Animal form and function: Are you an herbivore, carnivore, or omnivore? Animal adaptations for feeding and digestion

Laboratory Objectives:

After completing this 4 week lab module, you should be able to:

1) Understand basic skull and digestive system morphology of animals, digestive enzymes, and elemental/isotopic analysis related to feeding and digestion.
2) Consider functional aspects of morphology and enzymology to generate hypotheses to assess the feeding mode of "unknown" organisms
3) Understand basic concepts in biochemistry and enzymology, including: activity, specific activity, pH optimum
4) Integration information from diverse levels of biological organization to answer a single question and gain appreciation for interdisciplinary approaches to science.
5) Use the internet to acquire scientifically relevant information on animal adaptations for feeding and digestion
6) Manipulate and analyze data on morphometrics, enzyme measurements, and stable isotope analyses.
7) Appreciate the subjectivity of science and become more comfortable with ambiguity in interpretation of results, i.e., there is almost never "one right answer."

Table 1 – Overview of the laboratory module. Students are presented with three animals (human, crayfish, and unknown fictional animal), and are challenged to assess whether these animals are herbivores, carnivores, or omnivores based on structural, biochemical, and stable isotope features. Students will generate a hypothesis, then design a study to test the hypothesis. Results from the studies will be discussed to develop conclusions on feeding mode based on the available evidence.

Week			
1	Exercise 1	Introduce the questions. Discussion of recent relevant publications on meat eating in humans, and also determine what students currently believe/know about human and animal nutrition. Discuss dietary preferences of students and conceptions of diet and obesity. Discuss what evidence could be examined to determine feeding mode of an animal. Begin practice of measurements: Skull morphology, dentition, oral mechanical digestion	
2	Exercise 2	Explanation and practice of measurements:	

		Mammalian digestive system anatomy and fat, digestive enzymes, stable isotope analysis and sample collection. Preliminary development of hypotheses.	
3	Exercise 3	Finalization of hypotheses, analyze stable isotope data from Exercise 2, discussion of experiments/measurements to test hypotheses, conduct measurements.	
4	Exercise 4	Student presentation of compiled measurements, synthesis of all class measurements, discussion/debate and assignment of feeding mode to each of the three animals.	

EXERCISE 1
Determining what an animal eats and the importance of diet

Lab Study A – Diversity of feeding ecology and adaptations in animals

Materials

1-4 computer workstations per table
Internet connection
Optional: Books or other materials on animals and feeding adaptations

Introduction

The feeding capabilities of animals are a major aspect of animal diversification (recall the phylogenetics module earlier in the course), body structure/physiology, and ecosystem functioning. Animal nutrition can be related to: (1) skull, jaw, teeth structure, (2) gastrointestinal system structure, chemical environment, enzymes, and mutualistic symbiosis with microorganisms, (3) metabolic performance, body composition, behavior and activity. Nutrition can also vary greatly among individuals within a species and within taxonomic groups.

When describing an animal, what they eat is considered to be a major aspect of their biology. Surprisingly, nutrition can be misunderstood or poorly characterized. For example, an animal may be difficult to observe because it is rare or lives in an environment that is inaccessible. In this lab you will attempt to characterize the feeding biology of three animals.

(1) You will be given body parts of a fictional rare animal that has never been observed alive in nature.
(2) You will have live crayfish to conduct measurements on. Crayfish have traditionally been thought of as detritovores, but the view that they are actually highly carnivorous is gaining acceptance.

(3) You will assess the feeding biology of humans.

Although humans are readily observed and have been intensively studied, it is possible that accepted dogma can influence the interpretation of existing data/information

Procedure:

1) Divide into groups of 4-5.
2) Using the internet or other resources pick three animals from **three different** animal phyla.
3) As a group, answer the questions in the Results section below.
4) As a class each group will present their animal that is the best and worst understood in terms of their feeding ecology.

Results:

Answer Sheet

1) Animal 1: common name:_____ species name:_____
    i) What environment does the animal live in? Is food availability high or low, constant or intermittent?

    ii) Does the animal have high energetic demands due to activity, growth, or reproduction? Explain

    iii) Is the animal considered to be a carnivore, omnivore, or herbivore

    iv) Is the diet specialized or general? What are the main food items?

2) Animal 2: common name:_____ species name:_____
    i) What environment does the animal live in? Is food availability high or low, constant or intermittent?

ii) Does the animal have high energetic demands due to activity, growth, or reproduction? Explain

iii) Is the animal considered to be a carnivore, omnivore, or herbivore

iv) Is the diet specialized or general? What are the main food items?

3) Animal 3: common name:_____ species name:_____
   i) What environment does the animal live in? Is food availability high or low, constant or intermittent?

   ii) Does the animal have high energetic demands due to activity, growth, or reproduction? Explain

   iii) Is the animal considered to be a carnivore, omnivore, or herbivore

   iv) Is the diet specialized or general? What are the main food items?

4) What types of information can be used to determine what an animal eats?

5) Are there cases where this information is not feasible to collect or affected by the experiment/collection? Are there reasons why some information would be inconclusive?

6) Can there be negative results from a faulty understanding of an animal's diet? Examples?

Lab study B – Human nutritional ecology

Materials

Same as lab study A above

Introduction

Sometimes we do not always consider that humans are a type of primate and that ecology and adaptations are relevant to one of our most important activities: eating. Americans are generally omnivores, but there is some discussion of the necessity of eating meat on the one hand, and recent evidence that meat eating was an important factor in human evolution. Carnivory involves feeding at higher trophic levels. There is a limitation on the number of carnivores that can be sustained in an ecosystem. Recently, it has been argued that human population and associated climate change is unsustainable and the cannibalism will be necessary to support the protein needs of humans. A vegan lifestyle can be maintained in which humans appear to be perfectly healthy without eating animal products. See recent book by Paul Ehrlich and associated news articles:

(a) http://press.uchicago.edu/ucp/books/book/chicago/H/bo17588109.html
(b) http://www.washingtonindependentreviewofbooks.com/bookreview/hope-on-earth-a-conversation
(c) http://www.fao.org/docrep/010/a0701e/a0701e00.HTM
(d) http://www.slate.com/articles/health_and_science/feed_the_world/2014/05/meat_eating_and_climate_change_vegetarians_impact_on_the_economy_antibiotics.html

However, recent evidence suggests that increased meat eating may have been integral to human evolution. Prior to the recent advent of agriculture, meat was one of the only feasible food sources rich in calories. The caloric content of meat may have facilitated the evolution of a larger brain (which consumes massive quantities of energy). Furthermore,

hunting may have necessitated more sophisticated tool use and levels of group organization and culture. Further discussion can be found in:

> Carnivory enabled humans to reproduce faster:
> http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0032452
>
> Meat (and cooking it) may have been necessary to evolve larger brain size
> http://www.pnas.org/content/early/2012/10/17/1206390109
> http://www.livescience.com/24875-meat-human-brain.html
> http://www.ted.com/talks/suzana_herculano_houzel_what_is_so_special_about_the_human_brain

Procedure:
1. Divide into groups of 4-5.
2. As a group, answer the questions in the Results section below.

Results:

Answer Sheet for Individuals

1) Do you eat meat? If so, how frequently, what types, how much?

2) Why do you eat meat? Ideally, would you eat more or less?

3) What do you consider to be the positive benefits of eating meat? Negative?

4) Bluefin tuna sushi is among the most desirable and flavorful, and can cost hundreds of dollars for a single piece. Bluefin are likely to eventually be listed on the endangered species list. If you were offered a free piece of wild-caught bluefin tuna would you try it?

5) Do you think that humans should be classified as herbivores, omnivores, or carnivores? What criteria and standards do you use for classification?

Answer sheet for lab groups

1) As a group answer find information on the internet and answer the following questions:
   a Why would it be unsustainable for humans to continue eating meat by 2050? Is the average meat consumption by WSU students high compared to other countries or compared to prehistoric humans prior to the advent of agriculture?

   b What influence did meat eating potentially have on human evolution? What may have enabled humans to be effective hunters? Why might someone argue that eating meat is "natural" for humans?

2) As a group, present your findings to the class for 1a and 1b above.

Lab Study C – Oral adaptations for feeding

Materials:

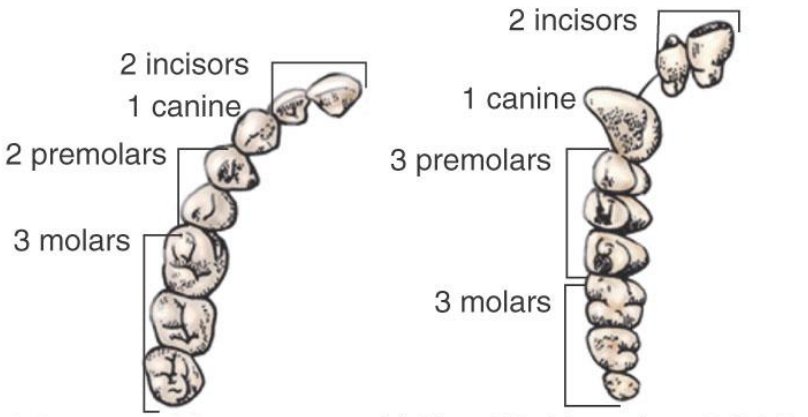
Students as subjects
Conner museum skulls (for visual observation only)
Replica skulls from "unknown organisms"
Bird skulls for beak comparisons
Rulers
Calipers

C1 Dentition of real skulls from the Connor Museum
Introduction:

Mammalian teeth can be divided into four basic types: **incisors**, **canines, premolars**, and **molars.** Incisors are adapted for biting food, canines for griping and piercing food, premolars for cutting or shearing food, and molars for grinding food. The **dental formula** describes the number of each kind of tooth that is present in the upper and lower jaw on one side of the skull.

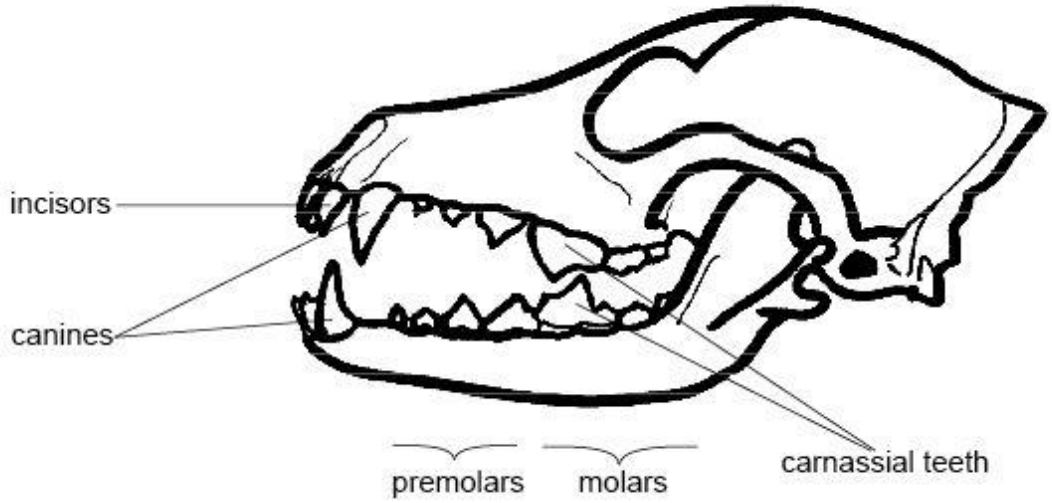
Obtain a human skull. To determine the dental formula for the human start in the middle of the upper and lower jaw and begin to count toward the left side. This is one quadrat. The first tooth type is called an incisor and you have two. The second tooth type as you move to the left is a canine and there is only one. As you move further toward the left ear the next tooth type is the premolar and there should be two. The last tooth type is the molar and humans normally have three. Count the lower jaw (mandible) teeth in the same way, again beginning in the middle of the chin. The dental formula for humans is given below. A horizontal line separates the upper and lower jaw formula.

<u>2-1-2-3</u>
2-1-2-3



You will be examining the mandibles of a variety of animals. It may not always be easy to differentiate between the different teeth types. A detailed description can be found at: http://animaldiversity.org/collections/mammal_anatomy/kinds_of_teeth/

From anterior to posterior in each quadrat of the mandibles. Incisors – most anterior of teeth; Canines – 1 per quadrat or absent, can be moderately to very long; Premolars – immediately posterior from the canines, highly variable in size and shape; Molars – most posterior, highly variable in size and shape.



Dental Adaptations for Various Diets. An animal's teeth are tools for catching food and preparing food for the stomach. The evolution of processing mechanisms in mammalian teeth gives greater efficiency in process food to a species. The diversity of types of teeth and dentition patterns that occurs in the mammals is an important factor in the success of the taxonomic group and a factor which increased diversity in the group. Five dietary types in mammals can be considered to be:

Insectivore
Herbivore
Gnawer
Carnivore
Omnivore

Each has somewhat typical shape to its teeth and a typical dental formula.

Procedure:

Obtain a skull of an animal from those on display. Determine the dental formula of the specimen and classify it as either an insectivore, herbivore, gnawer, carnivore, or omnivore using the information below. Once you have identified the dental formula type, exchange it for another skull. Try to find one example of each of the following feeding types.

Insectivores: Includes moles, shrews, and anteaters. The insect eaters have all four types of teeth, but most are similar in size and general structure. The teeth have sharp cusps and the jaw is relatively narrow and weak, for insects and grubs, which do not require strength to handle.

Herbivores: Includes sheep, bison, horse, elk, deer. These animals feed on grass, leaves, fruit, and other plant material. **Grazers** are a specialized type of herbivore that feed mostly on ground level grasses. The **browsers** are another specialized group, feeding on leaves and twigs. Herbivores lack canine teeth (although male animals may occasionally have them for fighting purposes) and the jaw is usually heavy and powered by strong muscles.

Some grazers are cud-chewers, re-chewing the food several times. These animals have run distinct cusps together to produce high ridges on the surface of the tooth. As the lower ridges scrape across the upper ridges the plant material is shredded.

Gnawers: Examples are rabbit, rodents, gophers, and beaver. These are specialized vegetarians that have sharp elongated incisors for scraping food like woody tissue and seeds. To compensate for the heavy wear on the incisors, they grow at the base, replacing warn and damaged areas and have a harder enamel on the front side of the incisor then on the rear. They too lack canine teeth like the herbivores.

Carnivores: Examples are dogs, cats, seals, and sea lions. These are the meat and fish-eating animals that have enlarged canines for catching and killing prey. They also have modified a pair of cheek teeth into elongated shearing blades that are called the carnassials for cutting meet into smaller pieces for swallowing. Incisors are usually present but they are generally very small. Carnivores usually retain some unmodified teeth for generalized functions. The jaw is usually large and powered by strong muscles which may attach to the saggital crest at the top of the skull.

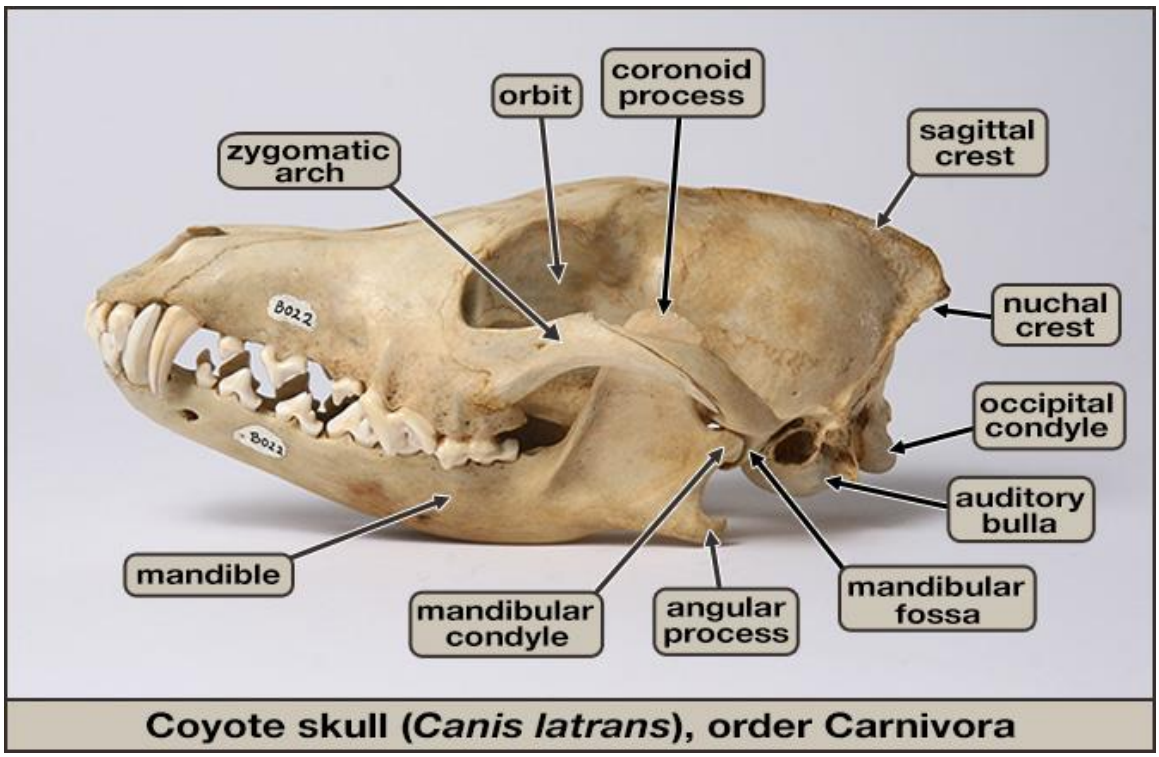
Omnivores: Examples are pigs, boars, primates, humans. Animals with a varied diet of meat and vegetable matter are omnivores and have multi-purpose dentition. All four kinds of teeth are present, but none are so highly specialized as in the animals above. The incisors are not enlarged nor very small, the canines are not fang-like, the premolars have pointed cusps but are not sharp or carnassial, and the molars are neither heavy as in grazers nor sharp as in carnivores. Specialized omnivores like humans and primates have low-crowned flattened premolars and molars to grind more fibrous foods like roots and seeds.

Results:

Give the dental formula for 7 of the different animal skulls:

Animal	Likely diet	Dental formula
1.		
2.		
3.		
4.		
5.		
6.		
7.		

Check your answers with TA



Skull structures from (http://www.deanza.fhda.edu/faculty/mccauley/6a_site_images/skeletons-images/coyote-skull-5084.jpg)

C2 – Detailed analysis of skull morphology from unknown replica skulls

A more detailed analysis of the skull can provide evidence for the feeding mode of an animal. You will be given three unknown skulls (A, B, and C) to examine. They are replicas, so feel free to handle them and to investigate how the parts fit together. Below is a description of some of the aspects of the skull that can be diagnostic of feeding mode (excerpted from http://www.mainstreetsmiles.com/dental-and-skull-anatomy-of-carnivores-herbivores-and-omnivores/)

Carnivores

Carnivorous animals subsist on the flesh, bones, and viscera of other creatures. Most carnivores have long, sharp teeth adapted to ripping, tearing or cutting flesh. While many also possess a few molars in the back of their mouths, and sharp incisors in the front, the most important teeth for carnivores are their long, sharp canine teeth. Carnivores drive these teeth through the flesh of their prey with the help of very large temporalis muscles, which are responsible for pulling the lower jaw upwards and backwards towards the skull. The temporalis muscles attach to the jaw at one end, and the top of the skull at the other end. To help accommodate larger temporalis muscles, some predators have evolved to have an enlarged ridge, termed the sagittal crest that acts as an attachment point or anchor for the muscle. However, the sagittal crest is not exclusively limited to carnivores, as it also appears in many herbivorous primates as well. Additionally, because predators

must capture and kill their food before they can eat it, some possess teeth that aid in prey capture. Cats, for example, use their four, long canine teeth to sever their prey's spinal cord. Some snakes have even more specialized prey-capturing teeth that have evolved into hypodermic-needlelike fangs to deliver venom into their prey.

Herbivores

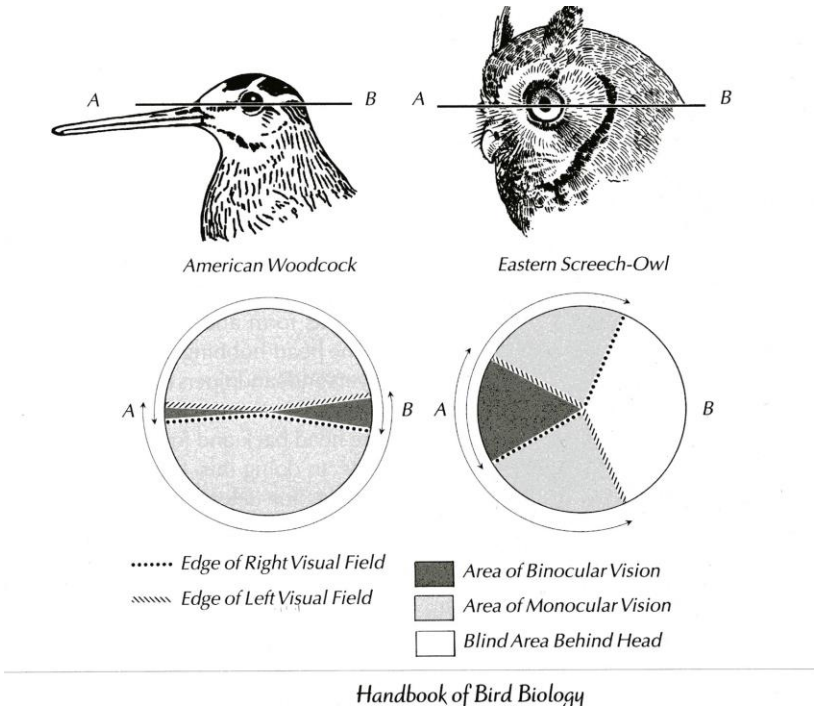
Herbivores survive by consuming plant material. While some are indiscriminate grazers that consume a variety of plants, others are specialists that only eat a single plant species. For example, goats may eat virtually any vegetation they encounter, but koalas subsist entirely on eucalyptus plants. In general, plant foods are difficult to breakdown and digest; so, many herbivores have several pairs of broad molars that they use to grind leaves, shoots, and twigs. Often, herbivores feature ridged molars and jaws capable of moving sideways. Both of these traits help herbivores to grind their food more effectively. Most herbivores are missing canines entirely, and those that do possess them usually have very small or reduced canines that are not very important for chewing food. Some herbivores have large incisors for clipping or tearing vegetation, but they may only occur on the lower jaw. For example, most deer lack upper incisors and press their lower incisors against their hard, upper palate to rip twigs and branches from trees. By contrast, horses have both upper and lower incisors that they use to clip vegetation cleanly. Some herbivores have evolved teeth that are no longer involved in feeding at all. For example, the large tusks of elephants are highly modified incisors. Elephants use their tusks to manipulate items in their environment, dig for water, and defend themselves. Walruses and some pigs also feature incisors that have evolved into tusks used for foraging, defense, and intra-species combat.

Omnivores

Omnivores, such as raccoons, opossums, bears, and humans, are animals that consume both plant and animal material. Accordingly, omnivores have dentition, skulls, and teeth suitable for handling a variety of foods. Most omnivores have evolved different types of teeth, located in different parts of their mouths. In such scenarios, each type of tooth excels at handling a different type of food. For example, humans use their incisors and canines for ripping and cutting, and their molars and premolars for grinding. Biologists describe animals with such teeth as having heterodont dentition. By contrast, the teeth of homodont animals, such as iguanas, are all the same shape. As with some carnivores that have teeth to aid in prey capture, some omnivores have teeth that help them to obtain, rather than process, their food. Rodents are famous for their long, continuously growing incisors, which they use to chew through husks, shells and wood. This allows them to access well-protected or difficult-to-access foods, such as nuts. Although rodents are omnivores that occasionally eat insects and scavenge carcasses, plant material makes up the bulk of their diet. Their dentition reflects this as well: Rodents have strong molars, yet lack canine teeth entirely. Instead, rodents have a gap between their incisors and molars, termed a diastema.

A note on vision: The placement of the eyes in the skull can influence the extent of the visual field and the area of binocular vision (with depth perception) vs. monocular vision.

In birds and mammals, predators tend to maximize binocular vision at the expense of size of visual field.



Handbook of Bird Biology

Examine the skulls and define the characteristics in the Table below

	Skull A	Skull B	Skull C
Incisors (large/small)			
Canines (long/short, pointed/dull)			
Molars/premolars Upper and lower surfaces (surface contact/no contact)			
Molars/premolars (grinding surface/shearing (cutting) surface/multipurpose surface)			
Jaw can move side to side (yes/no)			
Sagittal crest (present/absent)			
Orbital socket (Diameter large/small)			

Orbital sockets oriented to (front/side)			

Based on the findings from the table above, give a tentative identification of the three skulls:

	Carnivore/herbivore/ omnivore	Possible animal	Actual species (ask TA)
Skull A			
Skull B			
Skull C			

Get TA initials_____

C3. Bird Beaks

There are numerous structural features of bird beaks that vary in adaptation to food and how it is obtained, although the relationship between bill structure and diet is not as predictable as it is for tooth structure in mammals. For example, woodpeckers have long, tough, pointed beaks, along with a very robust skull that allows them to hammer holes in trees in search of food (when you visit the museum, look for the display of the woodpecker skull and its innovative tongue structures in the north gallery of the museum). In general, the thicker the beak, the more appropriate it is for cracking large seeds, but even small, deep beaks are used to crack seeds (for example, the house sparrow). Thin beaks are generally useful for manipulating prey, like caterpillars. Wide beaks are useful for catching flying prey, like mosquitoes. Hooked beaks can be used in a similar way to a mammal's incisors (biting and stripping), and long slender beaks can be used to gather nectar from flowers, like those seen in hummingbirds. Other variations observed in beaks include serrated edges for holding prey (like fish), or filter-like structures used to strain food particles from water.

In lab, you will see examples of three groups of birds: ducks, shorebirds, and raptors. The species within each group occupies very similar ecological niches. An ecological niche is the total sum of a species' use of abiotic and biotic resources in the environment. However, similar species cannot use exactly the same set of resources in the environment but occupy slightly different niches. This phenomenon is known as resource or niche partitioning. For example, all raptors are carnivores that feed on other animals. However, each species of raptor occupies a different niche because each one specializes on a particular type or size of prey, relies on a different method of hunting, or hunt in different times of the day. Similarly shorebirds utilize different depth of water and different types of prey and ducks can be either be herbivores, omnivores or carnivores.

Procedure and Results:

Carefully examine the bird beaks from the specimens provided. compare the different shapes, structures, or sizes of beaks that correlate with eating habits and food. Make educated guesses about what you think each specimen eats - how does the size and shape of the bill relate to its diet?

Bird Species	What is the most likely food type?
Ducks	
Surf scoter, *Melanitta perspicillatta*	
Mallard, *Anas platyrhynchos*	
Northern shoveler, *Anas clypeata*	
Common merganser, *Mergus merganser*	
Snow goose, Chen caerulenscens	
Shorebirds	
Least sandpiper, *Calidris minutilla*	
Long-billed curlew, *Numenius americanus*	
American avocet, *Recurvirostra Americana*	
American oystercatcher, *Haematopus Palliates*	
Greater yellowlegs, Tringa melanoleuca	
Raptors	
Cooper's hawk, *Accipiter cooperii*	
Northern harrier, *Circus cyaneus*	
Red-tailed hawk, *Buteo jamaicensis*	
Osprey, *Pandion haliatus*	
American kestrel, *Falco sparverius*	

Get TA initials_____