Lesson 3: Eating

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Learning objective for lesson 3: Students will understand the variety of feeding habits and feeding adaptations amongst the major dinosaurs groups

Learning objective 3.1: Describe the morphological characteristics of different animal feeding strategies.

The history of dinosaur evolution spans over 160 million years. In that time, dinosaurs diversified into a variety of forms and became adapted to a variety of ecological roles. The ancestors of dinosaurs were probably carnivores that fed on small reptiles and large insects. Over time, dinosaurs expanded their collective dietary preferences, and different kinds of dinosaurs evolved adaptations to feed on different kinds of food. Understanding what a dinosaur ate is important if we want to understand how that dinosaur lived and how it fit into a larger ecosystem. Sometimes, a dinosaur skeleton includes fossils of its incompletely-digested last meal inside of its ribcage, but such fossil gut contents are rare. Usually, to figure out a dinosaur's diet, palaeontologists must compare its feeding adaptations with those of modern animals whose diets can be directly observed.

Herbivores tend to have thin, ridged or "leaf-shaped" teeth for shearing and broad, flat teeth for grinding. Modern birds lack teeth, but herbivorous birds tend to have short, triangular beaks. Herbivores that browse high in trees, but cannot climb, have long legs and necks -- like giraffes. **Carnivores** tend to have sharp pointed teeth for piercing, and sharp hooked claws for holding onto struggling prey. Raptorial birds have sharp and hooked beaks and claws. Like modern carnivores, carnivorous dinosaurs usually have sharp teeth and hooked claws, and, like some carnivorous lizards, most also have teeth with serrated edges. **Serrations** are small sharp bumps on a tooth that are arranged in a line that usually runs from the tip to the base of the tooth. You can see serrations at work on the edge of a steak kn ife, and, just like the serrated knife edge, serrated tooth edges helped carnivorous dinosaur teeth to slice through flesh.

The tooth of carnivorous theropod, arrow points to a serrated edge. Photo by Angelica Torices.

These are only general patterns of adaptation, and some animals with specialized diets are adapted in very different ways. For instance, a parrot is a kind of herbivore known as a frugivore. **Frugivores** eat primarily fruit. The beak of a parrot is sharp and hooked (not unlike the beak of a carnivorous bird), because it needs to rip and tear apart the peels and protective husks of large tropical fruits.

The hooked beak of a hawk, a carnivore. Photo by W. Scott Persons.

Piscivores are specialized carnivores that primarily eat fish. Piscivores tend to have tall, sharp, conical teeth that usually lack serrations. These adaptations make piscivore teeth good at spearing and holding onto slippery fish. Piscivores also tend to have long jaws that are capable of snapping shut quickly. Piscivorous birds tend to have spear-shaped beaks that are long, strait, and sharp at the tips.

The long spear-like beak of a Common Loon (*Gavia immer*), a piscivore. Photo by W. Scott Persons

The skull of a piscivorous crocodilian, the gharial (*Gavialis gangeticus*). Photo by Jessica Edwards.

Insectivores are specialized carnivores that primarily eat insects. Some insectivores, like shrews and hedgehogs, have sharp piercing teeth for puncturing the chitinous exoskeletons of insects. But many insects are soft bodied and can be swallowed whole, without being chewed, so many insectivores have weak jaws and reduced teeth. Some insectivores, such as anteaters, pangolins, and echidnas, have no teeth at all. Because many insectivores must find their prey by digging, insectivores also commonly have large spade-shaped claws and powerful, but short, limbs.

The skull and forelimbs of a digging insectivore, the echidna (*Tachyglossus aculeatus*). Photo by Jessica Edwards.

Some carnivores, like hyenas, Tasmanian devils, and alligators, have sharp teeth for puncturing and ripping flesh but also have strong rounded teeth that enable them to crack bones – this is termed **durophagy**. Durophagy also requires extremely powerful jaws.

The skull of a bone-crusher, the Tasmanian devil (*Sarcophilus harrisi*). Photo by Jessica Edwards.

Omnivores are animals that eat significant amounts of both meat and plants. Humans are a good example of an omnivore, as are pigs, most bears, rats, crows, and many turtles. Omnivores tend to have either unspecialized beaks and teeth or a variety of teeth with different shapes (some shaped like those of herbivores and others like those of carnivores). In your mouth, you have pointed canines, which have a shape characteristic of a carnivore, and you also have molars, which have a shape characteristic of an herbivore.

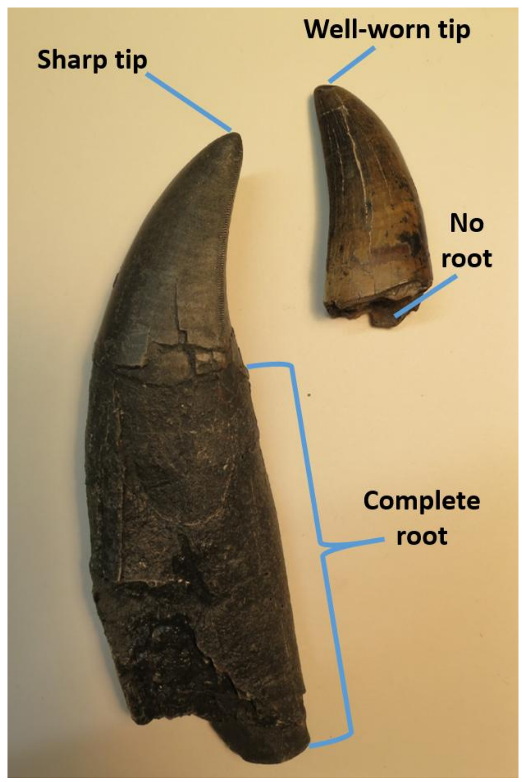
The skull of an omnivore, the peccary (*Tayassu pecari*). Photo by Jessica Edwards.

Learning objective 3.2: Compare tooth replacement in dinosaurs and humans.

You and I have a limited number of tooth sets. We have lost our baby teeth. Now that our adult tooth set has grown, our teeth will eventually get worn down or be gradually eaten away by bacteria. If we live long enough, toothless-ness or dentures is our inevitable fate. This is true of most mammals. However, dinosaurs were like modern sharks and crocodiles and were constantly growing new teeth throughout their lives. As new teeth grew in below older teeth, the new teeth would be pushed upward and would eventually replace the old. When an old tooth was ready to be replaced, its root (the portion of the tooth that anchored it in the gums and jaw) would be reabsorbed. **Resorption** is the chemical process by which a dinosaur breaks down its own teeth and bones so that the minerals and nutrients that compose them can be reused. After a new tooth was ready to replace an old one, and after the old tooth's root was reabsorbed, the top, or "crown", of the old tooth could be shed.

Tooth replacement in a tyrannosaur's lower jaw. Photo by Jessica Edwards.

Teeth that are ready to be shed still usually require a little help getting free from the little bit of gum that still surrounds their base. Remember wiggling and fidgeting with your loose baby teeth? Often loose teeth are shed while an animal is feeding. Throughout their lives, dinosaurs were constantly in the process of replacing teeth. It is estimated that *Tyrannosaurus rex* replaced each tooth once every 1.5 to 2 years. So, shed dinosaur teeth are not uncommon fossils to find and can be easily identified as shed because they are usually well-worn and lack roots. Shed teeth can be another useful tool for understanding a carnivorous dinosaur's diet. Often, the skeletons of dinosaurs will be discovered with many shed teeth nearby. That tells us that the dinosaur to whom the shed teeth belong was probably feeding on the other dinosaur's carcass. Note, however, that the presence of shed theropod teeth around another dinosaur's skeleton cannot tell us whether or not the theropod actively hunted and killed the other dinosaur, or if it was only scavenging on an already-dead dinosaur.



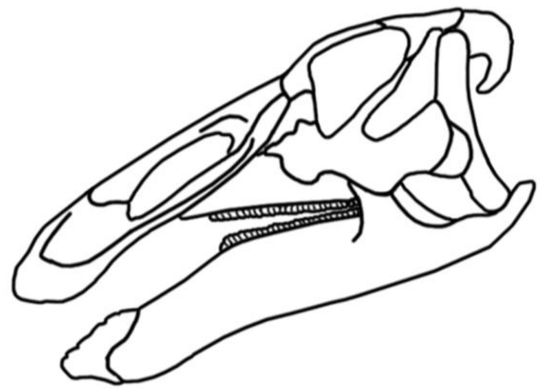
Comparison of a tooth removed from the fossil jaw of a tyrannosaurs and a shed tyrannosaurus tooth found in association with the disarticulated skeleton of a hadrosaur. Photo by W. Scott Persons

Learning objective 3.3: Compare the different ways of processing plant material.

The walls of plant cells are made of a compound called cellulose. **Cellulose** is tough stuff, and it makes plants a difficult source of food. Animals cannot digest cellulose on their own. Animals need help from bacteria that live within their stomach and intestines. Even with the help of bacteria, getting all the raw energy that a large animal needs to survive from plants is not easy. Chewing food before sending it down to the digestive organs helps, because chewing breaks plants into smaller pieces that are easier for bacteria and digestive enzymes to envelope.

The dental batteries of some herbivorous dinosaur groups are one way of dealing with the challenge of cellulose. Dental batteries are arrangements of densely packed teeth that collectively form a single, large chewing surface, and two groups of dinosaurs evolved dental batteries: hadrosaurs and ceratopsians. Because the individual teeth that make up dental batteries are small, and because chewing grinds teeth down quickly, dinosaurs with dental batteries replaced their teeth rapidly. In the skull of a hadrosaur, there can be over 1,000 teeth. Most of these teeth were not actively contributing to the chewing surface. Instead, they are replacements that were already fully formed and waiting in line.

The chewing surfaces of dental batteries are complex. Dinosaur teeth are made of a variety of hard tissues, including enamel (which usually covers the outside of a tooth) and dentine (which is usually common on the inside of a tooth). As a tooth in a dental battery was ground down, different tooth tissues were exposed, and these different tissues would be ground down at a slightly different rate -- making the chewing surface slightly uneven. The chewing surface of a dental battery is not simple, uniform, or smooth. It is intricate, varied, and abrasive.



The skull of *Edmontosaurus*. (Scott Hartman)

The lower jaw of a hadrosaur, in medial (tongue-side) view. Photo by J. Edwards.

The grinding surface of the teeth in a hadrosaur dental battery. Photo by V. Arbour.

The beak and jaws of the ceratopsian *Centrosaurus*. Photo by Jessica Edwards.

The dental batteries of hadrosaurs and ceratopsians are unrelated (that is, they evolved independently, and hadrosaurs and ceratopsians do not share a common ancestor that possessed dental batteries). The way hadrosaurs and ceratopsians used their dental batteries was also slightly different. In hadrosaurs, the chewing surfaces formed by the dental batteries are angled downwards, but still mostly horizontal. When hadrosaurs chewed, they moved their jaws backwards and forwards and also from side to side. The chewing surfaces formed by the dental batteries of ceratopsians are almost vertical. Teeth in the jaws of ceratopsians would have slid together like scissor blades, with the opposing lateral sides of the teeth doing most of the grinding. The dental batteries of both hadrosaurs and ceratopsians are inset in the jaw (that is, they are positioned close to the tongue). Inset teeth probably helped make room for large cheeks, and cheeks are important for holding in food while an animal chews.

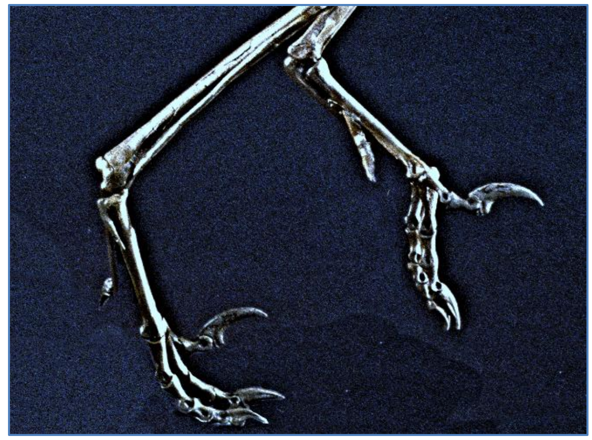
Unlike hadrosaurs and ceratopsians, ankylosaurs and sauropods had simple teeth that could be used to nip off vegetation but could only help break down their food a little. What these dinosaurs lacked in chewing ability, they made up for with guts. Ankylosaurs and sauropods have huge ribcages that housed immense digestive organs. Although it would have taken a long time for these dinosaurs to digest plant matter, they still got the energy they needed thanks to their extensive series of digestive vats and the sheer volume of food their digestive tracks were able to hold.

The skull of *Diplodocus*, a sauropod. By Jessica Edwards.

The small, leaf-shaped teeth of an ankylosaurs. Photo by Jessica Edwards.

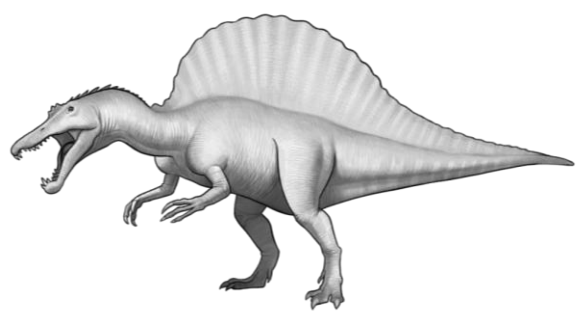
Oviraptorosaurs and ornithomimids are two kinds of herbivorous theropods. Many oviraptorosaurs and ornithomimids lack teeth, but some oviraptorosaur and ornithomimids skeletons have small masses of little stones inside their ribcages. These stones are called **gastroliths**. These stones were once part of the dinosaurs' gastric mills. A gastric mill is a special stone-filled digesting organ located near the stomach. Many modern birds, including chickens, have a gastric mill, which they fill by swallowing pebbles that they pick up from the ground. Gastric mills help these toothless animals to "chew" their food. Eaten plants are first sent into the gastric mill, where muscular contractions grind the rocks against each other and against the plants. This works just like grinding teeth, and the chewed-up bits of plants then continue into the stomach and are ready to be enveloped by bacteria and digestive enzymes.

In addition to sharp teeth, carnivores also have a variety of adaptations that help them catch, dismember, and eat their prey. **Dromaeosaurs** are a group of theropod dinosaurs with thin tails supported by special rod-like projections of their caudal vertebrae and chevrons. The famous theropod *Velociraptor* is a kind of dromaeosaur. Dromaeosaurs, along with their relatives the troodontids, had serrated blade-like teeth and a large sickle-shaped claw on each hind foot. These special foot claws resemble the retractable claws of modern cats, and could be raised off the ground. Keeping their claws raised would have prevented the claws from scratching the ground as dromaeosaurs walked, and this would have kept the claws sharp. Like retractable cat claws, dromaeosaur foot claws are probably specialized weapons used to slash and puncture prey, and may have also helped some dromaeosaurs to climb trees.



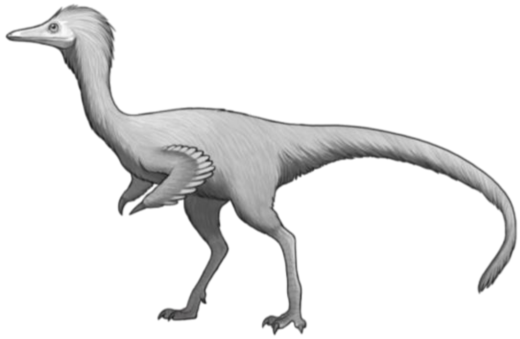
Feet and sickle-shaped claws of a dromaeosaur. Photo by Phil Currie

Spinosaurs are a group of theropods with skulls that strongly resemble those of crocodiles. Spinosaurs are thought to be piscivores. Like many modern piscivores, spinosaur teeth are conical, have sharp tips, and have few or no serrations.



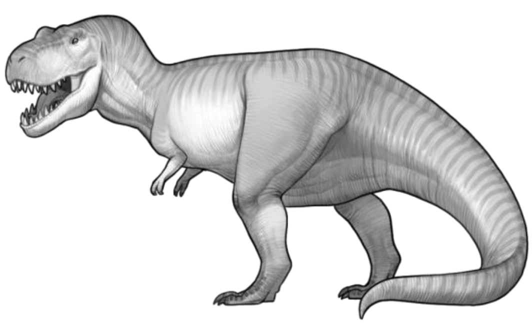
The spinosaur *Spinosaurus*. By Joy Ang

Alvarezsaurs are a group of small theropods with short front limbs and compact hands. Alvarezasaurs are thought to have been insectivores. Like many modern insectivores, most alvarezasaurs have reduced teeth and short, but strong, front limbs. The alvarezasaur *Shuvuuia* has one large spade-shaped claw on each hand. Its other forelimb claws and fingers were tiny and appear to have been useless.



The alverezasaur *Shuvuuia*. By Joy Ang.

Tyrannosaurs are a group of theropods that evolved late in the history of dinosaurs and have reduced front limbs and robust skulls. Tyrannosaur teeth have serrated edges and are well adapted for puncturing and cutting flesh. However, most tyrannosaur teeth have blunt tips and the attachment sites for jaw muscles in the skulls of tyrannosaurs indicate a capacity for tremendous biting force. It has been estimated that *Tyrannosaurus rex* (the largest of all known tyrannosaurs) had the most powerful bite of any animal (living or extinct). These adaptations indicate that tyrannosaurs may have been capable of durophagy. Note: durophagy is not synonymous with scavenging.

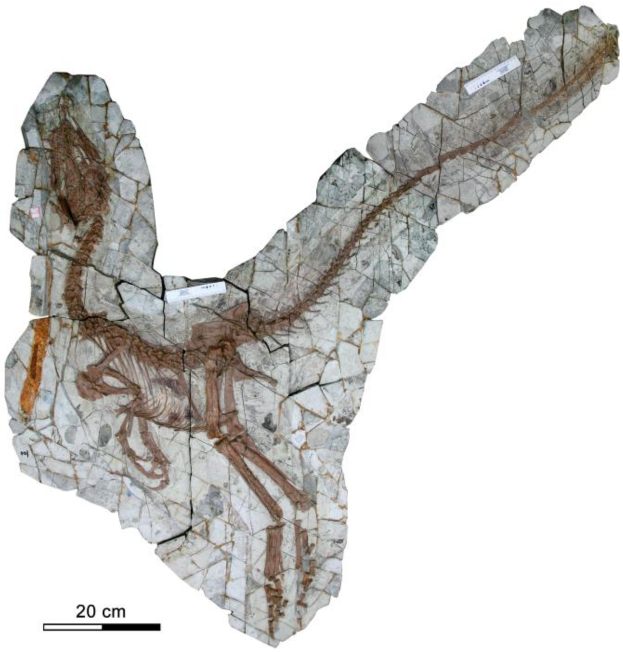


The tyrannosaur *Tyrannosaurus*. By Joy Ang

Scavenging refers to the consumption of an already dead animal by a carnivore that did not play a part in killing it. Durophagy can be beneficial to a scavenger, because it may allow a carnivore to access nutrients within the bones of a carcass that has already been picked over by other carnivores. However, many durophagous carnivores crush and consume the bones of animal that they themselves have killed, and many animals that are not capable of durophagy regularly scavenge. In fact, vertebrate carnivores that only scavenge are rare, as are those that never scavenge. Scavenging is an opportunistic part of virtually every carnivore’s life.

Learning objective 3.4: Describe various types of non-morphological indicators of diet.

Studying adaptations is not the only way to figure out a dinosaur’s diet. Sometimes dinosaur skeletons included fossil gut contents. Fossil gut contents are termed **cololites**. Cololites from hadrosaurs and ankylosaurs contain fossil plant material. Two specimens of the wolf-sized theropod *Sinocalliopteryx* contain fossil gut contents, and these show that *Sinocalliopteryx* ate birds and small dromaeosaurs. More cololites are known from the dromaeosaur *Microraptor* than from any other theropod. *Microraptor* had a diverse diet and evidently ate small mammals, birds, and fish. A cololite from the spinosaur *Baryonyx* includes fish bones and has helped to support the hypothesis that spinosaurs were at least partially piscivorous. **Gastroliths** are another kind of stomach content that can provide information on diet, although 'stomach stones' can also be used by aquatic organisms, like crocodiles, to help regulate buoyancy and their presence may be unrelated to diet in some cases.



***This Sinocalliopteryx* skeleton preserved the remains of its last meal. Image from: Xing L, Bell PR, Persons WS IV, Ji S, Miyashita T, Burns ME, Ji Q, Currie PJ. 2012. Abdominal contents from two large Early Cretaceous compsognathids (Dinosauria: Theropoda) demonstrate feeding on confuciusornithids and dromaeosaurids. PLOS ONE 7:e44012.**

***Sinocalliopteryx* fed on birds and other small dinosaurs! Image from: Xing L, Bell PR, Persons WS IV, Ji S, Miyashita T, Burns ME, Ji Q, Currie PJ. 2012. Abdominal contents from two large Early Cretaceous compsognathids (Dinosauria: Theropoda) demonstrate feeding on confuciusornithids and dromaeosaurids. PLOS ONE 7:e44012.**

Carnivorous dinosaurs often left bite marks on the bones of the dinosaurs they fed on. Tooth mark evidence shows that ceratopsians and hadrosaurs were commonly eaten by tyrannosaurs. Deep puncturing bite marks confirm that tyrannosaurs were capable of durophagy.

One last source of diet information comes from coprolites. **Coprolites** are fossil poop. Although it is often difficult to identify what kind of dinosaur a particular coprolite came from, coprolites can give information not only on what a dinosaur ate but how it was digested. Coprolites that have been identified as a tyrannosaur's contain large quantities of bone and show not only that tyrannosaurs were durophagous but that the bone tyrannosaurs consumed passed completely through their digestive tracts (unusual even among other durophagous animals).

Coprolite specimens in the University of Alberta collection. Photo by W. Scott Persons

Learning objective 3.5: Suggest dinosaur diet based on fossil evidence.

By the end of this lesson, you should be able to interpret the possible diets of dinosaurs based on evidence from the fossil record and comparative anatomy. If presented with a specific kind of dinosaur, would you be able to determine if it was a carnivore or a herbivore, and would you be able to justify your answer?

Supplementary Materials.

Herbivores:

Laelaps: Searching skulls for dinosaur diet clues. [Blog post]

Laelaps: Tooth turnover offers clues about *Diplodocus* diet. [Blog post]

Visualizations of hadrosaur and ceratopsian chewing movements from the Canadian Museum of Nature: [Videos]

Vagaceratops (a ceratopsian)

Edmontosaurus (a hadrosaur), and another video.

Carnivores:

Dinosaur Tracking: Did dinosaurs eat ants? [Blog post]

Dinosaur Tracking: Stomach contents preserve *Sinocalliopteryx* snacks. [Blog post]

Laelaps: Time to slay the *T. rex* scavenger "debate". [Blog post]

Laelaps: There's something fishy about *Microraptor*. [Blog post]

Natural History Museum: *Baryonyx*: the discovery of an amazing fish-eating dinosaur. [Video]