*. Wildlife Society Bulletin 11:146-152.

Conroy, M. J. 1996. *Abundance Indices*. Pages 179-192 *In* D. E. Wilson, F. R. Cole, J. D.Nichols, R. Rudran, and M. S. Foster. (eds.). *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*. Smithsonian Institution Press. Washington, D.C.

Diefenbach, D.R., M. J. Conroy, R. J. Warren, W. E. James, L. A. Baker, and T. Hon. 1994. *A Test of the Scent-Station Survey Technique for Bobcats*. Journal of Wildlife Management 58:10-17.

Easter-Pilcher, A. 1990. *Cache Size as an Index to Beaver Colony Size in Northwestern Montana.* Wildlife Society Bulletin 18:110-113.

Fuller, T. K. 1991. *Do Pellet Counts Index White-Tailed Deer Numbers and Population Change?* Journal of Wildlife Management 55:393-396.

Krebs, C. J., B. S. Gilbert, S. Boutin, and R. Boonstra. 1987. *Estimation of Snowshoe Hare Population Density from Turd Transects*. Canadian Journal of Zoology 65:565-567.

Neff, D. J. 1968. *The Pellet-Group Count Technique for Big Game Trend, Census, and Distribution: A Review*. Journal of Wildlife Management 32:597-614.

Proulx, G., and E. F. Gilbert. 1984. *Estimating Muskrat Trends by House Counts*. Journal of Wildlife Management 48:917-922.

Shaw, J. H. 1985. *Introduction to Wildlife Management*. McGraw-Hill Book Company, New York.

Uhlig, H. G. 1956. *The Gray Squirrel in West Virginia*. The Conservation Commission of West Virginia, Division of Game Management Bulletin 3. Charleston, West Virginia.

Van Dyke, F. G., R. H. Brocke, and H. G. Shaw. 1986. *Use of Road Track Counts as Indices of Mountain Lion Presence*. Journal of Wildlife Management 50:102-109.

Name____

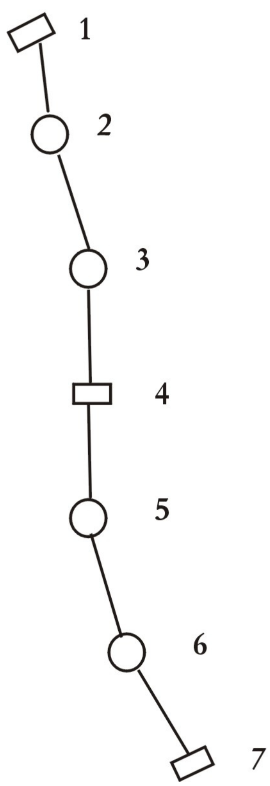
LAB MIDTERM EXAM

1. Use the key to the orders and the key to the skulls in your textbook to identify the species of mammal that each of the skulls on the front table belonged to. Fill in the blanks below as you proceed.

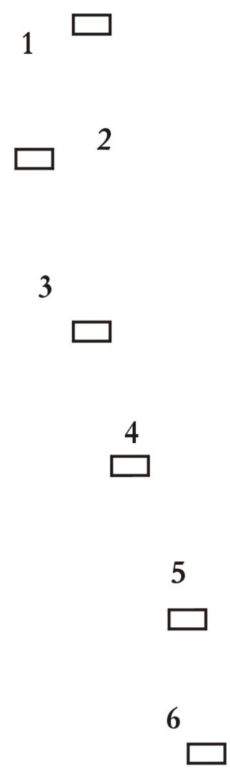
Skull #	Order	Family	Genus	Species (if applicable)

2. Use the information given to answer the questions below.
Below is a diagram and information about trap lines. The trap lines were both in riparian habitat dominated by willows, alders, rushes, sedges, and grasses. The trap lines are diagrammed below.

Trap line 1



Trap line 2



The results of your trapping effort are summarized in the table below

Trap Line 1

Trap night #	Trap #	Type of trap	Species	Comments
1	2	Pitfall	Montane vole	Adult Female
1	5	Pitfall	Vagrant shrew	Adult
1	6	Pitfall	Trowbridge shrew	
2	1	Sherman Box	Deer Mouse	Adult Male
2	3	Pitfall	Vagrant shrew	Dead
3	2	Pitfall	Vagrant shrew	
3	3	Pitfall	Montane vole	Adult female
3	4	Sherman Box	Montane vole	Juvenile male
3	5	Pitfall	Vagrant shrew	
4	6	Pitfall	Trowbridge shrew	
4	7	Sherman Box	Deer mouse	Juvenile Female

Trap Line 2

Trap night #	Trap #	Type of trap	Species	Comments
1	1	Sherman Box	Deer mouse	Adult Female
1	3	Sherman Box	Montane vole	Adult Female
1	5	Sherman Box	Deer mouse	Juvenile Female
1	6	Sherman Box	Deer mouse	Adult Male
2	5	Sherman Box	Canyon mouse	Adult Male
3	2	Sherman Box	Deer mouse	Adult Male
3	5	Sherman Box	Deer mouse	Juvenile Female
4	1	Sherman Box	Deer mouse	Juvenile Male
4	3	Sherman Box	Deer mouse	Adult Male
4	4	Sherman Box	Montane vole	Adult Male
4	6	Sherman Box	Deer mouse	Adult Female

A. What was your trapping effort, in terms of trap nights, at each trap line?

B. You have probably noticed that some species were trapped frequently on one trap line and not on the other. Also, some of the species trapped on Trap line 1 were not present on Trap line 2, even though the two trap lines were in very similar habitat. How can you explain these differences?

3. You have been asked to estimate the population density of skunks in a wetlands area. You decide that a capture-recapture (mark-recapture) survey is the best method for your purposes. You set out 30 traps baited with dead fish. The next morning you find that you have captured 16 skunks. You mark them with *shocking pink* clothing dye and release them immediately. Soon after, you are overcome by the smell of your clothing. Your stomach begins to turn, your eyes began to roll, and everything goes black. When you regain consciousness, you examine your wristwatch. Much to your horror, you realize that three days have passed. "Perfect!" you exclaim, "Now I can get started on my second trapping effort." You obtain more dead fish, bait the traps, sit down on a hillside, and wait for morning (your roommates wouldn't let you in the apartment). In the morning, you discover that there are 24 skunks in your traps. Eight of them have big shocking pink spots on their backs (they are marked skunks that were recaptured).

A. Using the Peterson Index (also known as the Lincoln Index), calculate the total number of skunks (N) that inhabit your study area.

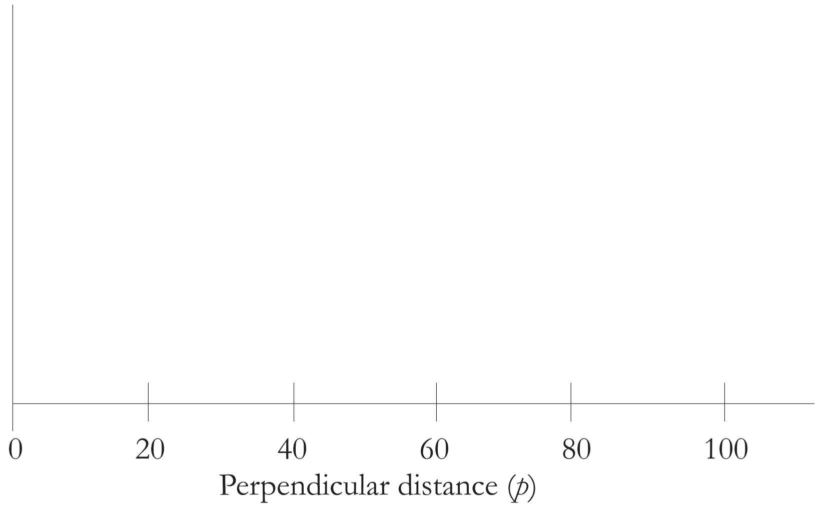
B. The dimensions of your study area are 100 $\times$100 meters. What is the population density of skunks at the wetland habitat at Feather River College?

C. What are three conditions that must be met for the results of a capture-recapture survey to be accurate?

4. You have just returned from a wildlife refuge on the savanna of Tanzania, where you were conducting research to determine the population density of Wildebeests. Part of your study involved walking a 1 kilometer (1000 m) long transect and counting the number of wildebeests that you could see from the transect line. Your data sheet is shown below.

Sighting #	Species	Perpendicular	Comments
1	Wildebeest	12	Charging male
2	Wildebeest	35	
3	Wildebeest	51	Running with #4
4	Wildebeest	52	Running with #3
5	Wildebeest	4	Adult Female
6	Wildebeest	7	Juvenile with mother (above)
7	Wildebeest	27	
8	Wildebeest	2	
9	Wildebeest	23	
10	Wildebeest	49	
11	Wildebeest	57	
12	Wildebeest	18	Appeared to be fleeing
13	Lion	5	I moved very quickly here
14	Wildebeest	76	The only one I see now
15	Wildebeest	65	
16	Wildebeest	32	
17	Wildebeest	93	
18	Wildebeest	41	
19	Wildebeest	35	
20	Wildebeest	53	
21	Wildebeest	25	

Graph the cumulative number of animals (on the Y-axis) against the perpendicular distance (on the X-axis) to estimate the effective width of your transect (w_e). Based on your estimate of w_e, what is the population density of wildebeests at your study site? Remember that density is number divided by area.



5. Assume that this past Tuesday, a group of elementary school students collected all of the deer pellets from their assigned study site. The site is about 0.8 acres in area. This afternoon (a Thursday) you conduct a thorough inspection of the orchard and count 104 pellet groups. Assuming that deer produce 13 pellet groups every day. What is your estimate of the population density of the deer in terms of deer per acre?

INTRODUCTION TO MAMMALOGY

Name: ____

LAB EXAM

Story problems (10 points each)

1. It is April of 1999. Over the last three months, Justin has been faithfully trapping feral cats and depositing them at the Humane Society. So far, he has removed 95 cats from his chosen site. Justin has been fiercely opposed in his efforts by Jessica Pillowhart, president of the local chapter of Cats Unlimited. Jessica is concerned that Justin is severely depleting the population of feral cats. Justin claims that he hasn't even dented the population yet. He tells Jessica that he conducted a capture-recapture study back in January and calculated that there were 147 cats at the site at the time. He feels that the cats have been reproducing almost as fast as he has been able to remove them. Jessica feels that the winter has been especially hard on the cats and that the population will soon go extinct if trapping continues. They agree to conduct a second capture-recapture study to determine who is right. On 21 April 1999, Justin and Jessica spend all day setting 300 traps all over the site. Jessica has spent $150 on gourmet catfood that will serve as bait. The next day, there are 48 cats in the traps. Jessica and Justin have a brief argument over how the cats should be marked. Jessica wants to tie cute little white ribbons in their hair. Justin wants to spray paint them fluorescent orange. They agree on using a small amount of green clothing dye instead. Jessica and Justin wait 7 days, then reset the traps. This time there are 60 cats in the traps. A total of 24 cats have a dab of green clothing dye on the napes of their necks.

   A. Using the Peterson Index (also known as the Lincoln Index), estimate the total number of feral cats (*N*) that inhabit the site in April 1999. Is Jessica correct in her belief that the population of feral cats there is on the verge of extinction?

   B. You may remember that there are three conditions that must be met for the results of a capture-recapture survey to be accurate? Which of these conditions would be difficult for Justin to meet during his capture-recapture survey of the feral cat population? Explain your answer.

2. Max Hallucinagen has spent the last two summers studying bigfoot sign in a local mountainous area. He is especially interested in bigfoot tracks and scat. Max followed a troop of 12 bigfeet over a period of 14 days during the summer of 1997. During the 2 week period, the troop produced 336 scat piles.

   A. Explain how you could develop an abundance index using the data that Max gathered on bigfoot scat production.

   B. During the summer of 1998, Max was unable to directly observe the elusive bigfoot troop. However, he noticed that 440 piles of bigfoot scat were produced over a period of 10 days in a mountain meadow near a stream. Using your abundance index (from part A), estimate the number of bigfeet present in the meadow.

Multiple Choice and short answer (2 points each)

Animal tracks:

3. What family does the animal that made these tracks belong to? (a) Ursidae (b) Felidae (c) Canidae (d) Mustelidae (e) Otariidae

4. What species of mammal made this track?

5. The animal that made this track was a (a) mink (b) feral cat (c) gray fox (d) opossum (e) skunk

6. The animal that made this track was a (a) raccoon (b) red fox (c) bobcat (d) beaver (e) mink

7. What species of mammal made this track?

8. What species of mammal made this track?

9. What is the easiest way to tell the track of a member of the family Canidae from the track of a member of the family Felidae?

10. Which of the following materials is useful for recording the tracks of mammals (a) metal soot plates with contact paper (b) fluorescent powder observed with a black light (c) smoothed out sand or soft soil (d) all of the above (e) none of the above

Skulls:

11. Describe the differences in the structure of the different types of head ornaments on the skulls in front of you.

12. What family did the animal with Skull A belong to?

13. What family did the animal with Skull B belong to?

14. What family did the animal with Skull C belong to?

15. Observe skull #15. What family did it belong to?

16. What are two unique features of the skulls of mammals in the order that this animal be longed to?

17. Which of the labeled teeth in this skull are the carnassial teeth?

18. Judging from the mandibular fossae of these two skulls, which animal was the most carnivorous? Explain.

19. What species does this animal belong to?

20. What family does it belong to?

21. What species does this animal belong to?

22. What family does it belong to?

23. What species does this animal belong to?

24. What order does it belong to?

25. What species does this animal belong to?

26. Did it have a plantigrade, digitigrade, or unguligrade stance?

27. What species does this animal belong to?

28. What family does it belong to?

29. What order does it belong to?

30. What species does this animal belong to?

31. What suborder does it belong to?

32. What species does this species belong to?

33. What family does it belong to?

34. What did this animal eat?

35. What species does this animal belong to?

36. What suborder does it belong to?

37. What species does this animal belong to?

38. This species gets around using (a) cursorial locomotion (b) saltatorial locomotion (c) rectilinear locomotion (d) psychokinesis (e) a particle accelerator.

39. What species does this mammal belong to?

40. What family does it belong to?

41. What species does this mammal belong to?

42. What class does it belong to?

Mammalogy EXAM 1

Name: ______________________________

EXAM 1

Matching (1 point each)

1. Xenarthra _____
2. Chiroptera _____
3. Monotremata _____
4. Primates _____
5. Didelphimorphia _____
6. Lagomorpha _____
7. Scandentia _____
8. Diprotodontia _____
9. Rodentia _____
10. Insectivora _____

(a) Egg laying mammals

(b) Opossums

(c) Shrews and moles

(d) Eutherians, no incisors, canines, low metabolism

(e) Single pair of “ever-growing” incisors on each jaw

(f) Small pair of incisors behind large upper incisors

(g) Order with trichromatic vision

(h) Order including kangaroos, wallabies, and koalas

(i) Forelimb, especially hand, modified to form wing

(j) Order includes similar ancestors of primates

Multiple Choice (2 points each)

11. Which of the following are characteristics of echidnas and platypuses? (a) No teeth in adults (b) Females lay eggs (c) males have ankle spurs (d) long and beak-like snout (e) all of the above (f) a, b, & c

12. Which of the following are characteristics of the shrews (family Soricidae)? (a) No teeth in adults (b) Toxic saliva (c) Excellent color vision (d) High metabolic rate (e) b & c (f) a & d (g) b & d (h) c & d (i) all of the above

13. The part of the brain that functions as a thermostat in mammals is the (a) cerebellum (b) hypothalamus (c) amygdala (d) pons (e) medulla

14. Which of the following species of bat nests in huge colonies and belongs to the family Molossidae? (a) Hoary bat (b) Big brown bat (c) California myotis (d) Mexican free-tailed bat (e) Flying fox

15. Which of the following does <u>not</u> belong to the family Hominidae (a) Gibbon (b) Chimp (c) Human (d) Orangutan (e) Gorilla

Define the following terms (2 points each)

16. Synapsid

17. Saltatorial

18. Altricial

19. Delayed implantation

20. Thermal window

21. Thermoneutral zone

22. Endothermic

23. Patagium

24. Keystone species

25. Torpor

Short answer (3 points each)

26. What does the presence of turbinals in the nasal cavities of cynodonts (a group of advanced mammal-like reptiles) tell us about them?

27. What are three ways that desert rodents can keep cool during hot summer days?

28. What are three functions of the placenta in eutherian mammals?

29. Why must most species of shrews stay near water?

30. Name two families of rodents with cheek pouches?

Slightly tougher short answer questions (5 points each)

31. Describe the three phases of prey capture in bats.

32. What are three differences between rabbits and hares?

33. What is copraphagy, and what purpose does it serve for lagomorphs?

Short essay questions (10 points each)

34. Briefly summarize the key changes that occurred in the teeth, jaws, and skeleton of the synapsid lineage; beginning with carnivorous pelycosaurs (Sphenacodontidae), continuing through therapsids (mammal-like reptiles), and ending with early mammals.

35. While vacationing in Borneo during your Spring break, you discover a species of bat that has never been described before. The bat is the size of a large microchiropteran or small megachiropteran. It has broad, short wings (low aspect ratio) and very large eyes. You notice immediately that there is a fleshy projection on the tip of the bat's nose, and that each ear of the bat includes a tragus. The bat has sharp canines and incisors, but its molars are smooth and flat and its palate is hard and ridged. Based on these characteristics, describe the foraging habits, navigation, flight, and habitat use of this species of bat. Explain your answer.

36. For many decades sherpas and mountaineers who ventured into the remote high elevation regions of the Himalayas have told stories of the yeti, or abominable snowman. Some have speculated that yetis might be a relict population of an early ape-like primate such as *Ramapithecus.* During your most recent visit to Mongolia, you learn from the local desert-dwelling people about a legendary yeti-like creature that wanders the barren sands of the Gobi Desert. Both types of yeti are large, bipedal, and hairy. However, there appear to be differences in the size, shape, color, and fur of the mountain and desert-dwelling yetis. You suspect that there are other differences as well. What physical and physiological adaptations do you expect to find in the two types of yetis? In what ways would you expect the Himalayan and Gobi Desert yetis to be different? Explain your answers. Be creative (Extra good answers will receive bonus points).

Name: ____________________________________

FINAL EXAM

Match the mammal orders with the appropriate description of their characteristics (1 point each)

1. Carnivora _____
2. Artiodactyla _____
3. Perissodactyla _____
4. Cetacea _____
5. Proboscidea _____
6. Sirenia _____
7. Hyracoidae _____

(a) Grazing with mesaxonic feet

(b) Large, muscular trunk, pair long tusks

(c) Herbivorous, marine, no hind limbs, front limbs modified as flippers, horizontally flattened tail

(d) Marine, echolocation or baleen plates to feed

(e) Herbivorous, paraxonic feet, horns, antlers Many species are ruminants

(f) Large pointed canines,specialized carnassial teeth

(g) Vocal herbivorous live in colonies, have hoof-like nails on toes, climb trees or rocks

Match the families of Artiodactyla & Perissodactyla with the correct description

(1 point each)

8. Suidae _____
9. Tayassuidae _____

(a) Herbivorous, horns (usually in both sexes) and a four-chambered ruminating stomach

(b) The fastest land animal in North America Each of its horns has an anterior prong

10. Giraffidae _____ (c) Includes the guanaco and vicuna. Ruminants with 3-chambered stomach, cleft upper lip, and toes with nails on the upper surface

11. Cervidae _____ (d) Grazing mammals that use hindgut fermenta tion, have mesaxonic feet, and are sometimes striped

12. Antilocapridae _____ (e) Big-headed pig-like, flat snout, small hooves, upper canines that point down

13. Bovidae _____ (f) Flat snout, upper canines curve up as tusks. *Facial warts*

14. Equidae _____ (g) Browsing/grazing, true horns (usually in both sexes), four-chambered ruminating stomach.

15. Camelidae _____ (h) Family that contains two long-necked species that haveossicones

Multiple Choice (1 point each)

16. All of the following are characteristics of elephants except (a) horizontal replacement of molars (b) ruminating digestive system (c) digitigrade feet supported by a fibrous pad (d) communication by low-frequency sound (e) cheek teeth with complex ridges

17. Which of the following whales is a baleen whale that feeds by skimming (a) blue whale (b) killer whale (c) bowhead (d) narwhal (e) sperm whale

18. Which of the following families does not have well-developed carnassial teeth (a) Ursidae (b) Mustelidae (c) Canidae (d) Felidae (e) Herpestidae

19. Which of the following is not a characteristic of the earless seals of the family Phocidae (a) no external ears (b) hind limbs rotated forward (c) lower incisors (d) abdominal testes (e) inflated auditory bullae

20. Which of the following families belongs to the suborder Feliformes (a) Otariidae (b) Ursidae (c) Hyaenidae (d) Procyonidae (e) Mustelidae

Define the following terms (2 points each)

21. Paraxonic

22. Mesaxonic

23. Population

24. r-selected

25. Logistic growth

26. Ecological niche

27. Character displacement

28. Unguligrade

29. Eusociality

30. Kin selection

31. Species-area relationship

Short Answer (3 points each)

32. How does the shape of the mandibular fossa (area where the lower jaw fits into the skull) vary according to diet among species in the order Carnivora?

33. Describe the differences in the physical characteristics and foraging behavior of mysticete whales that feed by gulping and mysticete whales that feed by skimming.

34. How did the changing climate of the early Tertiary period (especially the Eocene and Oligocene Epochs) affect the evolution of mammals in the orders Perissodactyla and Artiodactyla?

35. Give three reasons why it is advantageous for wolves to live in packs and share the responsibility of caring for the young of the alpha female and alpha male.

36. List 7 or more characteristics of members of the order Carnivora

37. Give three examples of altruistic behavior in mammals.

Longer but still short answer (5 points each)

38. Describe adaptations and strategies used by odontocete whales and dolphins to locate their prey.

39. Compare and contrast the digestive systems of monogastric (hindgut) fermenters and ruminant (foregut) fermenters. Also, discuss the advantages and disadvantages of each.

40. What is character displacement, and how does it relate to niche overlap and interspecific competition?

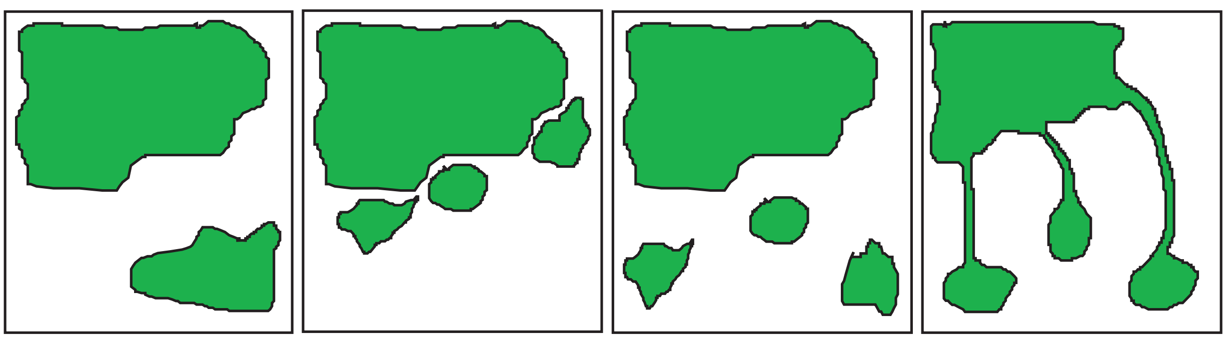
41. Your good friend Wanda Cosmos has just returned from a spiritual journey to a remote monastery in Burma, where she has spent the last six months meditating and mumbling mantras while seeking the union of her consciousness with the universal mind. During a particularly mystic moment, she saw a strange looking white and black animal climb out of a swamp and begin to forage among the lush jungle foliage. Wanda quickly slipped into a state of carnal degeneracy, seized a high caliber rifle, pulled the trigger, and sent the poor creature hurling into eternity. Inspection of the animal revealed that it had four toes on its front feet and three on the hind feet. The third digit was larger than the others and appeared to bear most of the weight of the animal. The creature had an interesting proboscis-like upper lip that curved down in front of its mouth. Its teeth were moderately high crowned and folded. The creature was too large for Wanda to lift, so she gutted it at the site of the kill. She noticed that it had a very large ceacum where the large and small intestines meet. What can you tell Wanda about the habits and the classification of the animal?

Essay questions (10 points each)

42. You are in charge of managing a population of the pine marten (*Martes americana*) in a remote forested region covering 20,000 hectares on the west slope of the Cascades in Oregon. Pine martens den in hollow trees and logs and feed on a variety of forest-dwelling small mammals. They are secretive animals that are seldom found anywhere near human settlement. The average size of the home range of adult male pine martens is about 260 hectares. Females have home ranges of around 65 hectares. Unfortunately, during the next 5 years, 13,000 hectares of the forest will be clear-cut, burned, then strip-mined by a multinational gold mining company. The Forest Service has presented you with four management plans. Diagrams of the how the forest will be fragmented under each plan are shown below.

Plan A *Plan B* *Plan C* *Plan D*

Forest



Your job is to select the plan that will result in the least damage to the pine martens and other forest-dwelling creatures. Explain which plan you would select and why it would be the least damaging option.

43. You have noticed that there is a strange cyclic pattern in the population density of the pine martens. You suspect that the abundance of pine martens is related to the abundance of its primary prey item in the area, the Douglas squirrel or chickaree (*Tamiasciurus douglasi*). When you examine data on chickaree abundance you find that it is also cyclic. Both species peak in their abundance about once every 10 years. How ever, the two cycles are out of phase. The pine marten population peaks a year or two after the chickaree population peaks. This means that chickaree population is declining when the pine marten population reaches its peak. How might you explain the cyclic pattern in the abundances of chickarees and pine martens? What factors do you think are responsible for the cyclic populations of each species?