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Understanding the Animal World

Course Guidebook

Dr. Donald E. Moore III

Director (Oregon Zoo); Senior Science Advisor
(Smithsonian's National Zoo and Conservation Biology Institute)



Smithsonian®



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Donald E. Moore III, director of the Oregon Zoo and senior science advisor at the Smithsonian's National Zoo and Conservation Biology Institute, is a conservation biologist with nearly 40 years of experience in wildlife conservation, animal welfare, and zoo management. He earned a bachelor's degree in Wildlife Management and Zoology and a doctoral degree in Conservation Biology from the State University of New York College of Environmental Science and

Forestry, as well as a master's degree in Public Administration from Syracuse University.

Dr. Moore worked at the Smithsonian's National Zoo from 2006 to 2016. He was the associate director of the Center for Animal Care Sciences from 2006 to 2014 and served as a senior scientist for conservation programs on assignment with the Association of Zoos and Aquariums. In his time at the Smithsonian's National Zoo, Dr. Moore helped implement major renovations, such as the Elephant Trails and American Trail exhibits.

Prior to joining the Smithsonian, Dr. Moore worked at the Wildlife Conservation Society in New York, where he was curator of Central Park Zoo, director of Brooklyn's Prospect Park Zoo, and cochair of the society's renowned Animal Enrichment Program.

Dr. Moore has led international workshops in modern zoo design and accreditation, animal behavior and enrichment, and ecotourism in Spain, Malaysia, and South America, where he has conducted much of his conservation biology research. In his free time, he likes to write and edit, producing work for both professional and popular audiences, including writing a book for children, Disney Learning's *Wonderful World of Animals*.

Dr. Moore is passionate about climate change and the actions people can take to help protect polar bears and other Arctic animals. He credits his strong conservation ethic to his upbringing in upstate New York, where he learned to fish, camp, hike, ski, and make jams and jellies. ■

About Our Partner

Founded in 1846, the Smithsonian is the world's largest museum and research complex, consisting of 19 museums and galleries, the National Zoological Park, and 9 research facilities. The total number of artifacts, works of art, and specimens in the Smithsonian's collections is estimated at 154 million. These collections represent America's rich heritage, art from across the globe, and the immense diversity of the natural and cultural world.

In support of its mission—the increase and diffusion of knowledge—the Smithsonian has embarked on four Grand Challenges that describe its areas of study, collaboration, and exhibition: Unlocking the Mysteries of the Universe, Understanding and Sustaining a Biodiverse Planet, Valuing World Cultures, and Understanding the American Experience. The Smithsonian's partnership with The Great Courses is an engaging opportunity to encourage continuous exploration by learners of all ages across these diverse areas of study.

This course, *Zoology: Understanding the Animal World*, offers a tour through the remarkably vast scientific field that covers all aspects of animal life, from their social habits to their intricately evolved physical systems. You will be introduced to this field by the acknowledged leaders in animal care, science, and education: Smithsonian's National Zoo and Conservation Biology Institute. From predators on the African savannah to birds of North and South America and beyond, these 24 lectures make sense of an interrelated world. The director of the Oregon Zoo and senior science advisor at the National Zoo will cover taxonomy, animal behavior, animal intelligence, animal ecology, and the shared and differing physiologies among animals. Video lectures feature footage from the National Zoo, its research parks, and animals in their natural habitats. This highly illustrated course will make sense of the wonder of the animal world in a way no textbook can. ■

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Scope

Zoology: Understanding the Animal World

Zoology is the scientific study of animals, but that simple definition belies the complexity of the discipline. Zoologists study not only the physical and behavioral characteristics of animals, but their interactions with their environments and all other life on the planet—including humans. Their work takes them from laboratories to zoos to wilderness, from exotic locations to suburban back yards, all in pursuit of the understanding and preservation of life on Earth.

In this introduction to zoology, we will begin by adopting the zoologist's perspective on animal life. What do we know about animals, and what do we still need to know? Why is animal biodiversity crucial to human survival, and how are zoologists working to preserve that biodiversity?

Next, we move into a study of reproductive biology. This is fundamental to any zoologist involved in conservation, because understanding how animals reproduce is crucial to ensuring their survival. Consequently, we will look at the myriad ways animals can reproduce—asexually, hermaphroditically, parthenogenetically, sexually, and sometimes more than one of the above—as well as how life history and environmental pressures influence reproduction. We will follow this with a study of how animals care for their children, another important piece in the puzzle of animal survival.

Then, we will examine the animal kingdom class by class, order by order, from the simplest invertebrates to the most complex mammals. We will examine the specialized adaptations that unite them as well as the diversity among them. We will look at the many economically and ecologically

valuable invertebrate species, both marine and terrestrial. We will also study the invertebrate parasites that endanger human and animal lives.

Next, we will look at the vertebrate classes, from fishes to amphibians, reptiles, and birds to the main mammal orders of Artiodactyla, Perissodactyla, Carnivora, and our relatives the Primata. We will discover how their unique adaptations for reproduction, respiration, feeding and digestion, and more help each animal survive and thrive in its ecological niche.

After learning about these taxonomic groups, we will look at some specialized topics in zoology. We will consider the relationships between an animal's exterior appearance and interior functioning, looking first at how size and structure affect an animal's metabolism and then at the protective and regulatory roles of such structures as skin, shells, and bones. After this, we will consider how an animal maintains its physical structures through its metabolic processes, and we will look at the curious case of the giant panda—an animal whose eating habits do not align with those of other bears.

Then, we will consider animal behavior and animal intelligence, looking at why animals act as they do. We will look at the difference between innate and learned behaviors and consider the nature of animal learning. We will ask questions such as these: Can animals solve problems creatively? Do animals have a sense of self? How do animals communicate with each other?

Next, we will consider the issue of disease in the animal kingdom, from the unique diseases that only affect specific animals to the zoonotic diseases that are transmitted between animals and humans. We will discuss what researchers are doing to discover, control, and prevent these diseases as well as how best to prevent human exposure to zoonotic disease. Finally, we will end the course by looking at a variety of contemporary issues in zoological research.

Throughout the course, we will visit with the biologists, researchers, and animal care specialists who work at Smithsonian's National Zoo and Conservation Biology Institute and at zoological study sites all over the world to sample their unique perspectives and experience. The end goal is to understand not only the biology of animals, but the important place of animals in our complicated and delicate ecosystem, as well as the major challenges to sustaining their health and the health of all life on Earth. ■

What Do Zoologists Do?

In this course, you will discover the amazing diversity of animal life and how it came to be. You will learn about how animals act and interact with their environments and with each other all over the world. You will also learn about the science of zoology. In the process, you will be introduced to animals from Smithsonian's National Zoo and Conservation Biology Institute.



Where Did Life Come From?

- ◆ Based on the fossil record and genetic evidence, we believe that life began on Earth approximately 4 billion years ago. The first life-form is called the last universal common ancestor. It was the first thing that we can say wasn't just a self-replicating molecule and was actually a living organism that evolved into all of the organisms that have ever existed on Earth.
- ◆ There have been many different kinds of life since then. We think there have been more than 1 billion distinct species on Earth through its entire history and that more than 98% of those species are now extinct. In fact, we don't really know how many different species of animals are alive on Earth today. We've catalogued around 1.5 million species, but we estimate that the number we haven't catalogued or even discovered range from another million to another 7 million.
- ◆ The first forms of life were what zoologists call protocells. They each had a membrane and cytoplasm and a number of functional structures in that cytoplasm working together to perform the most basic process we attribute to living things: self-replication.
- ◆ At some point fairly early on in the evolution of life, the nucleic acids came into being. We could say that this was the moment that life as we know it emerged, because now our common ancestor was self-replicating and passing on its characteristics to its offspring by means of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).
- ◆ When it comes to building an organism, DNA is the blueprint and RNA is the construction worker. The single-helical RNA molecule reads the instructions for protein building that are encoded in the double-helical DNA molecule, then takes those instructions from each cell nucleus—where the DNA lives—to the other structures in the cytoplasm of the cell, where all other chemical reactions necessary for life take place.

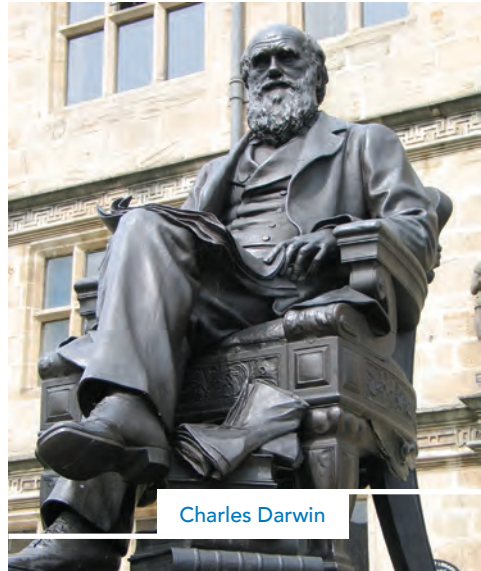
- ◆ When it comes to cell division, or mitosis, the DNA replicates itself. When the replication is complete, the nucleus splits itself in 2, then the cytoplasm splits itself in 2, and 1 cell becomes 2 cells.
- ◆ Sometimes the replication process doesn't go right, and the DNA of the new cell doesn't quite match the DNA of the old cell. These mistakes are called mutations.
- ◆ Human beings have 23 pairs of chromosomes—that is, molecules of DNA—in every one of their somatic cells. That amounts to about 6 billion individual nucleotides—6 billion bits of information per cell that have to be copied every time one of your cells divides. There are bound to be mistakes.



- ◆ Mutation is an important natural process. It's the process by which evolution occurs.

Evolution and Natural Selection

- ◆ Charles Darwin's theory of evolution is 1 of the 3 pillars of the science of zoology—the other 2 being Gregor Mendel's theory of heredity and Louis Pasteur's experiments disproving the theory of spontaneous generation.
- ◆ All 3 of these date to the middle decades of the 19th century. All 3 are backed up by decades upon decades of excellent work in experimental science. Only Darwin's work remains controversial in popular culture, perhaps because it's not really well understood.

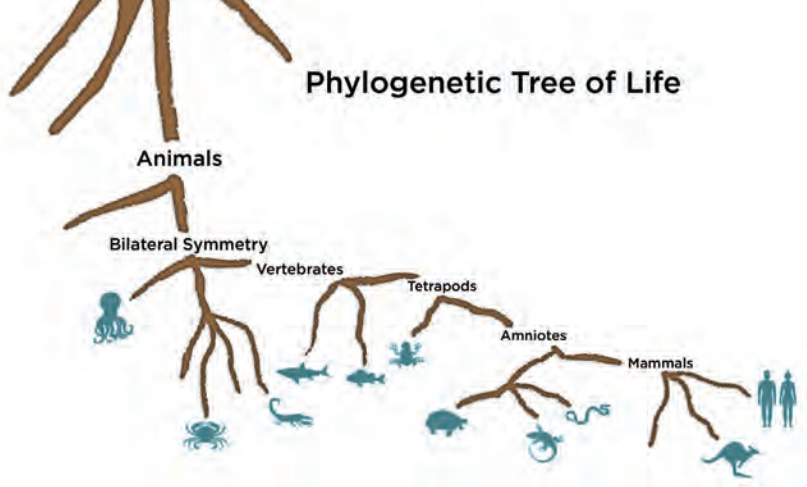


- ◆ The theory of evolution as it is taught today was really laid out by a biologist named Ernst Mayr in the mid-20th century. He taught that Darwin's theory was actually a system of 5 theories:
 1. That the living world is neither static nor cyclical but is undergoing perpetual change.
 2. That all living things descend from a common ancestor in a branching tree of life.
 3. That evolutionary processes produce multiplication of species by splitting and transforming older ones.
 4. That these processes happen very gradually by accumulation of many small changes, not single large changes.

5. That natural selection determines which changes are advantageous to a population of organisms, thus determining which organisms manage to reproduce and pass their features on to the next generation.
- ◆ For zoologists, natural selection is the most important part of this theory.
 - ◆ A related process to natural selection is artificial selection, which is when humans intentionally direct the breeding of animals or plants. Whether we're creating a Labradoodle or building a better banana, the idea is the same: The farmer, breeder, or scientist selects the desired trait and gets more of that trait in the next generation by giving certain organisms a reproductive advantage.
 - ◆ In natural selection nature does the same thing, except the selection isn't a conscious process. Nature isn't deciding which traits to breed into the next generation; instead, when a series of mistakes occur in DNA replication, this gives rise to a change in the next generation of animals, and those that survive and reproduce best provide offspring that continue the selection process.
 - ◆ Natural selection works on individuals within whole populations, not just on individuals in isolation, and it comes about because of the interaction of the individual within the population and its environment. If enough changes accumulate in a population, generation after generation, natural selection may create a whole new species over time.

The Tree of Life

- ◆ "Animal" is one of the top-level divisions of the phylogenetic tree, or tree of life, the tree on which we map out all the relationships between all the millions and millions of species on Earth. An animal, by definition, is an organism that eats other organisms.



- ◆ Species are the smallest, lowest division on that tree, the leaves. Although technically there are subspecies, and even breeds when we're talking about domestic animals, we're mainly going to be concerned with the species level, because of how a species is defined.
- ◆ According to Ernst Mayr, a species is "a reproductive community of populations (reproductively isolated from other species) that occupies a specific niche in nature." It's not about what an organism looks like or how it behaves, but whether it can produce offspring with other similar organisms that survive in the same habitat.
- ◆ The phylogenetic tree shows the different divisions along the path from kingdom to species: kingdom, phylum, class, order, family, genus, and species. The modern taxonomic classification system has 6 kingdoms, of which Animalia is one. Within the animal kingdom, there are several dozen phyla, divided into more than 100 classes, thousands of orders, hundreds of thousands of genera, and millions of species.
- ◆ Another, more modern method of classification is called cladistics. A clade is determined by the presence of shared characteristics that are developed over evolutionary time. These characteristics can be

traced back to the group's most recent common ancestor but are not found in more distant ancestors.

- ◆ Cladistics looks at taxonomy from a multidimensional perspective. A clade includes a species and all of the species that are descended from that ancestor. If species are the leaves on the tree of life, a clade is a group that includes a branch, all the sub-branches, all the sub-sub-branches, and all the leaves. And you can have clades within clades, depending on which branch you start from.
- ◆ While a class or a family or an order might tell us who a species' closest relatives are, a clade helps us describe how a species got there. The grouping itself demonstrates the process of evolution from a common ancestor.
- ◆ The specific scientific classification of animals is changing all the time as the genetic evidence and fossil records improve. Modern zoological research is discovering subtle but important differences between species that aren't necessarily apparent to the naked eye.

Zoologists

- ◆ Zoologists not only run zoos, but they also study animals in the wild, practice conservation biology, and much more. They study the entire natural world, all the complicated interactions and systems in the environment, and how they can best be managed for the health of the entire planet.
- ◆ While most of the time the public sees a zoo as an entertaining and educational way to spend a Saturday afternoon—and it is—an average accredited zoo is also a vital part of research and conservation activities going on across the world.
- ◆ Conservation biologists study the Earth's biodiversity and figure out ways to protect and preserve it in a way that benefits the individual animals and all life on the planet. They evaluate how animals interact



with their habitats and with humans, and they also evaluate the health of those habitats. Our environments are healthier and more resilient if they can keep their historical complement of diversity.

- ◆ A habitat evolves as an integrated system, from the tiny bacteria in the soil to the largest mammals. When something throws that system off—for example, a sudden reduction or explosion in the population size of a species—it has a cascade effect on all the other living things in that system.
- ◆ Human activities, such as pollution, encroachment, introduction of foreign species, creation of monocultures, and poaching of plants and animals can throw a system out of balance. Human needs and desires often come into conflict with the rest of the living things around us. But we need these systems just as much as the animals do.

Suggested Reading

Dugatkin and Trut, *How to Tame a Fox*.

O'Brien, *Tears of the Cheetah*.

Gibbons, "Smithsonian Scientists Use Extinct Species to Reclassify the World's Remaining Two Species of Monk Seal."

Wilson, *The Diversity of Life*.

Zimmer, *The Tangled Bank*.

A large herd of African buffalo is gathered in a dry, open landscape. The animals are dark brown with prominent, curved horns. The ground is sandy and sparsely vegetated with small, dry shrubs. The background shows a vast, open plain under a clear sky.

Lecture 2

Animal Reproduction: Genes and Environment

This lecture will explore the diversity of reproductive biology and sex in the animal kingdom. It will cover asexual and sexual reproduction as well as sexual behaviors in different animal groups, including some of the weirdest, yet most fascinating, sexual behaviors in the animal kingdom.

Sexual and Asexual Reproduction

- ◆ Asexual reproduction is producing progeny with only one parent and without any specialized sexual organs. This means that individual animals leave clones behind. These animals are genetically identical to their parents except in rare cases of genetic mutation.
- ◆ Amoebas and some other single-celled organisms reproduce through asexual reproduction, such as binary fission, which means equal cell division, or budding, which means unequal cell division. Binary fission only occurs in single-celled organisms, not in higher animals. Budding occurs in single-celled organisms as well as some plants and a small number of aquatic animals.
- ◆ There are other forms of asexual reproduction in animals that are more complex. For example, a hermaphrodite is an animal that has both male and female reproductive organs in the same individual. Thus, these creatures can potentially mate with every individual they meet from the same species. Most hermaphrodites in the animal kingdom are invertebrates. There are only a few hermaphrodites among thousands of species of insects. But there are many hermaphroditic worms.
- ◆ Another method of reproduction is parthenogenesis, which is a modified form of sexual reproduction for which males and females are present in the population, but females can develop unfertilized gametes, or eggs, into living offspring without a contribution from the male. This form of reproduction happens in bees, wasps, some lizards, and other animals that we consider not as complex as birds and mammals, and there are several types of parthenogenesis in the animal kingdom.
- ◆ Eggs and sperm are formed by the process of meiosis. In mitosis, which is ordinary cell division, all the chromosomes in the cell's nucleus are doubled and then the cell splits in 2. But in meiosis, the chromosomes are doubled and then the cell splits in 4.



- ◆ The result is that each of the 4 cells—the gametes, which is the general name for eggs and sperm—has 1 set of chromosomes instead of 2, like the rest of the cells in your body.
- ◆ Cells with only a set of chromosomes are called haploid. If they have 2, they're diploid.
- ◆ In sexual reproduction, an egg and sperm fuse and restore the diploid state. You have half of your mother's DNA and half of your father's DNA. Two sets of chromosomes fuse, and your cells become diploid.
- ◆ But in parthenogenesis, we only have eggs. And eggs are haploid.
- ◆ In one form of parthenogenesis known as ameiotic parthenogenesis, females are capable of producing diploid eggs. Females produce offspring by spontaneously activating a diploid egg, which is followed by normal embryonic development. In these cases, the

mother's chromosomal complement is wholly passed on to the offspring, so the offspring can be considered her clones.

- ◆ Haplodiploidy is a combination of parthenogenesis and sexual reproduction. In honeybees, we have proper meiotic egg production and proper meiotic parthenogenesis. A queen bee produces haploid eggs, but she has a few different ways she can handle them.
- ◆ First, she can lay unfertilized eggs. These eggs become haploid male offspring, which are called drones. They have one function in life: to fertilize a queen's eggs. Second, if the queen is carrying sperm from a drone, she can choose to fertilize some of the eggs she lays. The offspring that hatch from the fertilized eggs are female diploid bees, which become worker bees or new queens.
- ◆ These aren't the only options for parthenogenesis. In fish, we sometimes have gynogenesis, when a diploid egg is hormonally



stimulated to develop by the presence of sperm, even though the sperm don't contribute genetically to the offspring.

- ◆ In some insects and flatworms, sometimes haploidy spontaneously corrects itself and the offspring becomes diploid even though it came from a haploid egg, or 2 eggs will fuse to create a diploid individual, a form of self-fertilization, or autogamy.
- ◆ Variants on parthenogenesis appear because they confer a survival advantage to a particular species in its particular environment.
- ◆ Asexual reproduction offers a species 2 big advantages, and they're both about population numbers.
 1. If you are a self-fertilizing hermaphrodite or a parthenogenetic female, then you only need to produce 1 surviving baby per generation to ensure the survival of your species. In a sexually reproducing species, you need at least 2 individuals, 1 male and 1 female.
 2. Single asexual individuals can reproduce more quickly than a member of a sexually reproducing species. In honeybees, the queen can lay 2000 eggs in one day, and perhaps a million in her lifetime. The complex, sexually reproducing mammals get nowhere near that rate.
- ◆ This means that zoologists working in conservation practice can quickly replace more of a critically endangered asexually reproducing organism than they can a sexually reproducing one. The disadvantage is that there will be no genetic variation among the organism's descendants.
- ◆ This may be an advantage if the environment is stable and just right, but climate change is making environments less stable all over the world. As a result, asexually reproducing animals may be more susceptible to new diseases and changes in temperature than those that reproduce sexually.

- ◆ Because animals that sexually reproduce seem to have the upper hand in terms of adaptability, that may be why the parthenogenetic form of reproduction is comparatively uncommon. Sexual reproduction is therefore an advantage when genetically robust reproduction is preferable to fast reproduction.
- ◆ In sexually reproducing organisms, there are 2 sexes: individual males and females in the species. Because there is at least some genetic variation between the 2 parents, the recombination of their genes creates variation between the parents and their offspring, and even between siblings.
- ◆ Unlike some of the parthenogenetically produced animals, each of us is always genetically diploid: Each of our cells has 2 complete sets of chromosomes. And this happens because 2 haploid gametes—1 egg and 1 sperm—fuse, forming diploid cells once again.
- ◆ The first of these cells following fertilization is called the zygote and is formed by the egg and sperm cell fusing. These diploid zygotes have copies of half of each parent's DNA, which allows a little extra diversity between individuals within each species.
- ◆ In addition to this, the process of meiosis—the process of creating gametes—fosters even more genetic variation through the independent assortment of traits. The offspring created through this process are not only different from their parent because they have only half the parent's

DID YOU KNOW?

Some corals are only male, and some corals are only female. Some corals that are only male or female are that sex one summer and then will switch to the other sex the next summer.



genes, but they're also different from each other because they have different sets of their parents' genes.

- ◆ Invertebrates engage in some of the most amazing forms of sexual reproduction—reproduction that occurs outside the animals' bodies, especially among the marine invertebrates.

Corals

- ◆ Corals reproduce in 2 ways: asexual reproduction, mostly through fragmentation, and sexual reproduction, where they produce egg and sperm. Most corals are hermaphrodites, and they produce egg and sperm simultaneously.
- ◆ Some corals are only male, and some corals are only female. Some corals that are only male or female are that sex one summer and then will switch to the other sex the next summer.
- ◆ Most of them are simultaneous hermaphrodites, meaning that they produce egg and sperm at the same time, and they will usually release that in an egg-sperm bundle that floats to the surface of the water, where it will then break apart. When the bundle breaks apart, the sperm is activated, starts swimming around to look for an egg, and hopefully finds an egg of the same species of coral. Then, they fertilize, at which point you have a fertilized egg, or basically an embryo, the beginnings of a new baby coral.
- ◆ While asexual reproduction is good for reproducing the number of corals, it doesn't do anything for the genetic diversity of the population, which also matters. Sexual reproduction, just as in any other organism, is what helps keep the spreading of the genetic diversity of that population.
- ◆ One thing that sexually reproducing corals have in common with many invertebrates is that they are producing more eggs, sperm, and larvae than will ever possibly settle and become adults. Broadcast

spawners can release thousands or even millions of gametes, only a few of which will manage to achieve fertilization. And only a few of those will survive to become larvae, and only a few of those larvae will survive to become adults.

Other Reproductive Strategies

- ◆ Another reproductive strategy is to produce fewer young that are more capable of surviving to adulthood.
- ◆ Some invertebrates and vertebrates have a spermatophore, or sperm capsule, that helps a male deliver sperm directly to a female in one way or another. The advantage of a spermatophore is that a male only needs to mate with a female once, and there is a relatively high chance that he is the father of that female's embryos.
- ◆ An advance beyond the spermatophore is internal fertilization, in which the male needs to be in contact with the female. All reptiles have internal fertilization.
- ◆ But even among reptiles there are a few species that give birth to live offspring, called viviparous reproduction, which is common in environments that may be too cold, or where the warm season is too short for optimal development of eggs. North American garter snakes, banded water snakes, and timber rattlesnakes that live in seasonally cold environments all give birth to live young that are ready to eat and act like miniature adults.
- ◆ This also occurs in the ocean. Skates and rays internally fertilize eggs during sex, as do their relatives the sharks. Internal fertilization is efficient, and it increases the likelihood of fertilization by reducing sperm wastage in the open water.
- ◆ It also protects the young, allows them to arrive in the world as miniature versions of their parents, and even allows the mother to select a new environment that is optimal for her offspring and allows



Timber
rattlesnake

her to move there prior to giving birth. Internal development of offspring ensures that the energy-rich eggs produced by females are not eaten by predators and that most of the energy spent by females on reproduction is passed to the embryos.

- ◆ While animals that give birth to live young are called viviparous, rays represent a third variation: They are ovoviviparous, which means that their embryos rely on substantial yolk within the egg during initial stages of development. After the yolk nutrients stored in the egg have been absorbed by the embryo, it ingests or absorbs an organically rich uterine milk called histotroph, which is produced by the mother and secreted into her uterus.
- ◆ By comparison, many other bony fish lay eggs. The infant fish go through metamorphosis as they develop from embryo to larva, or fry, and then onto the juvenile stage while the tiny creatures absorb the yolk sac. After the yolk sac is absorbed, the individual fish needs to be able to feed on its own.

Suggested Reading

Grandin and Johnson, *Animals in Translation*.

Judson, *Dr. Tatiana's Sex Advice*.

A group of seven giant pandas are sitting on a wooden platform made of logs. They are all eating bamboo stalks. The pandas are of various ages and are surrounded by a large pile of bamboo. The background shows a lush green forest with trees and a wooden fence.

Lecture 3

Mammal Reproduction: Pandas and Cheetahs

Smithsonian National Zoo's reproductive sciences team is a leader in studying reproductive biology and technologies in the world's endangered species. This lecture will introduce 2 of these focal species: giant pandas and cheetahs. In this lecture, you will learn about the vital role that zoos play in saving animals from extinction. In addition to breeding animals, zoos play a huge role in research and technological innovation.

Mammalian Reproduction

- ◆ Mammals evolved alongside birds and became dominant life-forms on Earth after the extinction of the dinosaurs.
- ◆ One of the most primitive extant mammals is Australia's platypus. With its webbed feet and duck-like bill, it even looks like a weird cross between a mammal and a bird. However, it has hair and nourishes its young with milk, all characteristics of a true mammal. Its rear opening is called a cloaca, and it combines both excretory and reproductive parts. A female makes a nest of grass underground in the banks of the stream. In this nest, she lays eggs.
- ◆ Another Australian native, the spiny anteater, also produces eggs. But instead of laying her egg in a nest, the female gathers it into a temporary pouch in her underbelly, where a single baby hatches after only 7 to 10 days. The infant remains for 45 days or more in the mother's temporary pouch, where it drinks mother's milk and grows.
- ◆ The platypus and spiny anteater are classed as monotremes, from the Greek word meaning "one opening." Their cloacae serve as openings for reproduction and for elimination of waste.
- ◆ A more complex type of mammal, the marsupial, also reproduces via internal fertilization. But like true mammals, most marsupials have separate outlets for reproduction and waste. They also carry their young in pouches.
- ◆ Take kangaroos, for example. After fertilization, the embryo spends about a month free-floating inside the mother's uterus, feeding off of a choriovitelline placenta, which is formed out of the yolk sac of the female's egg. After their month in utero, the tiny bee-sized neonate marsupials are essentially still embryos when they emerge and crawl to the mother's warm pouch. There, they latch onto one of 13 nipples and drink the nutritious milk for almost 8 months.

DID YOU KNOW?

The platypus and spiny anteater are classed as monotremes, from the Greek word meaning “one opening.” Their cloacae serve as openings for reproduction and for elimination of waste.



- ◆ Non-marsupial mammals, such as humans, remain inside the mother’s body for a much longer period of time and have a chorioallantoic placenta. Rather than a free-floating embryo with a yolk-like placenta, the embryo takes root in the uterine wall, and the placenta attaches itself to the mother’s circulatory system. This type of placenta allows the embryo of a placental mammal, such as a human, bear, or cat, to remain inside the uterus for a long time while it develops.
- ◆ The growing fetus is attached by the umbilical cord to the uterine wall, and significant oxygen and nutrients are delivered to the fetus by the mother’s circulatory system. Waste products from the fetus go in the opposite direction, diffuse through the mother’s blood, and are excreted from her body through her kidneys.

- ◆ A placental reproductive strategy means that the growing fetus does not need an eggshell, nor does it need to take the risky journey at a very early stage from the mother's uterus into a pouch. Instead, placental mammals remain safely in the mother's body until they are substantially grown. Still, after a placental mammal is born, the mother provides it with nutritious milk to stimulate its growth even more and enhance its chances of survival.

Giant Pandas

- ◆ The giant panda, historically rare in nature, has been listed on the global endangered species list since 1990. As of 2016, there are fewer than 1900 adult pandas living in China's bamboo forests. Although pandas were moved from "endangered" to "vulnerable" status in 2016, they're still under threat in the wild.
- ◆ Smithsonian's National Zoo and Conservation Biology Institute have been studying giant panda reproduction for more than 40 years. The first pandas—Ling-Ling and Hsing-Hsing—arrived in Washington DC as diplomatic gifts from China in 1972. We now know that if the pairing is right, wild pandas and pandas in human care breed just as well as other bears. But Ling-Ling and Hsing-Hsing's 5 offspring did not survive more than a few days.
- ◆ Breeding giant pandas is challenging because they have a very short breeding season. The female is receptive to the male and can conceive for only a few days every year. Breeders don't want to miss this window of opportunity. In addition, they need to make sure that the male and the female get along so that if there is natural mating, it is successful.
- ◆ The female has a very short estrous, or reproductive cycle every year. It starts with a rise of estrogen, which is paired to the growing of a follicle with an egg in the ovary. Then, the egg is expelled from the ovary, and there is a period of 24 hours when the egg can be fertilized by sperm. We are now able to closely monitor the rise in

estrogen and the ovulation itself by monitoring the hormones in the panda's urine to give a precise timing of these events.

- ◆ In the male, testosterone, which is the hormone that drives spermatogenesis, starts being produced much earlier than the female enters the estrous cycle. Breeders must have a good idea of where the female is in the estrous cycle and then introduce the male and female together at the right time.
- ◆ The goal is to have natural breeding between the male and female. When that doesn't work, though, breeders have to use assisted reproduction, or artificial insemination, either using fresh semen or frozen semen.



- ◆ In giant pandas, it's also challenging to monitor pregnancy because it doesn't have a fixed duration from year to year and from individual to individual. Pregnancy can last between 3 and 6 months. This is due to the fact that there is a period of delayed implantation of the embryo at the beginning of the process that can be variable, so it's not clear when exactly the embryo is implanted into the uterus of the female.
- ◆ In the giant panda, the fetal development is basically limited to the uterus, so it's extremely difficult to notice physical changes. The uterus is very small, and inside the uterus there is a small fetus, which is extremely difficult to see even with the best ultrasound probe. Only at the end of the pregnancy are people really able to see anything.
- ◆ Once the baby is born, it sticks to the female for many weeks before it's able to walk. After that, the female stays with the cub for more than a year, which is huge in terms of investment of the mother toward the offspring.
- ◆ Giant pandas are solitary animals. They only mate for the breeding season. Then, the female takes care of the cubs by herself.
- ◆ An advantage of having animals in captivity is that humans can study them properly. People can monitor their reproduction, understand their nutrition, and study their genetics.

Cheetahs

- ◆ Smithsonian National Zoo's research biologists are at the leading edge of studies of mammalian reproductive biology, which helps save endangered species. Smithsonian biologists have been studying endangered cats, such as clouded leopards, lions, tigers, and cheetahs, for decades.
- ◆ About 10,000 years ago, there was a natural population bottleneck associated with the last ice age. The whole cheetah population was reduced to only about 12 to 20 individuals. The population

recovered, and there were approximately 100,000 animals in the wild just about 100 years ago. Today, it is estimated that there are between 7500 and 8000 animals in the wild. We've lost about 90% of our wild population just in the last 100 years.

- ◆ The biggest threat to cheetahs in the wild is loss of habitat. As more and more people move into cheetahs' natural home ranges and put up farms and fences, cheetahs are not able to maintain their normal, natural home ranges. They're not able to interact with members of the opposite sex for normal reproduction, and they also lose a lot of their prey base.



- ◆ The biggest challenge facing cheetahs in zoos and breeding centers is understanding their biology and behavior. Cheetah females especially are very difficult to manage for successful reproduction. They don't have what we think of as normal estrous cycles. They have sporadic and intermittent cycles that make it very difficult for humans to interpret and manage for successful reproduction.
- ◆ In the wild, a male cheetah comes across a female's territory and smell where she urinated, defecated, or slept and pick up on olfactory cues that let him know that that female is either coming into estrous or is in estrous. Then, the male starts following her and looking for her. Because cheetahs' home ranges are so large, it may take a day or 2 to actually find her.
- ◆ The male cheetah uses a unique vocalization called a stutter bark to let the female know that he is in her territory, has picked up on her scents, and is looking for her because she smells good to him. Breeders use this to their advantage by letting the male smell the female yards or enclosures. Then, hopefully the male will stutter bark, and then the breeders can introduce the male and female.
- ◆ For successful cheetah reproduction, choice by the male or the female is very important. Choice goes both ways, so sometimes a male prefers a female over others, but sometimes a female prefers a male over others. Just because a male is excited about a female and thinks she smells good does not mean that the female will be receptive.
- ◆ Cheetahs who are pregnant are secluded in Smithsonian's cheetah breeding facility until after they give birth. When the cubs are very small, the mothers and cubs need quiet and privacy.
- ◆ Sometimes there are pseudopregnancies in cheetahs and other carnivores. Female cheetahs will ovulate when they are bred, which means that an egg is released from their ovary, and they will have an increase in progesterone, which will stay elevated for about 60 days even if they are not pregnant. That's called induced ovulation.

- ◆ For the first 2 months or so after a female is bred, it's impossible for caretakers to know based on her hormones if she's actually pregnant. The increase in progesterone will often make the cheetahs act as if they are pregnant, and they will also gain weight. They may gain weight for 60 days and then not be pregnant.
- ◆ To identify pseudopregnancy versus real pregnancy, researchers are actively looking at biomarkers—proteins that are produced during pregnancy and excreted in the feces from the females. They are collecting the fecal samples and extracting the proteins from those samples to try to pinpoint specific proteins that can be mapped during the early stages of pregnancy.
- ◆ An average litter size for cheetahs is 3. Managing the cubs can be difficult, depending on the mother. Some females are very relaxed and willing for people to check the cubs to make sure they're healthy and monitor their development and growth. Other females get very nervous if anyone handles their cubs, in which case caregivers slowly introduce to the female the idea that they are going to approach her den, with the end goal of getting her comfortable with people handling her cubs.

Suggested Reading

Wenshi, *A Chance for Lasting Survival*.

How Animals Raise Their Young

All organisms have a limited amount of energy to carry out the processes of life, including growth, respiration, movement, and reproduction. Time and energy invested in one process means less time and energy available for another. These selective pressures have a powerful effect on animal behavior, and ultimately on how each species evolves to fit into its environment. An animal's reproductive strategies reflect these environmental pressures. In a related way, these selective pressures also affect parenting behaviors.

Human Parenting

- ◆ Humans give birth to a single baby about 97% of the time. It takes most babies 1 year to 18 months to walk on their own, and most of the time parents are carrying them around much longer than that. Talking takes at least as long as walking, sometimes longer.
- ◆ This investment in our offspring not only costs us energy, it gives us fewer opportunities to mate while we are raising our kids and therefore reduces the overall number of offspring we can have—what zoologists call reproductive success. The benefit we gain from this investment is increased survival of our offspring.
- ◆ Humans are at one extreme of the parenting continuum: We have very few offspring and we make an intense investment in each one. But in many other species, the mother and father don't help their offspring at all. This is most evident in explosively breeding species, such as corals and salmon.



- ◆ The human style of caring for offspring is an extreme example of what zoologists call *K*-selection. The corals' and salmon's style is called *r*-selection. The theory of *r/K*-selection is one of the simpler ways to describe why different animals have different parenting styles.

Invertebrate Parenting

- ◆ We might think that advanced care of offspring is indicative of advanced life-forms, such as long-lived crocodilians or birds and mammals. But caring for offspring occurs in crustaceans, such as lobsters, crayfish, and pillbugs, and in scorpions and spiders.
- ◆ Crayfish and lobsters reproduce sexually. Maybe because of their hard exoskeletons, reproduction takes place while the female is molting. The pair copulates, and then the female partner releases her eggs. The eggs are fertilized as they travel from gonad to genital pore and out of her body.
- ◆ The sticky eggs get caught on fine bristles on her pleopods, the short fin-like appendages on her abdomen. These are also called swimmerets. The eggs are carried for a few weeks to a few months, depending on the species, until the larvae, known as zoea, hatch and can swim on their own.
- ◆ In crayfish, eggs develop like this through the winter and subsequent spring, a period during which female crayfish do not eat. After hatching in May or June, young crayfish larvae live for a month attached to the female's pleopods. Throughout this period of care and protection of eggs and young, females also continuously fan and groom the eggs and hatchlings to provide ventilation and remove waste.
- ◆ Why would crustaceans be so different from a coral or a salmon? Both salmon and lobster produce lots of eggs, so why do salmon leave the eggs and lobster protect them under their tails?

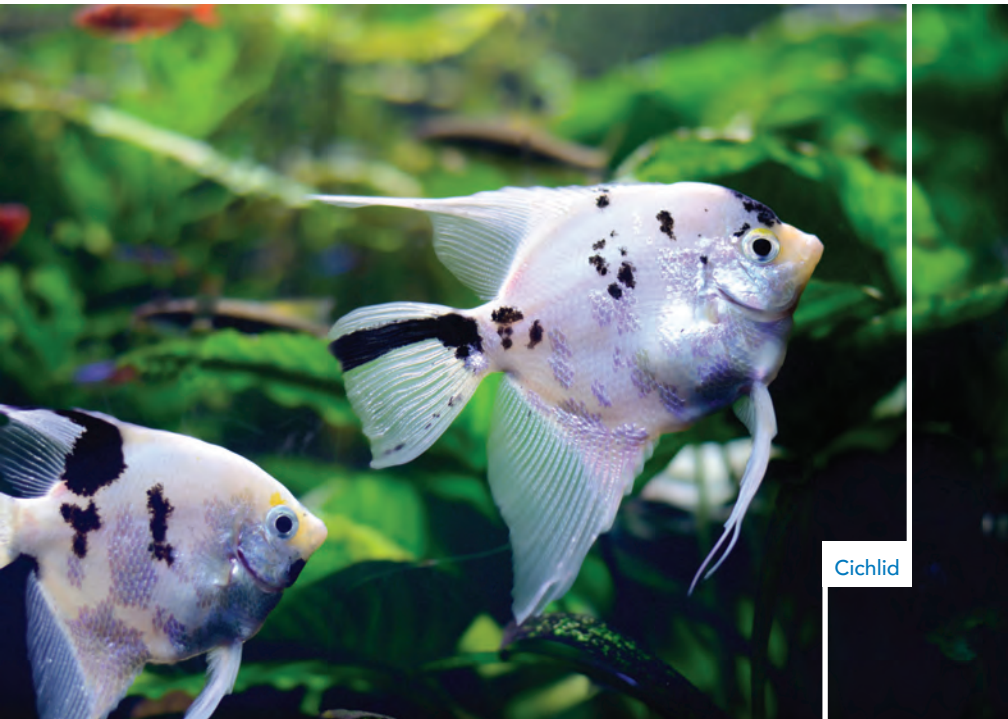
DID YOU KNOW?

Female crayfish do not eat through the winter and subsequent spring while her eggs, attached to her abdomen, develop.



- ◆ In his book *Sociobiology*, renowned ecologist E. O. Wilson suggested an alternative to r/K -selection theory. He suggested that parental care is a response to ecological pressures. He also suggested that 4 particular issues factored into an animal's style of parental care:
 1. How stable is the animal's environment?
 2. How stressful is the animal's environment?
 3. How predictable are the resources in the animal's environment?
 4. Does the animal have any significant predators in its environment?
- ◆ When the environment is unstable, when it's stressful, when resources are unpredictable, and when predation is severe, Wilson argues that greater parental care should be a winning strategy. Based on Wilson's theory, we would expect that something in the environment in which crayfish evolved pressured these animals toward more parental care.
- ◆ Today's insects and crayfish evolved from a common crustacean ancestor more than 350 million years ago. As insects moved from water to land, they faced some similar pressures for providing parental care as their water-dwelling ancestors faced.
- ◆ Most species of modern insects, however, avoid the costs of parental investment. Some female insects have swordlike appendages at the back of their abdomens that are egg depositors called ovipositors. They use these to hide their eggs in or on vegetation, in crevices in the bark, inside of a leaf, or some other place where the eggs are out of sight and away from egg predators. Most can use their ovipositors to place their eggs in small clutches, removed from one another in space and even in time.

- ◆ Entomology professor Douglas Tallamy suggests that, for most insects, the opportunity to spread reproduction and egg clutches over time and space has made childcare both unnecessary and too costly for the possible benefit. But for those insects with fewer chances to breed, parental care can be the only way to ensure that their offspring live on after them.
- ◆ Some *r*-selected species, such as mouth-brooding cichlids from Africa's great lakes, put up quite a fight in defense of their young. Many species of mouth-brooding creatures are territorial, laying their eggs in a nest scraped into the lake bed by parents who also guard the eggs. Others are mouth brooders of both their eggs and later their youngsters.
- ◆ Mouth-brooding fish usually have fewer and larger eggs than nest-building fish and many fewer eggs than fish that spawn in open water. Mouth-brooders eat less than the normal amount of food while they are brooding their young in their mouths.



Cichlid

Altricial versus Precocial Animals

- ◆ Some babies are born relatively helpless and some are born ready to take on the world. Altricial animals are immature and helpless at birth, while precocial animals are capable of a high degree of independence from birth. The mothers or fathers of these infants have evolved reproductive physiology and behaviors to maximize the survival of their young.
- ◆ Some birds, such as robins, sparrows, and other perching birds take lots of care of their young after hatching. All perching birds hatch babies that are altricial. These little birds hatch with their eyes closed, have little or no downy feather covering, are not capable of departing from the nest for some time, and are fed by their parents.
- ◆ Ducks, shorebirds, and pheasants, on the other hand, are precocial. Their babies hatch with their eyes open, are covered with down, and leave their nest within a couple of days. Some precocial birds, such as ducks, follow their parents after hatching but find their own algae or insect food. Pheasant and grouse chicks, however, walk after their parents and are shown seed, leaf, and terrestrial insect food by the adults.



- ◆ Scientists think that these different modes of bird development are tied to 2 important aspects of the bird's environment: food availability and predation pressure.
- ◆ The strategy of precociality emphasizes the ability of females to find abundant resources before laying eggs. Females of precocial species, such as ducks, must produce energy-rich eggs to support the greater development of the chicks while in the egg. Eggs of precocial birds contain almost twice the calories per unit weight as those of altricial birds.
- ◆ Females in altricial species, such as robins, do not face such large nutritional demands before egg laying. Instead, they need to find sufficient food to feed their helpless young through to fledging.
- ◆ Precociality is also a winning strategy in an environment where predators are common. Precocial young have some ability to avoid predation because they leave the nest early and are most often well camouflaged, and there is a much smaller chance of the whole clutch being preyed on.
- ◆ On the other hand, while the altricial chicks are in the nest, the entire brood is very vulnerable to predation, so these species depend on nest camouflage and parental defense for survival. In fact, males and females take turns guarding the nest, so predation pressure affects the behavior of both parents, not just mothers.
- ◆ Behavioral ecologists such as John Alcock use a cost-benefit approach to analyze why females usually provide more parental care than males. They suggest that this is because females lay the eggs and therefore can expect to be genetically related to all offspring in their broods. Males who provide care incur a greater potential cost, because they may be helping nestlings that were sired by themselves as well as by other males.
- ◆ Although we think of bears as impressively powerful animals, their babies are highly altricial. Bears have the largest adult-to-infant weight

ratio in the mammal group, about 750 to 1. Baby bears are born with eyes and ears closed and very little hair covering. They are incapable of moving out of the den and need extensive parental care before they leave the den.

- ◆ The difference in size between a 230-pound mother giant panda and her quarter-pound baby is remarkable. The National Zoo has been fortunate enough to be home to many baby giant pandas since 1972. Giant pandas are born pretty altricial; barely the size of a butter stick, they can't do much without their moms.
- ◆ Precocial mammals, on the other hand, are able to move around on their own shortly after birth and have camouflage colors and cryptic behaviors to avoid predation while trailing their parents and nursing until they are capable of feeding on their own. Females of precocial species have longer gestation times, and like all mammals, females of reproductive age need to maintain the best-possible physical condition.
- ◆ Altricial and precocial infant strategies both have their evolutionary advantages. Each strategy depends on the species' environment, nesting habits, predator-prey relationships, and feeding strategies.

Golden Lion Tamarins

- ◆ One of the most amazing examples of unique parental care in mammals is in golden lion tamarins. Brazil has a lot of tropical forest, and around 3000 of these small, reddish-orange monkeys remain in the Atlantic coastal forests west of Rio de Janeiro.
- ◆ Smithsonian's National Zoo and others began a conservation breeding program for this species in the 1970s, and adults had problems raising their twin young.
- ◆ This species eats low-calorie insects and tree gum in their native forest habitat, and they probably get their water from bromeliads in the trees. Parents need to carry the youngsters around for protection, rather than leaving them in their tree-cavity nests.



- ◆ The mother expends a lot of energy on lactation, and it is common for the male to carry the twins. The adult golden lion tamarins are the first ones out of their nests in the morning and the last ones to go into the nest each night.
- ◆ National Zoo scientist Dr. Devra Kleiman and her students studied golden lion tamarin behavior and found that the family group benefits from subadult helpers, like human teenagers babysitting the kids. The helper time in the family group helps the teenagers become better parents when they have babies of their own.
- ◆ It was only after Dr. Kleiman and colleagues figured this out and replicated this social grouping in zoos that we could reintroduce golden lion tamarins into newly protected habitat in Brazil, and now their future looks brighter.

Suggested Reading

Clutton-Brock, *The Evolution of Parental Care*.

Kleiman and Rylands, eds., *Lion Tamarins*.

Tallamy, "Child Care among the Insects."

Verdolin, *Raised by Animals*.

Helpful Corals, Clams, and Crustaceans

Invertebrates are animals without backbones, and marine invertebrates are some of the most economically important animals on the planet. Oysters and clams along American coasts provide valuable food (and even pearls) for our society. Crabs and lobsters add millions of dollars to local coastal economies, and most humans think that they taste delicious. A clean and well-functioning estuary ecosystem creates economic activity from these marine resources and creates jobs.

Sea Sponges

- ◆ Among the 5000 or so species of sea sponges, fewer than 12 are harvested for human uses worldwide. Sea sponges are not plants, but very primitive animals with no brain or central nervous system.
- ◆ Sponges are the simplest multicellular animals, and they arose as aggregates of non-differentiated cells, evolving more than 540 million years ago. The multicellularity of sponges is an adaptive path toward larger body size because the many small units allow for greater surface areas to be available for metabolic activities that simply increasing the size of a single cell would not accomplish.
- ◆ A sponge body is an assemblage of different kinds of cells in a matrix, supported by a skeleton of fibrous collagen protein and needlelike spicules. These organisms do not look or behave like other animals, so it wasn't until the 18th century that they were accepted as animals by zoologists.
- ◆ Sponges feed by filtering plankton drawn in through incurrent canals, and their digestion is intracellular because there are no organs or tissues in this organism. Respiration and excretion are by diffusion across cell membranes.
- ◆ Sponges can reproduce by asexual budding or by sexual mixing of eggs and sperm. Most sponges are monoecious; that is, they have both female and male sex cells in the same individual.

DID YOU KNOW?

Sponges sit at the bottom of the food chain, or food web, in the world's oceans, so their survival is critical to the survival of the rest of the marine animals our economies depend on. When we harvest sponges, it's important to keep sustainability in mind.



- ◆ Free-swimming sponge larvae eventually settle to the ocean floor. Sea sponges then remain anchored for their entire lives. Harvest of parts of these organisms without damaging the anchoring system allows the sponge to regenerate those body parts. Additionally, entirely new sponges can develop from fragments of sponges dropped onto the seafloor.

Mollusks

- ◆ Mollusks, or Mollusca, are a large phylum of invertebrate animals that includes clams and oysters. Scientists recognize more than 90,000 species of mollusks, and this is the largest phylum of marine animals, with almost 1/4 of all named marine organisms.
- ◆ Although they originated in the seas more than 500 million years ago, some have evolved adaptations to live in brackish and freshwater. Today, a large number of mollusk species, including freshwater mussels and snails, live in freshwater and terrestrial habitats.
- ◆ Diversity in size, shape, color, habitat, and even behavior is typical of the Mollusca group, which is normally divided into 8 extant taxonomic classes. These classes include gastropods, the largest group, with more than 65,000 species of snails, slugs, conchs, and relatives, and the bivalves, with about 20,000 species of clams, oysters, scallops, and mussels.
- ◆ The most complex class within the mollusk group is the cephalopod mollusks, which includes octopus, squid, and cuttlefish, some of the most cognitively advanced of all invertebrate species. The giant squid is the most massive of all known invertebrate species, at 18 meters long and weighing almost 900 kilograms.
- ◆ These marine mollusks have diversity in movement as well; octopi and squid move quickly via jet propulsion. Even scallops can “clap” themselves away from danger, or they can remain glued to a rock in the tidal zone, like oysters or mussels do for most of their lives.

- ◆ The bivalves have so much morphological diversity that it is most useful to define them by the features that unite them. All bivalves have a hinged outer shell (also called a valve) and a mantle, and most have a foot or threads used for burrowing or anchoring the creature into the substrate.
- ◆ Clams, oysters, and other bivalves breathe solely through gills that are part of the animal's mantle. The gills are so different in different types of bivalves that gill morphology is a major indicator for bivalve systematics.
- ◆ Reproduction in bivalve creatures is bisexual. For fertilization to occur, it is crucial that as many oysters as possible spawn at the same time. Spawning is cued by water temperature and salinity in midsummer. During an oyster's first spawning period, the creature will be reproductively male, and then it will transform to female for subsequent spawning cycles.



Clam

- ◆ Some types of bivalves, notably mussels, have a byssal gland that produces a byssal thread to attach them to a rocky surface. It is sometimes easy to observe groupings of these proteinaceous threads extending from one mussel to another in a mussel bed.
- ◆ The bivalves that we call clams, including surf clams, quahogs, and cherrystone clams, are burrowers that lack a byssal gland and develop a specialized foot as they grow. This wedge-shaped muscle can be expanded and contracted so that the clam can burrow into soft sand.
- ◆ The biomass, or the weight of individuals in an area, of these creatures is as important from an ecological point of view as is the harvest from an economic point of view.
- ◆ Much of the American oysters' historic beds disappeared over the last 200 years due to construction of cities and suburbs along seacoasts. However, some good habitat remains, and here the oysters provide substrate for marine creatures such as barnacles and worms.
- ◆ A high density of oysters over a high percentage of their historic range within an estuary and with a growing population is a good sign for the ecosystem as well as the economy.

DID YOU KNOW?

During feeding, an oyster can filter more than 1 gallon of water per hour, which it does by drawing water over its gills. Scientists estimate that Chesapeake Bay oysters historically filtered the entire bay's 15 trillion gallons of water every 3 to 4 days.



Crustaceans

- ◆ Crustaceans are members of the phylum Arthropoda, which includes their terrestrial relatives the insects and spiders. Crabs, lobsters, and shrimp are all members of the crustacean subphylum.
- ◆ Arthropods are invertebrate animals with a particular set of shared characteristics inherited from their common ancestor. These creatures have bilateral symmetry, segmented bodies, 6 or more jointed limbs, and most often a hard, chitinous external covering called an exoskeleton that is replaced during molts throughout the creature's life.
- ◆ This hard exoskeleton is limiting, and in order to grow, all arthropods need to shed a current skeleton in favor of a new and larger one. The stiff exoskeleton is supported by movable jointed legs, and



Shrimp

these are specialized for different functions, such as the rear walking legs and forward grabbing and crushing claws of crabs.

- ◆ Although we mostly associate them with the Chesapeake Bay, blue crabs range all along the Atlantic coast from Canada to Argentina. Blue crabs live in a wide variety of habitats throughout their lives. These crabs have a high tolerance for changes in both water temperature and salinity, so they can survive almost anywhere in the bay.

- ◆ Crabs are meat-eaters that feed by predation and scavenging. If you can find it on the ocean floor, they eat it, including fish, clams, oysters, mussels, snails, worms, insects, and even each other.
- ◆ Habitat loss and increased nutrient loading have been the greatest threats to blue crabs. Reducing nutrient runoff from suburban lawns, farms, and other areas and maintaining healthy stream and river sheds, as well as healthy seagrass beds, have been important for a healthy Chesapeake Bay and recovering blue crab populations there.
- ◆ Compared with the blue crab, the American lobster comes from colder, deeper water areas but is just as prized as a source of food. Lobsters are also in the arthropod order Decapoda, which includes about 10,000 species of shrimp, crabs, crayfish, and lobsters.
- ◆ The chitinous exoskeleton of these creatures is typically dark and turns red when the creatures are boiled for dinner. Lobsters are omnivores and eat fish, bivalves, and other crustaceans as well as

DID YOU KNOW?

Each female blue crab will only mate once in her entire life, while each male will mate with as many females as he can attract during his lifetime.



DID YOU KNOW?

Although a luxury item today, lobsters were used as fertilizer by Native Americans in American colonial times, and indentured servants demanded that they be fed this cheap and available food no more than 3 times weekly.



some plant life and even their own molted shells.

- ◆ As adults, male lobsters will molt about once each year, and females will molt once every 2 years. Lobsters can only grow through these moltings. Sometimes they eat their own hard shells after molting, which replaces body calcium and helps the soft shell harden. With each molt, a lobster can gain 15% in length and 40% in weight.
- ◆ Lobsters are so important to the stable ecological processes of the oceans because they scavenge all types of dead animals and their parts. They are also efficient predators that are active at night. Their biology is still poorly known, so zoologists continue to focus their studies on lobster ecology and reproduction.

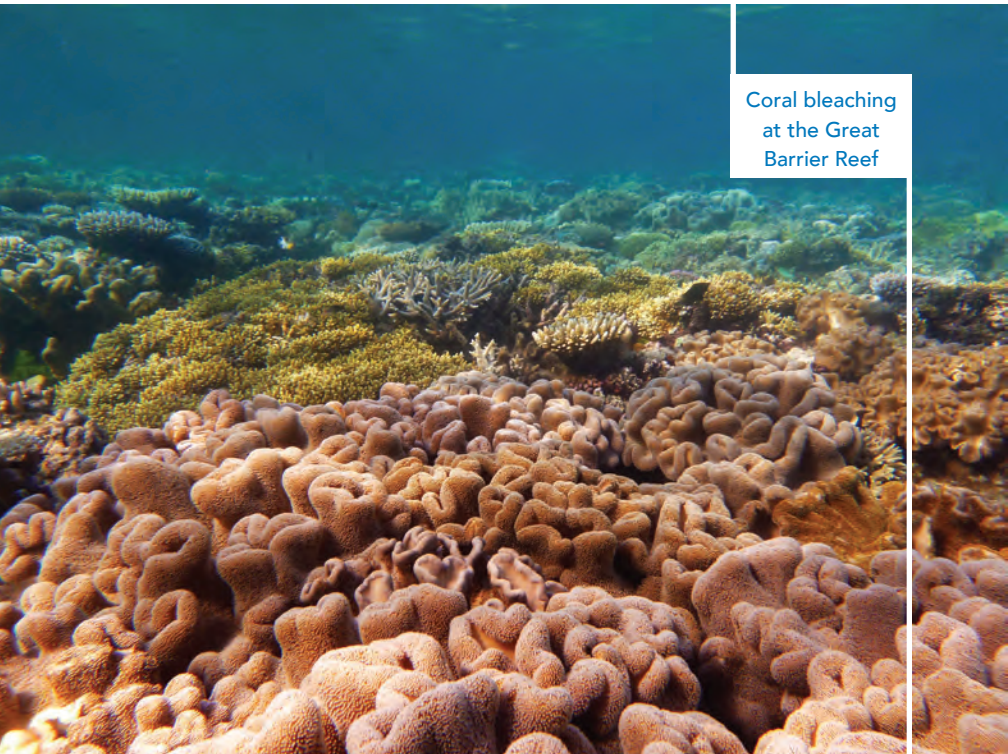
Corals

- ◆ Corals are also important ocean resources. Corals are primarily important because they are the basis of an entire ecosystem and secondarily because they are a resource to us.
- ◆ Vibrant, multicolored coral reefs surpass even tropical rainforests in their levels of biodiversity, supporting living corals, worms, conchs, spiny lobsters, and other invertebrates, as well as many species of fish.

- ◆ Healthy coral reefs support tourism by recreational divers as well as commercial fishing. Almost half of all fishes depend on coral reefs and similar habitats for some of their lifestyles.
- ◆ Corals are simple, radially symmetrical animals in the phylum Cnidaria. Cnidarian cells include the famous nematocysts, or stinging cells notable in sea jellies such as sea nettles, Portuguese man-of-war, and moon jellies. Corals and anemones are in the class Anthozoa, which appears in the fossil record more than 500 million years ago.
- ◆ The reef-building corals are symbiotic associations between cnidarian animals and colorful photosynthetic creatures called zooxanthellae that live inside these animals. Corals precipitate calcium carbonate from seawater, which helps anchor them and build their skeletons, which we call the reef.
- ◆ Reef-building corals require warmth, sunlight, and undiluted seawater. They are found in some of the sunniest, most beautiful tropical spots in the world.



- ◆ Healthy ocean reefs are important for our survival on Earth because they are a keystone ecosystem. Reefs provide homes to many organisms that our planet needs to stay healthy. If reefs are destroyed, our health will be threatened by the uncertain effect on our ocean's ability to support green algae, which produces 50% of the oxygen on our planet.
- ◆ Despite their incredible value for ecological services and for humanity, the beneficial symbiosis between corals and zooxanthellae is under threat. Over the last century, pollution and climate change have taken their toll on reef ecosystems, particularly in the form of coral bleaching.
- ◆ Bleaching occurs when the zooxanthellae are stressed by the temperature or chemical conditions in the surrounding water, which can break the important symbiotic bond and the algae are expelled. The corals can survive for a few months without their important



Coral bleaching
at the Great
Barrier Reef

symbionts, but if they do not get them back within about 10 weeks, the coral can die.

- ◆ Experts estimate that almost 60% of the world's coral reefs are in danger of bleaching, and the number of bleaching events recorded by marine biologists in the past century has increased by more than 10-fold.
- ◆ Although coral reefs occupy only about 1% of the footprint of the world's oceans, more than 25% of all marine life lives in these habitats. Without coral, there may be no fish. Without fish, what happens to humans?

Suggested Reading

Eakin, "Lamarck Was Partially Right."

Hardt, *Sex in the Sea*.

Livie, *Chesapeake Oysters*.

Warner, *Beautiful Swimmers*.

Bees, Butterflies, and Saving Biodiversity

There are more than 1 million species of insects, which is more than half of all known extant species on our planet. Insects have a huge amount of biomass and are often hugely prolific animals. They are extremely important to the planet ecologically and to humans economically. This lecture will explore adaptations of some of the most important animals on our planet: invertebrates from terrestrial ecosystems.



Insect Pollinators

- ◆ Insects have been around for 400 million years according to the fossil record, and we can learn from the behavioral rules that have shaped their evolution.
- ◆ Humans cannot live without the Earth's many insect pollinators. Among the 1 million species of insects, there are many pollinators.
- ◆ Pollination, an essential function for plant life, is the transfer of pollen grains from the anther, or male flower parts, to the stigma, the female part of the flower. The goal of live plants is to reproduce, and successful pollination allows plants to produce seeds that carry the species' legacy through the next generations.
- ◆ Without animal pollinators, Earth's flowering plants and ecosystems would not survive. Humans would struggle more to survive because pollinators are necessary to produce our diversity of food crops. About 1/3 of the foods we eat rely to some extent on bees: all vegetables and fruits, including almonds, tomatoes, broccoli, apples, blueberries, peaches, oranges, and many other crops.
- ◆ Butterflies, beetles, flies, ants, and even wasps act as pollinators, in addition to bees. Some flowers open at night and are pollinated by moths.
- ◆ Plants attract animal pollinators by offering food in the form of sugary nectar or protein-rich pollen from flowers, and in this way achieve active transfer of their genetic material to the next generation. Flowering plants have a diversity of flower shapes, colors, scents, and even structure and amount of nectar per flower.
- ◆ Flowers vary based on the type of pollinators they have, and such coevolution of shape, scent, and color allows the plant and animal to more successfully interact. These characteristics are so well known to biologists as grouped traits that they can be used to predict the type of pollinator that will visit and aid the flower in successful reproduction.



White Darwin's
orchid

Bees

- ◆ There are 20,000 species of bees, including honeybees, out of hundreds of thousands of species of pollinators. This diversity suggests that we need to provide a diversity of flowering plants so that these creatures can thrive.
- ◆ The bee life cycle begins with reproduction. Sexual reproduction is the norm for insects, and honeybees—the best-known bee pollinators—are no different.
- ◆ During a mating flight, the virgin queen bee may mate with many males. The male inserts his endophallus into the queen during her one-and-only mating flight, discharges his sperm, and leaves his endophallus behind in her as he withdraws. This rips his abdomen open, and the male dies after mating.



- ◆ Once a queen has mated, she stores more than 5 million sperm and may lay more than 1 million eggs in her lifetime. The queen forms a new colony during the winter season by laying eggs in individual cells within a honeycomb structure made of beeswax.
- ◆ The queen can choose to fertilize or not fertilize an egg as it moves through her oviduct. Fertilized eggs all become female worker bees, while unfertilized eggs become drones, or male bees. The worker bees can also lay eggs, but they are unfertilized, so the insect that emerges is a drone.
- ◆ The larva spends 3 days developing nervous and digestive systems, as well as its outer body covering, before hatching. At this stage of development the larvae have no antennae, legs, wings, or compound eyes—only simple eyes.
- ◆ Worker bees feed the larvae with either honey or royal jelly, a substance made of pollen and glandular excretions from worker bees, until the larvae's adult development into workers, queens, or drones is complete. The whole process takes about a week.
- ◆ When the queen can no longer lay eggs, a new queen will emerge to take her place. In honeybees, the larvae that received the royal jelly from the workers are the ones that can become queens.
- ◆ In addition to all these duties nurturing larvae, workers also collect pollen. Honeybees have leg structures that are adaptive for pollen gathering and other activities. Each bee carries her pollen back to the hive, where it is pushed into a waxy cell within the comb.
- ◆ Other workers care for the pollen in the hive. It is the primary source of protein for the bees in the hive. The pollen is needed in the first 5 to 6 days of a worker bee's life to allow these creatures to secrete wax later in life. The workers that work on secreting wax gorge themselves on honey beforehand and hang in groups near the area where comb is being built through the wax-synthesis process.

- ◆ Honey that is so valuable for humans is collected as nectar by the bees, and then the sugary substance is placed in the waxy cells of the honeycomb, where its water evaporates as the open cells are fanned by the bees' wing movements.
- ◆ Most bees fly tens or hundreds of yards in their quest for pollen and nectar. This is important because about 1/3 of our food crop depends on bees, yet bee species and numbers have been declining. Over the past 2 centuries, millions of acres of old fields with diverse flowering plants have changed either to millions of acres of houses with monocultures of grass in the suburbs or to millions of monocultures of food crops.
- ◆ It is simply more difficult for bees to find the close-in food they have evolved to find. This complex of factors has contributed to the phenomenon known as colony collapse disorder, which happens when worker bees abandon their hives in large numbers, with the result that colonies cannot sustain themselves.
- ◆ Research shows that 3 major factors contribute to colony collapse disorder: arrival of some stressful disease; stressors in the environment, including pesticides and other pollutants; and reduction in habitat and local plant diversity.
- ◆ Individuals can offset these impacts by using their own backyards to grow pesticide-free pollinator gardens by planting native plants, or by allowing ground-nesting bees to nest in the backyard. Another way to help bees is to leave dead limbs on trees; they're good for pollinating bees' nesting sites.

Butterflies and Moths

- ◆ Bees require both nectar and pollen as food sources throughout their life cycle. In contrast, adult monarch butterflies are floral generalists that only require energy-rich nectar from the diversity of flowers they visit.

- ◆ These butterflies convert the nectar's sugars to body fat that sustains them during migration and through the winter, when many flowering plants are in winter dormancy. Scientists note that nectar sources are particularly important during late summer and fall as monarchs migrate to overwintering sites.
- ◆ There are about 20,000 butterfly species around the world, and these are outnumbered by more than 150,000 species of moths. Like all insects, every butterfly or moth has 6 legs, a head, and a body in 2 parts: the thorax and abdomen. Butterflies and moths also have 2 wings, feelers or antennae, big eyes, and a specialized tube-shaped feeding organ called a proboscis.
- ◆ Most butterflies have small knobs on the ends of their feelers, and moths do not; in fact, many moths have antennae that are very feathery in shape. These antennae are for smelling and feeling. Many moths do not have a proboscis, because as adults they survive on energy they stored when they were caterpillars.



- ◆ At rest, most butterflies fold their wings up, while moths rest with their wings flat.
- ◆ Butterflies and moths can taste, smell, and see, but not in the ways humans can. Butterflies and many insects have taste sensors in their feet. In contrast to humans' single-lensed eyes, butterflies have compound eyes, so they can see in many directions at once but apparently they can't see as clearly as we can.
- ◆ Most butterflies spend the night in a quiet spot to avoid predators and may be found sunning themselves during the day. Many night-flying moths are dark and have camouflage patterns, so they are also more difficult for predators to find at all times.
- ◆ The wings of butterflies are covered with thousands of tiny colored scales, all of which overlap like roof tiles to create patterns on the wing. Some moths have large "eyes" on their hind wings to scare predators.
- ◆ Every butterfly or moth begins life as an egg. A tiny larva called a caterpillar hatches from the egg and begins eating preferred food plants. After it grows through several larval stages, or instars, the caterpillar turns into a pupa, called a chrysalis, where the amazing changes of metamorphosis occur.
- ◆ Metamorphosis is characterized by dramatic transformations of creatures from one life stage into another. During this biological process of change, a plant-dwelling caterpillar has specialized mouthparts for chewing plant leaves and many pseudo-legs for walking, then develops a cocoon, and then changes into a butterfly with wings for elegant flight and a curled, siphon-like proboscis that helps it suck up its sugary liquid nectar diet.
- ◆ Metamorphosis in monarchs and other butterflies or moths ends as the creature breaks out of the protective chrysalis and a beautiful adult emerges. This amazing new monarch needs to breathe and stretch its new wings before it can fly and find mates to create the next generation of its species.



- ◆ To do this, its mouthparts also change so that the adult can feed on the nectar of many different kinds of wildflowers. And while feeding on nectar, the monarchs contribute to Earth's environmental health by pollinating wildflowers, mostly those that provide flower clusters that are open during the day and have surfaces that support the monarch's tiny feet.
- ◆ Interactions between flowering plants and pollinators occur on many ecological levels. The disappearance of beautiful butterflies has more implications than simply loss of color in nature around us. Habitats around the world are disappearing, impoverishing the environment for animals and people.

Pollinator Conservation

- ◆ Pollinators and pollinator habitats have intrinsic value as ambassadors for the conservation of all invertebrates, aesthetic value for human art and culture, and educational value to teach children about plant and animal life cycles. Pollinators are indicators of healthy ecosystems that will allow human life on Earth to continue.
- ◆ On a broad scale, the abundance and diversity of insect pollinators are positively correlated with overall plant species diversity. On a species scale, some flowering plant species support a huge variety of insect pollinators, and this may depend on whether pollinators are generalists or specialists.
- ◆ Global action is needed for pollinators that are declining around the world. Consumers should use products that are pollinator-friendly. And people can contact their elected representatives and



other policy makers and teach about pollinators so that these policy makers have an appreciation for the essential role our pollinators play in the world's environment, for ecological health, and human food production.

- ◆ Discover the number of native flowering plants and pollinators in your area and how you can help them thrive. If you don't have enough gardening at home, try volunteering for a local zoo, park, or natural area that has wildlife-friendly gardens and build your legacy of a healthy environment for future generations from there.

Suggested Reading

Agrawal, *Monarchs and Milkweed*.

Benyus, *Biomimicry*.

Carter, *Butterflies and Moths*.

Grissell, *Bees, Wasps, and Ants*.

McGavin, *Insects*.

Seeley, *Honeybee Democracy*.

Tallamy, *Bringing Nature Home*.

Deadly Invertebrates: Vectors and Parasites

This lecture will explore adaptations of some of the most economically important animals on our planet: invertebrates that have adverse effects on humans. Locusts and other invertebrate creatures devour human crops, and mosquitoes and other biting invertebrates deliver parasites and disease into humans. Both of these adverse impacts cost human society billions of dollars and millions of human deaths per year.



Mosquitoes and Other Biting Flies

- ◆ The deadliest animal on Earth is actually the lowly, tiny mosquito. According to the World Health Organization, mosquitoes spread malaria, West Nile virus, yellow fever, dengue fever, and several other diseases, killing more than 2.5 million people per year.
- ◆ Mosquitoes and other biting flies sense the world differently than we do. Mosquitoes can detect the carbon dioxide we give off when we are breathing, as well as our mammalian body heat, and they are very attracted to both. The female mosquitos are the ones who bite us, but both sexes have exquisitely sensitive sensory systems.
- ◆ Each kind of mosquito is active at species-specific times of day, usually dawn and dusk. Mosquitoes are also affected by ambient temperatures, the amount of light in the environment, and even the amount of moisture in the air.
- ◆ Many mosquitoes are only found at certain heights above the ground, the better to find victims. When you are outdoors when they are active, you are likely to be bitten unless you wear protective clothing and insect repellent.
- ◆ Malaria, carried by the *Anopheles* mosquito, is the main reason that mosquitoes are considered the deadliest of all animals. More than 400,000 people die of malaria each year, although hundreds of millions more suffer from malaria annually.
- ◆ More than 40% of the world's population lives in areas

DID YOU KNOW?

A male mosquito using its antennae can hear the whirring of a female mosquito's beating wings 1/4 of a mile away.





occupied by *Anopheles* mosquitoes, and most of those affected are African children under 5 years of age. But malaria's victims aren't limited to Africa. It is an awful disease, causing fever, chills, and weakness that seem to clear up but always come back. In some cases, it causes liver failure and death.

- ◆ Although there are treatments for malaria, the parasite evolves quickly, and more than 70% of cases seem to be resistant to quinine and other treatments now. The debilitation of sub-Saharan Africa human populations from malaria reduces development and national productivity and therefore is a serious health problem.
- ◆ Increasing education about mosquitoes and the use of bed nets to prevent entry of mosquitoes so that they cannot bite sleeping children, and increasing use of effective modern antimalarial drugs, helps mitigate the widespread effects of malaria.
- ◆ Disease is spread not only by mosquitoes, but also by tsetse flies that spread sleeping sickness and kissing bugs that spread Chagas disease. There are more than 125 species of kissing bugs—some are found in more than half of the states in the United States—and every one can be host to the trypanosome parasites that transmit Chagas disease.

- ◆ Disease is also transmitted to people and other mammals by ticks and fleas. Lyme disease, caused by the spirochete bacterium *Borrelia*, is carried by ticks. Even household dogs are very likely to get Lyme in areas where Lyme is prevalent in the tick population, so they should be protected by effective drugs that can be prescribed by a veterinarian.
- ◆ Fleas live everywhere there are other mammals. These small pests transmit typhus, caused by rickettsial organisms, as well as Bubonic plague, caused by the bacterium *Yersinia pestis*—this is the Black Death organism that killed tens of millions of Europeans in the 14th century.
- ◆ But nothing really compares to mosquitoes: West Nile virus, Zika virus, and chikungunya are all examples of viruses transmitted to humans by mosquitoes. Because mosquitoes are arthropods, they are called arthropod-borne viruses, or arboviruses.
- ◆ Several viruses that affect humans are carried by day-active *Aedes aegypti* and *Culex* mosquitoes, which makes these mosquitoes doubly dangerous to day-active humans. Arboviruses can be transmitted by other arthropods as well.



Dragonfly

- ◆ Some insects are enemies of mosquitoes that help in their control. For example, dragonflies and their damselfly relatives love to munch on mosquitoes. Although adult dragonflies only live a few months, their larvae can live underwater for years before they become adults. So, adult dragonflies are eating up flying adult mosquitoes while dragonfly larvae devour as many mosquito wigglers as they can find in the water.

The Spread of Disease

- ◆ Sometime around 200,000 years ago, our species, *Homo sapiens*, emerged in eastern Africa and eventually spread around the world. Until about 15,000 years ago, at the end of Earth's most recent ice age, humans had migrated to virtually every area on Earth where humans could survive, bringing some parasites with them and collecting others on the way.
- ◆ During our relatively short history on Earth, humans have acquired a huge number of parasites: about 300 species of helminth worms and more than 70 species of protozoa out of the tens of thousands of wormlike species on our small planet.
- ◆ "Helminth" is a general term meaning any wormlike parasite with an elongated, flat or round body, and our human medical community has separated clinically relevant groups based on general external shapes and organs they inhabit.
- ◆ Parasites that infect humans have been classified as either heirlooms or souvenirs. Heirlooms are considered those parasites that we inherited from our primate and human ancestors in Africa, and souvenirs are considered those that we have acquired from animals with which we have come in contact during our evolution, human migrations, and agricultural practices.
- ◆ Our human development of settlements and cities facilitated the transmission of infections from human to human, and when we

opened up trade routes, it resulted in the wider dissemination of parasitic infections.

- ◆ The relatively recent Columbian Exchange, which flourished from the earliest 16th century to the mid-19th century, exchanged parasites between the New World and Old World.
- ◆ In recent times, the spread of human immunodeficiency virus (HIV) and acquired immune deficiency syndrome (AIDS) and the immunosuppression associated with these conditions has apparently resulted in the establishment of a number of new opportunistic parasitic infections throughout the world.
- ◆ We have learned a lot about the past history of parasitic infections from studies of archaeological artifacts, such as the presence of helminth eggs or protozoan cysts in coprolites (fossilized or desiccated feces) and naturally or artificially preserved bodies. A new science, palaeoparasitology, has emerged from these studies, and it has helped us understand our longtime relationships with human parasites.

Worms

- ◆ Helminths share body plans in that they are bilaterally symmetrical, their sense organs and nerve centers are concentrated in the head, and they have a dorsal and ventral surface.
- ◆ The flatworms, or Platyhelminthes, and the roundworms, or nematodes, that infect humans have adaptive anatomic features that reflect common physiologic requirements and functions.
- ◆ The outer covering of all internal wormlike parasites is the cuticle, or tegument. Flatworms have ways of holding onto their hosts. Ribbon-shaped tapeworms (the Cestoda) have a head called a scolex that has hooks to embed in host tissues. Leaf-shaped flukes (the Trematoda) have suckers for adhesions instead. Male nematodes



Helminth

of several species possess accessory sex organs that are external modifications of the cuticle.

- ◆ The internal alimentary, excretory, and reproductive systems of these creatures can usually be identified by an experienced observer. Tapeworms are unique in this large grouping because they lack an alimentary canal, which means that nutrients must be absorbed through the tegument.
- ◆ Blood flukes and nematodes have 2 sexes, while other flukes and tapeworm species that infect humans are hermaphroditic.
- ◆ Tapeworms are gutless wonders. There are more than 1000 species of tapeworms known to parasitologists. Like other Cestode species, tapeworms require at least 2 hosts and are digestive tract parasites.
- ◆ Although *Taenia saginata* is called the beef tapeworm, it lives as an adult in the human intestine. The juvenile forms live in the intermuscular tissue of cattle, and eating undercooked or rare beef

is a way for a human to get this parasite, which can reach a length of 30 feet or more in the human gut. About 1% of American cattle are infected. You can avoid infection by beef and pork tapeworms by thoroughly cooking your meat or by being a vegetarian.

Spiders

- ◆ Most spiders are harmless to humans because they help control injurious insects, but this does not reduce human fear for these small creatures.
- ◆ There are a few spiders in the world that can give painful or even fatal bites. Several highly aggressive large spiders live in the American tropics, and there is a dangerous funnel-web spider in Australia. In North America, there is the small though infamous black widow spider that has a neurotoxic venom, and about 4 or 5 bites out of 1000 are fatal.
- ◆ The brown recluse spider has a violin-shaped marking on the dorsum of its cephalothorax. Their venom is hemolytic, so it produces death of tissues and skin surrounding the bite. Otherwise, the bite is mild, although there are apparently a few unconfirmed deaths of small children and older individuals from brown recluse spider bites.

DID YOU KNOW?

Most people are more afraid of spiders than flies, but maybe they have that backward. Do you know what happens when a fly lands on your food? Houseflies have sponging mouthparts and cannot chew their food, so they vomit enzymes onto their food—your picnic plate—to dissolve the food, and then they slurp it up.





Suggested Reading

Grove, *Tapeworms, Lice, and Prions*.

Hillyard, *The Private Life of Spiders*.

McGavin, *Insects*.

Packard, *The Making of a Tropical Disease*.



Lecture 8

Bony Fish, Skates, Sharks, and Rays

This lecture will explore the adaptations, biology, and conservation needs of some of the most interesting animals on our planet: the fishes. In Earth's animal kingdom, there are more than 28,000 species of fishes, a broad designation that includes almost 1000 species of sharks, skates, and rays, as well as 27,000 bony fishes. This lecture will use "fishes" to mean 5 of the 7 vertebrate classes, grouping some very diverse aquatic creatures together. The fishes make up almost half of all vertebrate species on Earth, and they are extremely important to the planet ecologically and to humans economically.

Fish

- ◆ Zoologists recognize a fish as an aquatic vertebrate with gills, bilateral appendages that occur in the form of fins (when present), and usually a skin with scales of dermal origin.
- ◆ This modern zoological concept of a fish is used more for convenience than for taxonomy because the 28,000 living species of modern bony fishes, sharks, skates, and rays make up more species than all other species of vertebrates combined. The ray-finned bony fishes make up more than 99% of the total species covered here.
- ◆ Bony fishes evolved about 430 to 440 million years ago, in the Silurian geologic period. These aquatic creatures dominate and have evolved adaptations to the world's oceans, lakes, rivers, and streams—from the hottest to the coldest and from the saltiest to the freshest.
- ◆ In adapting to the physical limits of these habitats, fishes have shaped the basic body plans and physiologies that have evolved into modern fishes.

DID YOU KNOW?

Water is really heavy! Pick up a gallon of water and then imagine the weight of millions of gallons of water in lakes, rivers, waterfalls, or oceans.



- ◆ Water is about 800 times denser than air. As one swims deeper, the pressure against the body increases; for fishes swimming at depths of 2000 feet or more, it can be more than 100 times greater than at the surface. The advantage of this environment is the near-weightlessness characteristic of the environment for fish and even scuba-diving humans swimming through it.
- ◆ This characteristic of an upward force pushing against an object in the water is called buoyancy. Fish achieve buoyancy through several different adaptations:
 - Their bodies are streamlined for movement through their dense watery environment.
 - They can choose to move up or down in the water column just by adding or subtracting air from their swim bladder.
 - The shapes of their fins and tails allow them to move quickly forward or at an angle by using body and tail motion for acceleration and fins as rudders or brakes.
- ◆ Almost all fish have gills for gas exchange. Gills are respiratory organs that many water-dwelling animals have and that contribute to gas exchange in a water environment. We see them in fishes, some water-dwelling invertebrates, amphibians, and even other animals as they develop.
- ◆ Terrestrial creatures that have gills, such as hermit crabs, have needed to develop adaptations to keep their gills moist so that they can successfully respire while on land. Fishes have not needed that trait because they live in water.
- ◆ Fish such as mudskippers, which spend part of their time out of water, have evolved moisture-retaining chambers around their gills that are remarkably similar to the chambers in land crabs.
- ◆ Fishes have gills that are the most efficient respiratory organs in the animal kingdom, with the ability to absorb oxygen from a viscous medium—water—that has less than 1/20 the amount of oxygen as air.

Oxygen has a rate of diffusion into bodily tissues that is thousands of times higher in air than in water.

- ◆ Fishes have excellent visual and olfactory senses, including a lateral line system that is sensitive to water currents and vibrations. The lateral line along the sides of fishes is a sensory organ that helps them feel vibrations and other movement in the surrounding water.

Sharks

- ◆ Sharks, and their relatives the skates and rays, make up about 940 species of fishes that have skeletons made of cartilage. These wondrously adapted creatures evolved before the dinosaurs and have remained almost unchanged since then.
- ◆ Although it looks fearsome, with the pointy snout and small eyes, the body shape of the shark is a streamlined form that is an adaptation for moving through the water quickly. Many sharks have a more streamlined spindle shape or torpedo shape.
- ◆ Sharks have paired pectoral and pelvic fins, and dorsal fins, which help with turning ability and stability in the water. They have an asymmetrical, or heterocercal, tail, which sweeps back and forth to provide forward thrust and uplift when needed.
- ◆ Sharks have paired nostrils on their snouts, or rostrums,

DID YOU KNOW?

There are a few species of sharks that are dangerous to humans, but you have a greater chance of being killed by lightning or a bee sting than by a shark.



which contribute to olfactory sensory abilities of these creatures. Dissolved chemicals in the water are picked up by neuro-receptory cells in the inside of the nares, and olfactory signals are sent from there to the brain.

- ◆ The tough skin is covered with dermal placoid scales, which reduce the turbulence of water flowing along the body while the creature is swimming. These scales, called denticles, are shaped like backward-pointing teeth and are different from other kinds of scales that provide protection. Although they come in different shapes, scales are most often arranged on the body to provide overlap from the head to the tail.
- ◆ Sharks are not as fecund as bony fishes, such as cod, which produce millions of eggs at a time. And their young take a long time to reach sexual maturity. This contributes to their inability to rebound from overharvest for human food.

Rays

- ◆ Rays make up half of all species in this group of cartilaginous creatures. They are specialized for swimming along the bottom of the ocean or, for freshwater rays, rivers.
- ◆ All rays have bodies that are dorsoventrally flattened, and their pectoral fins have been greatly enlarged to act as underwater wings that, when undulating, propel the body forward.
- ◆ Amazonian river stingrays are the only rays known to permanently dwell in freshwater. These freshwater river rays have lost any ability to migrate between freshwater and their ancestral marine environments due to a highly refined osmoregulatory system that allows them to survive in freshwater.
- ◆ Other sharks and rays have evolved physiological adaptations that allow them to osmoregulate in salt water. Instead of actively pumping

minerals and salts out of their bodies as ocean-dwelling bony fishes do, the ocean-dwelling rays and sharks have evolved to regulate their internal salt concentrations to be the same as the salt concentrations in the water environment outside the body. They do this by maintaining adequate concentrations of the enzymes and organic solutes within their bodies in the presence of salty body fluids.

- ◆ Amazonian rays live in freshwater rivers, so they have problems opposite those of their marine relatives. Instead of losing water to an external saltwater environment, freshwater rays have to worry about gaining water because their internal body salt concentrations are higher than the salt concentration of freshwater. The water in which they live has very low salt concentrations, and water will seek to equalize salt concentrations across cell barriers.



DID YOU KNOW?

Ocean waters are usually saltier than the blood of most fishes.



- ◆ One result of the diminished need for salt excretion is that the freshwater river stingrays of the Amazon basin no longer have a need for the rectal salt-excreting glands found in saltwater rays that eliminate excess body salts. So, in Amazon rays, these structures are vestigial—that is, the organs are reduced in size and are also no longer capable of secreting salts from the body system.
- ◆ Amazonian rays have been isolated from salt water for so long that they have also lost the ability to retain urea salt. This adaptation requires the Amazonian rays to sever ties with their ancestral ocean environment, so they are freshwater rays in our modern era.
- ◆ Freshwater and ocean rays all have 2 rows of 5 gill slits on the bottom, or ventral, side of their bodies. They also have 2 modified gill slits located behind the eyes on the upper, or dorsal, side of their body called spiracles.
- ◆ Because the ray's mouth is often at or below mud level, water enters through the spiracles on the dorsal surface, and this prevents the gills from being clogged with silt, something that is important for efficient respiration. This anatomical adaptation allows rays to breathe more easily while they are hiding in the sand and mud.
- ◆ The rays have long, whiplike tails that are armed with one or more spines, and these spines have venom glands at their base. The spines can seriously wound or even kill a predator or human.

Fish Conservation

- ◆ The U.S. Fish and Wildlife Service estimated fishing in the United States to be worth more than \$3.6 billion per year, or \$10 million per day. Climate change may affect these fisheries in negative ways, despite the historic and current efforts of licensed fisherpeople and other conservationists who help protect these fish and their habitats.
- ◆ Keeping ornamental fishes in home aquariums is one of the most popular hobbies in the world. More than 1500 fish species are kept in aquariums, and this hobby industry is valued at more than \$1 billion per year, with fish imports about \$300 million of that. This level of trade could be unsustainable, but fish conservationists have worked to make it sustainable.
- ◆ Biologists at New England Aquarium have worked since 1991 on Project Piaba, a program that works with local fisherpeople in the Rio Negro region of the Amazon to protect tropical ornamental fish and pristine tropical forests.
- ◆ Fisherpeople in the Amazon rely on collecting millions of cardinal tetras and other ornamental fish from pristine forest waters to sustain their local economy; to keep river waters clean for this economic activity, the fisherpeople also need to help protect their local tropical forests from development and overcutting.

DID YOU KNOW?

The opah—the world’s first-known warm-blooded fish—lives 150 to 600 feet below the surface of the ocean, where the water is about 50° Fahrenheit. Unlike most fish, which are the temperature of the water they swim in, the opah can be 20° Fahrenheit warmer than the surrounding water.



- ◆ Catching thousands of tetras for export is both ecologically and economically sustainable, because it saves fish that would otherwise die during the dry season. These fisherpeople of the Amazon protect the local rainforest, take large numbers of fish in a sustainable way, and help sustain their local economy.

Suggested Reading

Hastings, Walker, and Galland, *Fishes*.

Klimley, *The Biology of Sharks and Rays*.

Project Piaba, <http://projectpiaba.org/>.

Stokstad, "Scientists Discover First Warm-Bodied Fish."



Lecture 9

Amphibians, Metamorphosis, and Ecology

This lecture will explore amphibian biology and adaptations. You will learn about such topics as amphibian diversity, frog and salamander body shapes, what different amphibians eat, and how we can help amphibians thrive on our planet. Amphibians are an ancient group, older than the dinosaurs; they were the earliest land-dwelling vertebrates, first invading this alien environment about 375 million years ago. Their fossils have been found on every continent, including Antarctica.

Amphibians

- ◆ The age of amphibians began when lobe-finned fish ancestors crawled up out of the water and started leading their double lives in water and on land, a lifestyle that has survived robustly into our modern times. Large amphibians were most abundant about 350 million years ago. They grew to up to 12 feet long and had huge jaws lined with rows of sharp teeth.
- ◆ In our modern world, amphibians are still found in diverse environments, from the moist tropics through dry deserts to cold areas of the northern forest, although they all need some kind of dampness to maintain their moist skins. The only continent the world's amphibians don't live on today is Antarctica, which has been frozen for about 15 million years.
- ◆ Amphibians begin life in eggs that are typically deposited in water in large groups called egg masses. The freshwater bodies where the eggs are laid are often those that are most likely to be predator-free: ephemeral pools that are dry most of the year but are formed



by spring rains, or maybe the shallowest parts of a pond where predators cannot move easily.

- ◆ The eggs are externally fertilized as they are laid and may form large clumps, as in frog egg masses, or long strings, as in toad egg masses.
- ◆ The amphibian embryo develops inside the egg into the tadpole stage. The fishlike tadpoles have no legs after hatching and have gills for absorbing oxygen from the water as well as strong tail fins to help them swim fast and avoid underwater predators.

- ◆ In these early developmental stages, frog and toad tadpoles have what looks like an enlarged head on the fishlike tail. The head will grow into the body and head of the adult, while the tail will be lost. Salamander tadpoles look more like fish in their more streamlined shape, and all salamanders keep their tails as adults.
- ◆ Tadpoles mostly eat algae and sometimes very small, slow, water-dwelling creatures. Tadpoles of salamanders and large frogs may also eat crustaceans and even one another, especially as their mouths get wider as they grow.
- ◆ When they have eaten enough and reach a particular size, tadpole shape and even body parts begin to change. This biological process is called metamorphosis. Tadpoles develop their external hind legs first, while the front legs are forming behind the head but hidden

DID YOU KNOW?

You should always wash your hands after touching animals as a matter of good hygiene; this is especially true for amphibians, because they might have toxins or bacteria on the surface of their skin.



under the skin. As the tadpole changes, its eyes bulge more, it loses its gills, and it begins to look more like an adult.

- ◆ As the growing amphibian becomes ready to live on land, it begins to look a lot less like a fish and more like an adult of its species. Adult amphibians have wider mouths and bigger tongues. They are more carnivorous and eat insects, worms, and other food. The adult amphibian's mouth and diet, head and body shape, way of breathing, and behavior have all changed through the extraordinary biological process of metamorphosis.
- ◆ Nearly 90% of the world's almost-7000 known amphibians are frogs and toads, while only about 10% are salamanders, and less than 3% are limbless, wormlike creatures known as caecilians.
- ◆ All amphibians have a permeable skin and are different from mammals, birds, and reptiles in not having a hairy, feathery, or scaly covering over their bare, moist skin and in needing a damp or watery environment for their eggs and tadpoles.

Salamanders

- ◆ Salamanders have long tails and short legs and look a bit like lizards but have moist rather than scaly skin. The United States has the greatest diversity of salamanders in the world, concentrated in the Appalachian Mountain and West Coast moist habitats.
- ◆ These creatures are difficult to find, even when numerous. They are active mostly at night or during dark, rainy days and are fond of damp, darkened hiding places in leaf litter, under logs, and between rocks.
- ◆ Salamanders are very diverse. They can be anywhere from as large as the 6-foot giant Chinese salamander or as small as the 1-inch seep salamander. They also can be fully aquatic, such as the hellbender



and other giant salamanders, or they can be pretty terrestrial and live their lives fully on land or both on the land and in the water.

- ◆ Some salamanders lay their eggs in the water, and they will hatch into larvae which then will metamorphose into adult salamanders on land. Some salamanders will lay their eggs on land, and they will keep them moist and wrap around them until they hatch into salamanders.
- ◆ In some deciduous forests, there are so many red-backed salamanders that their biomass outweighs other vertebrates. Salamanders play a vital role in our ecosystem. They are so abundant and so long lived, and they contribute energy up the food chain. They eat decomposers on the forest floor and pass that energy up the chain.
- ◆ Salamanders can breathe in 3 different ways.
 1. Some salamanders are paedomorphic, which means that they retain their juvenile characteristics, their gills, which they have as

larva. For example, the mudpuppy retains its gills and breathes through those as an adult.

2. Some salamanders, such as the hellbender, have lungs but don't use them to breathe. They respire through their highly specialized skin and use their lungs for buoyancy in the water. Hellbenders have folds down their sides to increase the surface area for oxygen absorption.
 3. There is a group of terrestrial salamanders that are called lungless salamanders that breathe fully through their skin and the tissue in their mouths.
- ◆ All salamanders have to have a moist environment because they don't have watertight skin. Because they have highly specialized skin, they can be considered environmental indicators. Their skin is very sensitive, and they will respond quickly to environmental change, so they're a good species to look at to determine ecosystem health.
 - ◆ In Smithsonian's National Zoo, researchers in the Appalachian salamander lab study salamanders and how they're affected by their environment. They study how temperature changes affect the stress levels and immune response of hellbenders in particular, but they also study red-backed salamanders, one of the most common salamanders in the world.
 - ◆ The biggest threat to salamanders, much like many other species, is habitat destruction. This affects salamanders both in aquatic and terrestrial habitats, because decreased forested area increases runoff, which increases siltation in the water. The siltation settles on the eggs and stops them from developing.

Frogs and Toads

- ◆ Frogs and toads are the noisy members of the amphibian group, and along with birds and a few mammals, they are the only vertebrates we know of that use mating vocalizations.



DID YOU KNOW?

Jim Henson's Kermit the Frog was so famous as a TV and movie star that he now lives at Smithsonian's National Museum of American History (and has for more than 20 years).

- ◆ Different frogs have different songs, chirps, and croaks. A citizen science project called FrogWatch USA trains students, backyard scientists, and others to listen for different songs and identify frogs in their area. These citizen scientists are building a better database of where frogs range.
- ◆ Scientifically, there is no true distinction between frogs and toads. Both belong to the order Anura. Beneath that taxonomic level, there is a family of so-called true toads, the Bufonidae, but when it comes to species names, many of the creatures we call toads

are technically frogs, and many of the creatures we call frogs are technically toads. Really, it's a distinction in nomenclature without a difference in biology.

- ◆ That said, there are some physical characteristics that generally belong to things called frogs and other characteristics that belong to things called toads.
- ◆ Both frogs and toads are amphibians without tails. The bulging eyes and nostrils of frogs are on the tops of their heads, enabling these creatures to breathe and see while they are hidden in the water or in plants. Frogs will be found in or near water, unlike the land-loving toads. Frogs will have smoother skin than toads, which have bumpier skin.
- ◆ Behaviorally, frogs are more timid than toads and will jump away if startled, while a toad may just sit still. Frogs normally have larger, more muscular legs adapted for big jumps and feet for strong swimming, while toads have relatively shorter legs designed for short-hopping.
- ◆ In the hundreds of different body forms toads and frogs have evolved for swimming, jumping, hopping, burrowing, and climbing, it is not always possible to label a "frog" or a "toad" in any place in the world. But in the United States, these generalizations will often help you determine which is which.

DID YOU KNOW?

Scientists have estimated that a toad can eat 200 bugs in a single evening. This is amazing because a toad has a short tongue and needs to walk up to its prey to get it into its mouth.



- ◆ Jumping is a great defense for amphibians that blend in with their environments but taste good. Another good defense is to be active at night so that it is more difficult for predators to find them. On the other hand, poison dart frogs of the tropics are colorful, move slowly, and are active during the daytime, so skin toxins are perfect for frogs with this warning coloration and behavioral adaptations.
- ◆ Toads also produce toxins through the warty-looking bumps on their skin, and these glands—especially the ones near a toad’s eyes or ears—produce repelling or poisonous substances that protect them from predators, so toads don’t need to jump quickly out of the way. If a predator even licks a poison dart frog or toad glands, it can get very sick, be paralyzed, or even die.
- ◆ Frogs have long, sticky tongues that they shoot rapidly at their prey. Frog tongues are attached at the backs of their mouths, rather than at the front, as human tongues are. The frogs flip their sticky tongues out, and the sticky ends grab onto the prey insect.
- ◆ When a frog or toad has an insect in its mouth, there is the action of swallowing it. Both creatures have bulging eyes, and when they blink during eating, they push their eyes backward toward their mouths and their eyes help push the food down into the creatures’ throats.
- ◆ Despite their amazing adaptations, amphibians are in trouble around the world. At least 30% of all amphibians are considered threatened by human-caused threats as diverse as habitat loss, pollution, overexploitation, introduced species, climate change, and disease. Since 1980, scientists think that more than 120 species of amphibians have gone extinct.
- ◆ We also believe that amphibians are sensitive bioindicators for ecological threats and can help humans identify environmental threats early for 3 reasons: Amphibians’ permeable skin absorbs toxic chemicals and therefore reflects toxicity in their environments, amphibian species are exposed to double jeopardy from environmental stressors because they live both in water and on land,

and amphibians' jelly-coated eggs don't have much protection from the environment.

The Importance of Amphibians

- ◆ There are human cultural reasons we care about frogs and their relatives. Ever since our ancestors became truly human, frogs have been ubiquitous symbols of rebirth for humans. They are symbols for rain and symbols for life in many cultures.
- ◆ In addition, we use frogs for our own benefits. The world's humans eat almost 80,000 tons of frog legs each year. Each year, we buy millions of frogs and salamanders as pets and use millions of frogs in medical research and testing programs.
- ◆ Furthermore, amphibians provide ecological and economic services to the world. Adult amphibians eat mosquitoes and other invertebrates, which helps control small disease-carrying pests around human populations.
- ◆ Amphibians play a crucial role in the food web, especially as predators and as prey for other animals, and loss of amphibians would result in disastrous ecosystem-wide effects in terrestrial and aquatic environments.
- ◆ Find out about amphibian conservation activities in your area. Engage with a local FrogWatch chapter, participate

DID YOU KNOW?

A population of 1000 tiny tree frogs, each about 1 inch long, consumes an estimated 5 million mosquitoes, gnats, and other pesky creatures every year.



with iNaturalist or your local zoo or aquarium in recording the amphibians in your area, or help organizations such as Smithsonian and Amphibian Ark that are helping save amphibians for future generations.

Suggested Reading

Christian-Albrechts-Universitaet zu Kiel, "Frog Tongues."
O'Shea, Halliday, and Dickey, *Reptiles and Amphibians*.

Reptiles: Adaptations for Living on Land

Many people fear reptiles. They look primitive and are extremely different from humans. Furthermore, people are attacked by crocodiles and gators. But most reptiles are harmless to humans—if you leave them alone. This lecture will explore adaptations of reptiles. It will cover topics including the evolution of water-retaining eggs and sensory adaptations, the role of reptiles in our environment, and how we can help reptiles thrive on our planet.

Reptiles

- ◆ Among the vertebrates, there are about 30,000 species of fish, almost 7000 species of amphibians, about 10,000 species of birds, and about 10,000 species of reptiles. The reptiles have adapted to life on land by enclosing the watery environment that gives life with a water-retaining egg and a watertight skin.
- ◆ The reptile group includes turtles, lizards, and snakes, which make up the order Squamata; the New Zealand reptiles known as Tuatara; and the big reptilian predators of the order Crocodylia. These animals combine primitive, advanced, generalized, and specialized adaptations for life on Earth.
- ◆ Zoologists often group the reptiles with birds because of cladistics, in which we group various taxa by common evolutionary descent rather than separating them by differences. Crocodylians and birds are grouped into the Archosaur clade based on several derived characteristics. They are more closely related to each other than either crocodylians or birds is related to other reptiles.



Tuatara

- ◆ The Archosaurs includes the dinosaurs. Dinosaurs are more closely related to birds and crocodilians than they are to any other living reptiles. The sister clade of the Archosaurs is the Lepidosauria, which is where we find the lizards, snakes, and turtles. The 2 clades—Archosaurs and Lepidosauria—are also descended from a common ancestor, so together they form the group Reptalia.
- ◆ The result is that we now use the term “non-avian reptiles” to refer to the living turtles, lizards, snakes, tuataras, and crocodilians, along with extinct dinosaurs.
- ◆ Birds and non-avian reptiles both share a single middle ear bone. Compare that to mammals, which have 3. Both have a lower jaw consisting of 5 or 6 bones; the jaw of a mammal has 1 bone. Both birds and non-avian reptiles lay large, yolked eggs.
- ◆ Crocodiles and birds have 2 features that are not in other reptiles. They have a bony eye socket, called an orbit, that is shaped like an inverted triangle, and they both have muscular gizzards as part of their digestive tracts.
- ◆ Unlike bird eggs, which are always hard-shelled, non-avian reptiles’ eggs may be hard-shelled or soft-shelled and leathery. Hard, mineralized shells provide mechanical support and limit water loss while allowing passage of gases. Both mineralized and leathery eggs serve to keep the embryo moist during development, an adaptation for life on land.
- ◆ Alligators, turtles, and some snakes and lizards lay their eggs in nests. This is called oviparous reproduction. But because sperm cannot penetrate the eggshell, reptiles must reproduce by internal fertilization.
- ◆ That said, many lizards and snakes lack shelled eggs, because they are viviparous, which means that they give live birth. Viviparous reproduction provides greater protection for the embryo from predators and dehydration. It is common for reptiles that live in

colder environments or environments with warm seasons that are too short for optimal development of eggs. Live-bearing reptiles include North American garter snakes, northern water snakes, and timber rattlesnakes, all of which may be found as far north as New England and Canada.

Reptilian Reproductive Adaptations

- ◆ There are 3 fascinating things about reptilian reproductive adaptations: sperm storage, parthenogenesis, and temperature-dependent sex determination.
- ◆ First is sperm storage. Many female reptiles, like the amphibians that evolved before them, are able to mate at one time and fertilize eggs at another. This trait is considered a symplesiomorphy—that is, a shared ancestral trait that is not indicative of current close taxonomic relationship.
- ◆ Specialized tubules for sperm storage evolved independently in turtles, lizards, and snakes. In most turtles, the tubules are in the oviduct, at the end farthest from the ovary. The tubules are basically glands that also secrete albumen.
- ◆ In some turtles, the tubules are in the uterus instead. In iguanid lizards, the sperm storage tubules are vaginal, and they do not secrete albumin. In the primitive tuataras and in the crocodylians, sperm storage is poorly studied, so we don't know if or where they exist.
- ◆ No matter where it occurs, long-term sperm storage is an adaptation that allows reptiles to delay fertilization and hatching until better conditions are available for laying and hatching eggs.
- ◆ The second reptilian reproductive adaptation is parthenogenesis, which is basically asexual reproduction. Whiptail lizards are parthenogenetic. A female can lay viable eggs without fertilization—



without a male. These babies are basically little female clones of the mother.

- ◆ The advantage of parthenogenesis is that you can reproduce and quickly colonize an area. You can increase your population size much quicker than with sexual reproduction because you don't have to find a male. The disadvantage is that you have very little genetic variability, which means that you're not able to adapt to a changing environment via natural selection. Environments are constantly changing, and this makes these populations very susceptible.
- ◆ The third interesting thing about reptile reproduction is temperature-dependent sex determination (TSD). In short, the sex of many reptiles is determined by the ambient temperature of the nest.
- ◆ This phenomenon was first described in agamid lizards in the 1960s by French zoologist Madeleine Charnier, but it takes place in a number of other reptiles, and each species responds differently to these temperature changes.



- ◆ In many turtle species, eggs from warmer nests result in all-female hatchlings while eggs from cooler nests result in all-male hatchlings. Some crocodylian species show TSD that is just the opposite: Low nest temperatures less than 30° Celsius produce only females while high nest temperatures above 34° Celsius produce only males. In the American alligator, the low and high temperatures result in female hatchlings while intermediate temperatures produce all males.
- ◆ Not all reptiles are affected by TSD. Zoologists suggest that there are 2 types of sex determination in the reptile group: TSD and genotypic sex determination (GSD). TSD occurs during a critical period of incubation called the thermosensitive period. This critical period occurs after the egg has been laid. In GSD, sex determination occurs at fertilization.
- ◆ TSD and GSD are not mutually exclusive. Zoologists have shown temperature reversal of genetically determined sex. These studies suggest that some reptiles may show transitional evolutionary states between complete GSD and complete TSD.

Reptilian Characteristics

- ◆ One of the most noticeable differences between amphibians and reptiles is the skin. Reptiles have dry skin, unlike the moist skin of amphibians that makes them vulnerable to dehydration on dry land. A shift away from the amphibian skin's respiratory function is associated with changes in skin morphology.
- ◆ Unlike the bony, dermally derived scales we find in fishes, reptile scales are made of keratin from the epidermis. The epidermal hard form of keratin in reptile skin not only makes the skin watertight, but it also provides protection against wear and tear in the terrestrial environment.
- ◆ Different types of reptiles have different types of scales. Turtles have platelike scutes that develop new layers of keratin as they wear down. In crocodiles and alligators, scales remain in place and grow gradually throughout life to repair the wear. Lizards and snakes have famously evolved a shedding interval: New keratinized epidermis grows beneath the old outer scale layer, and then the old is shed.
- ◆ The skin and eyes of these creatures have chromatophores, color-bearing cells that give them their amazing colors. These skins are prized by humans for alligator and snakeskin leathers, which are then made into handbags and shoes, sometimes causing conservation threats for the desirable species.

DID YOU KNOW?

Reptiles have stronger jaws than fish and amphibians.



- ◆ Turtles and tortoises have bony jaws covered with keratin, and they have no teeth. The jaws are strong enough to grab and tear at plant material, and the tongue is muscular and can help move food around. These adaptations evolved as a response to their herbivorous dietary niche.
- ◆ In most reptiles, bony joints allow the snout and upper jaw to move on the rest of the skull. Even the snout bones can be raised to open the mouth wide or lowered to maximize bite force between the jaws. Various jaw adaptations have allowed the thousands of reptile species to adapt to different diets, including the mostly vegetarian diets of turtles and tortoises and the live-prey diets of snakes and crocs.
- ◆ Just as turtles and lizards adapted to herbivorous, omnivorous, and carnivorous lifestyles, all snakes evolved to become carnivores. The snakes include nonvenomous as well as venomous species, depending on their prey and ecological niche.
- ◆ Some crocodiles grow to hundreds of pounds and are known to attack large mammals, such as deer, antelope, cattle, and even people.

DID YOU KNOW?

The common garter snake of North America is a harmless nonvenomous snake that eats slugs, earthworms, tadpoles, and other small creatures. Because of this, it has a relatively small mouth and small teeth that are adapted to manipulating its small prey.

Meanwhile, nonvenomous Old World pythons and New World boas can eat large vertebrate animals such as deer because of their large size and ability to disarticulate and rearticulate their jaws.

Rattlesnakes and their pit viper relatives are venomous and kill rodents for food, which they do not chew. They simply swallow them whole.



- ◆ Many turtles live for 50 to 60 years, with one box turtle aged 124 years and a giant tortoise documented to reach an age of 152 years. Well-documented ages for alligators are in the 50- to 65-year range, and some species have been documented living into their 80s in captivity. There are lizards like Gila monsters that have lived 25 to 30 years. Many snakes live 10 to 25 years, and one boa constrictor in a zoo had a documented age of 40 years.
- ◆ The adaptations that allow these reptiles to survive to such an old age include water-conserving nitrogen excretion; rib ventilation of the lungs in crocodilians, lizards, and snakes; higher-pressure cardiovascular systems; and an expanded brain and sensory organs.
- ◆ Almost all reptiles have very good eyesight, olfactory senses, and ability to hear. Even the snakes, although very quiet and without external ears, can actually hear. Studies have shown that pythons can detect airborne sounds between 80 and 160 hertz, apparently because of vibration in their skull bones.
- ◆ Crocodilians, unlike snakes but like their relatives the birds, have external ears. Baby crocodilians chirp to their doting mothers from



inside their eggs, and they also vocalize after they have hatched. Male alligators bellow loudly during the breeding season.

- ◆ Unlike most other non-avian reptiles, crocodylians provide extensive maternal care. The mother can hear the vocalizations from her hatching young and opens the nest to allow the hatchlings to emerge easily. She then guards her young for up to 2 years after hatching.
- ◆ Although many reptilian species have survived unchanged for millions of years, growing human populations, habitat conversion for human use, and climate change have all contributed to declining reptile populations around the world. Not much is known about the status of reptiles globally, though.
- ◆ Among the 10,000 or so species of non-avian reptiles, fewer than 1400 have been evaluated by the International Union for Conservation of Nature. But 35% of reptile species worldwide that have been evaluated are considered threatened or endangered.

DID YOU KNOW?

In the genus Cuora—of which the Asian box turtle is a part—there are 12 species of semiaquatic box turtles, and 11 of those are critically endangered. They were once, and still are, very coveted in the pet trade because they are so beautiful and long lived.



How to Help Reptiles Survive

- ◆ Don't buy reptile skin products when you travel internationally, because many of those products are from unknown or endangered species.

- ◆ Don't buy reptiles as pets, because the ongoing trade has a huge impact on the wild populations of these creatures.
- ◆ Support legislation that protects reptile habitat, even if it means humans will have fewer roads or housing developments.
- ◆ The future of reptiles may help determine the future of mankind because these wonderful animals occupy so many important habitats.

Suggested Reading

Orenstein, *Turtles, Tortoises and Terrapins*.

O'Shea, Halliday, and Dickey. *Reptiles and Amphibians*

Pickrell, *Flying Dinosaurs*.

Quinn, "How Is the Gender of Some Reptiles Determined by Temperature?"



Lecture 11

Beaks, Claws, and Eating like a Bird

Birds are the only animals on Earth with feathers, which is what makes them birds. The variety of birds, from the world's tiniest bird—the bee hummingbird, weighing just 1/15 of an ounce—to the largest bird on Earth—the ostrich, weighing up to 350 pounds—is truly amazing. This lecture will dive into the science of ornithology, the study of birds, by exploring bird feeding adaptations. The lecture will cover bird beaks, what different birds eat, and how we can help birds thrive on our planet.

Waterfowl

- ◆ One of the most amazing adaptations of a bird is the bill, or beak. Bird bills evolved more than 85 million years ago, resulting in the wide variety of shapes seen today. The many bill shapes are adaptations to the many habitats birds live in and niches in which they feed.
- ◆ Despite their huge diversity of shapes, lengths, and even color, all beaks have an underlying bony structure consisting of an upper and lower mandible. These bony structures are covered by keratin derived from epidermal cells to form the fine structure of the beak.
- ◆ There are holes somewhere in the beak structure, usually at the base, and these external nares connect to the respiratory system. These structures first evolved in the dinosaur ancestors of birds more than 140 million years ago, and since then, there has been an incredible radiation into modern beak forms over 85 million years.
- ◆ The spatula-shaped beaks of ducks and geese help them eat vegetation and small

DID YOU KNOW?

There are about 50 million active birders in the United States and many more around the world. Watching birds in individual backyards is one of the most popular kinds of birding.

If you want to set up your own bird-watching location, a simple way is to establish a bird feeder where you can watch it. Make your bird feeder and birdbath locations either less than 3 feet or more than 30 feet from windows to reduce window strikes. Then, simply get out your binoculars and your bird-identification app!



invertebrates. Inside these beaks are small, toothpick-like projections called lamellae, which act like strainers that filter out mud, water, and other underwater stuff the duck doesn't want to eat. These strainers are very necessary because waterfowl and other birds do not chew their food, and the lamellae can help them keep small plants, seeds, and bugs in their beaks to swallow.

- ◆ Some waterfowl, such as mallards, are adapted for dabbling-style feeding. They just tip their tails up and heads down and feed near the bottom in the shallows. Their bills are rounded, with a little hook on the end that they use to move unwanted items aside.
- ◆ Other ducks, such as the colorful North American wood ducks, have different-shaped bills that are adapted for feeding on acorns and other tree nuts that are common in the flooded woodlands where they live.
- ◆ Geese and swans have long necks and can feed in deeper water, often on grasses of river bottoms.

DID YOU KNOW?

Like ducks and geese, flamingoes are filter feeders. They feed with their heads down and beaks upside-down in the water, so, unlike beaks in other birds, the lower flamingo bill is the larger one, and the upper bill is the smaller part of the beak structure.



- ◆ Diving ducks, such as the mergansers, have streamlined bodies, and their feet are set far back to make for easy swimming underwater. Their narrow beaks are designed to grab small fish.
- ◆ All of these bird beaks are amazing adaptations for specialized feeding in watery niches.

Birds of Prey

- ◆ All birds of prey—collectively called raptors—have powerful, strongly hooked beaks for ripping and tearing meat in a predatory niche. Hawks, eagles, falcons, and owls fall into this group. Their beaks are sized relative to their body and also have diet-adapted shapes.
- ◆ Most raptors have sharp talons, or claws, that are used to grip and kill prey. Raptors use their sharp beaks to cut meat into pieces that are easy to swallow. Different species of raptors eat different prey. However,

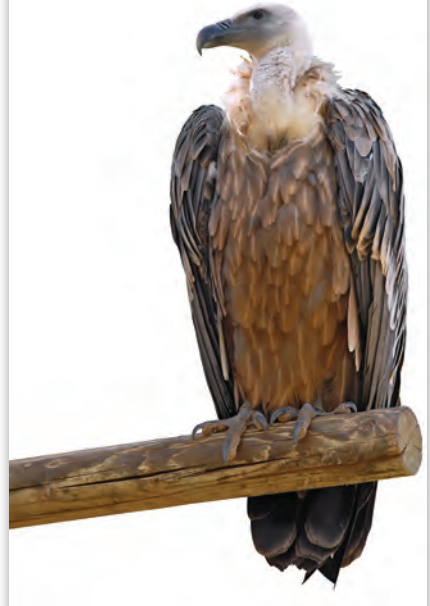


they all help humans by eating animals that we consider to be pests.

- ◆ The supreme owl in North America, the great horned owl, has an incredible grip. Owl talons are amazingly strong, as are the beaks of vultures.
- ◆ Vultures are supreme cleaners of our environment. Turkey vultures, black vultures, and the largest of vultures—indeed, the largest of all raptors—condors, will consume carcasses as large as big deer until there is nothing left. In some instances, they'll even consume the bones.
- ◆ Raptors are at the top of the food chain, having evolved into a niche available for carnivorous flying hunters. They have evolved these amazing adaptations of gripping talons and tearing beaks because of the advantage they confer for hunting.

DID YOU KNOW?

Vultures have bare heads to keep their feathers clean while they are plunging into a body cavity, going after the guts and bones they thrive on.



Seed-Eating Birds

- ◆ Some of the birds we observe around backyard birdfeeders have much subtler but still amazing adaptations to take advantage of the

Crossbill



food sources in their particular niche. Seed eaters, for example, have tiny beaks that act like nutcrackers.

- ◆ Different beaks are shaped for different seeds. For example, goldfinches are specialized to reach the smallest of seeds from teasels and thistles. They can do so without poking their eyes with the sharp, protective projections on these plants. Large finches and cardinals eat larger seeds from different plants within the same regional environments.
- ◆ Crossbills have crossed bills that allow them to pry open pinecones to get to the nutritious nuts that lie within.
- ◆ Small seed-eating birds have feet that allow the birds to perch atop tiny branches of the plants where they find their food. And some feet, such as the feet of a nuthatch, allow birds to walk straight up and down tree trunks to get to the seeds and insects they want to eat.

Nectar-Eating Birds

- ◆ Of all birds, parrots have some of the most dynamic beaks. Within their large beaks are mobile tongues which help parrots manipulate their food. Some birds in the parrot family, such as the lorikeets and lories of the Australasia region, have brush-tipped tongues that help them drink nectar and eat soft, juicy fruits. Other parrots and their macaw relatives use their huge hooked beaks like nutcrackers to open varieties of tree nuts. And their large, muscular tongue helps some species of parrots mimic human speech and other sounds.
- ◆ Robins use their ears to listen for worm sounds and their eyes to look for worm movement. A robin may cock its head to get a better focus on the worm before it makes a final grab. They often catch worms early in the morning and eat fruits later in the afternoon.
- ◆ Hummingbirds have long beaks like straws, with a long tongue to gather nectar from different flowers. There are more than 300 species of hummingbirds in the Americas—and only in the Americas.

A photograph showing several lorikeets perched on a dark, textured tree branch. The birds are brightly colored with blue heads, red chests, and green wings. The background is a soft-focus green, suggesting a lush forest environment. A small white box with a blue border is positioned in the lower-left corner of the image, containing the word 'Lorikeet' in blue text.

Lorikeet

- ◆ In the Old World, sunbirds look similar to hummingbirds, but the 2 groups are not related. There are about 100 species of sunbirds.
- ◆ Different species of nectar-eating birds take their nectar from different flowers and in different ways. Some species have long, specialized bills that reach way down into a flower's nectary, while others have short, pointy bills that they stab into the base of the flower.
- ◆ Sunbirds need to perch to get their sweet food, while the hummingbirds can hover at their preferred flowers to get all the nectar they need. They can tell how much nectar is in each flower and in each patch of flowers, and when the nectar-filled flowers are depleted, they'll move along.

Insect-Eating Birds

- ◆ Fly-catching birds, such as swifts, swallows, and phoebes, have funnel-like beaks that are bordered by hairlike feathers that help guide insects into the beak funnels while flycatchers are in flight. These fly-catching birds are incredibly fast fliers so that they can chase mosquitoes and flies.



Swallow

- ◆ Each of these birds has its own insect-eating niche. Swifts fly through the air with their mouths open, hoping to catch insects that drift on air currents. Swallows fly quickly after larger prey. They expend more energy hunting this way, but eat larger insects that pack an energy-rich punch. Phoebes sit on branches waiting for insects to fly close. When they do, the birds swoop down and quickly catch their next meal. These insect eaters are small, with high metabolic rates, and need to eat early and often.
- ◆ Shrikes eat larger prey than the flycatchers eat. They also have larger beaks than the flycatchers and eat not only large insects such as locusts, but also small animals such as lizards. To eat prey of this larger size, they need to take small bites. So, they need to store the prey somewhere while they eat it. They impale their prey on a spiked object, such as a hawthorn tree thorn. As the prey item lies there dead, impaled on the thorn, the shrike sits next to it and picks it apart bite by bite.
- ◆ North America's largest woodpecker, the pileated woodpecker, makes large rectangular holes by using slow, powerful hammering strokes. Smaller woodpeckers, such as downy and hairy woodpeckers,

DID YOU KNOW?

Woodpeckers are adapted physically for all of their food-searching hammering behaviors. In fact, scientists are studying woodpeckers to develop better shock-absorbing helmets for airplane black boxes and football players.

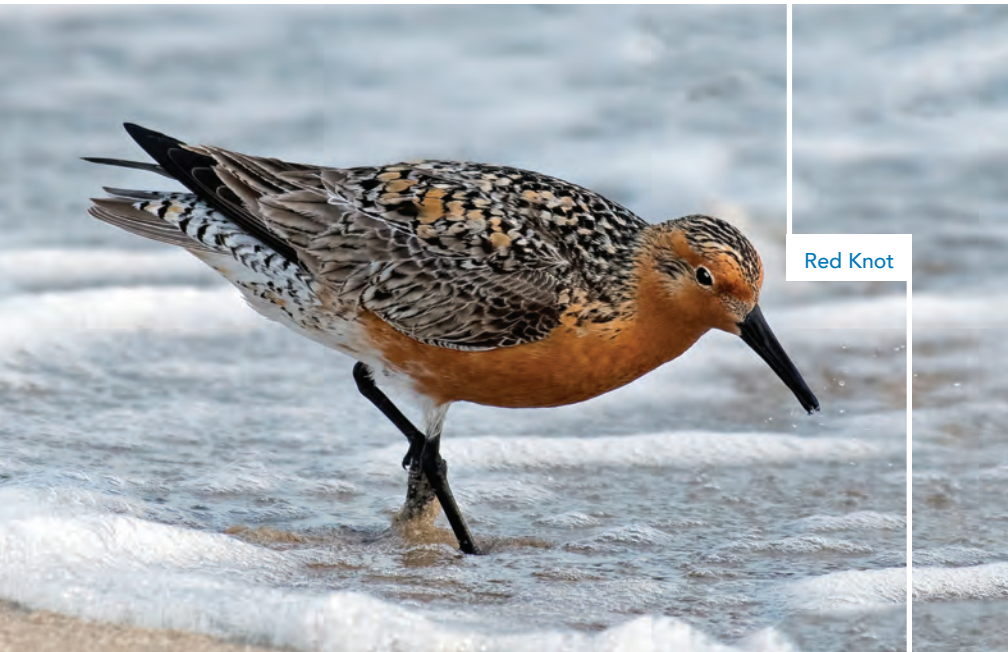


have smaller beaks, make smaller holes, and use lighter and faster tapping to make those holes. All woodpeckers are amazing chisellers, with their icepick-like beaks and hammering behavior. They chisel their holes into dead trees to get at the insects within.

- ◆ Toucans' large beaks are not heavy. Instead, the shape of the bill allows these tropical birds to reach fruits other birds can't reach. When they eat juicy fruits with those long bills, the juices don't run onto their feathers. So, their beak also helps the birds keep their feathers clean.

Shorebirds

- ◆ Although shorebirds have short bills, long bills, straight bills, and curved bills, they are all similar in their beak shapes being like tweezers. The red knot, a type of sandpiper shorebird, migrates north to the United States from as far south as Argentina, flying almost 5000 miles from there to their Arctic nesting grounds. Their migration is timed perfectly with a horseshoe crab egg-laying extravaganza on the Delaware shores each spring.



Red Knot

- ◆ Biologists are monitoring horseshoe crab populations to ensure that they remain at a sustainable level for human and shorebird use. Scientists from Smithsonian's Migratory Bird Center migrate with their teams to the Delaware Bay each spring to monitor the shorebirds migrating by catching them, weighing them early in migration and late in migration, and monitoring them all the way to their nesting grounds in the Arctic.

Fishing Birds

- ◆ Pelicans use an entirely different approach than many other fishing birds, either flying or swimming cooperatively in groups and then using their long beaks with monstrous throat pouches to catch fish prey. They then strain water from the scooped-up food before swallowing the pouch full of fish. There are 8 species of pelicans found throughout the world, and they have survived almost unchanged for 30 million years.
- ◆ Herons are iconic fishing birds, with their spear-like fishing beaks and behaviors of fishing while standing still in the trees or at the edge of ponds or other water bodies. The largest ones in North America are the great blue heron and great white egret, each standing about 3 feet tall and can stretch to 4 feet tall with a 4-foot wingspan.
- ◆ Penguins, with their waddling gait and tuxedo-like coloring, are supremely adapted to life in the cold aquatic environments of the southern seas, so much so that their fine, dense feathers cover the birds' blubber layers. They have webbed feet and small wings that act like flippers so they can swim far and swim deep. They cannot fly in the air but swim through the water at speeds up to 30 miles per hour.
- ◆ There are almost 20 species of penguins, and each has a razor-sharp beak for catching the fish it feeds on. They are exquisitely adapted to eating fish like anchovies, but humans have depleted this prey around the world. Many species of penguin are now endangered due to fish-stock depletion and habitat changes.



- ◆ We can help penguins survive by choosing sustainably harvested fish when we eat fish at home and in restaurants. Monterey Bay Aquarium has developed Seafood Watch guides and an app that we can use when buying fish. It allows us to know which fish are sustainable and which are rare and need our help in allowing their populations to rebound.
- ◆ Another fishing bird is the kingfisher. There are 90 species of kingfishers, divided into 3 main groups: river kingfishers, tree kingfishers, and water kingfishers. They are found on every continent around the world, except for Antarctica. Their colors are amazing, their voices are loud, and their shape is consistently streamlined, starting with the pointed bill they use for catching fish during a rapid dive into the water.

DID YOU KNOW?

One of the most amazing things about kingfishers is that we have used their amazing shape to reengineer high-speed trains.



Suggested Reading

Greensmith, *Birds of the World*.

Lederer, *Beaks, Bones and Bird Songs*.



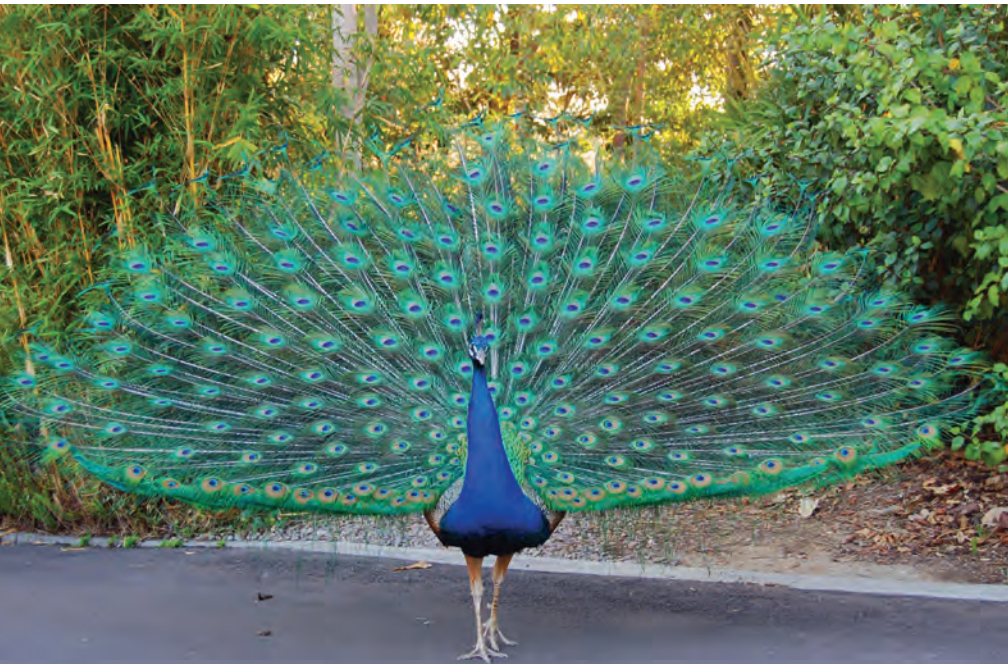
Lecture 12

Form and Function: Bird Nests and Eggs

Birds make scrape nests; rock nests; bank nests; nests made of stones, mud, sticks, and grass; nests in crevices, under waterfalls, in trees, and even underground; tiny nests; enormous nests; apartment-style nests; and well-hidden nests. With all that variation in nests, there are also variations in eggs. Bird eggs are round and white, pear-shaped and speckled, blue, red, dull, metallic, small, and huge. This lecture will explore bird breeding, nesting, and chick-raising adaptations. It will cover topics including mating behavior, nest forms, and how different chicks are built for survival.

Bird Reproduction

- ◆ Bird reproduction is as variable as the almost 10,000 species of birds are. These variations allow birds to survive in a wide variety of habitats, from the canopy of tropical rainforests to the frozen surface of Antarctica.
- ◆ The purpose of a courtship display is to attract a mate. Among birds, as in most animals, the male is the one who puts on the courtship display. That's because courtship displays require a lot of energy, and a reproducing female needs to save her energy for actually producing offspring.
- ◆ Indian peacocks display their amazing shimmering tail-eyes, and only the males have these glorious tail feathers. In addition, males have iridescent heads and necks in that striking color called peacock blue, and blue mixed with green on their breasts, bellies, and backs.



- ◆ Peacock wings are mottled black and white, and their tails combine all of these colors, along with shades of gray and brown. Females, on the other hand, are primarily gray and brown with just a touch of blue-green iridescence on their necks.

- ◆ The peacock's vibrant coloring and huge tails are costly to these birds. The tail is an impediment to flight, and their bright coloration stands out against their environment. This makes them more vulnerable to predation.

- ◆ So, how would such an adaptation survive? The answer comes from Charles Darwin, who first proposed the idea of sexual selection. By Darwin's definition, males differ in reproductive success either because of their ability to attract females or because of their ability to compete with other males for mates.

- ◆ Male peacocks are dandies, pretty boys that females love to mate with because of their long, beautiful tails. Hypotheses for the evolution of these long tails have accordingly varied from the simple idea that females prefer pretty boys to the notion that males have long tails because they are healthy, and females prefer healthy husbands. Both of these hypotheses make sense (and cannot be easily separated).

DID YOU KNOW?

Female peacocks are properly called peahens, and the gender-neutral term is "peafowl."



- ◆ The notion of female choice in reproduction is important not only for the species in the wild, but for humans working in animal breeding sciences and conservation breeding programs. If females don't have a choice, they sometimes will not mate successfully with the males that some humans select for them. Giving animals a choice of mate whenever possible is important not just for peacocks, but for any number of species.
- ◆ There are many other birds in which the male's physical appearance is much more colorful than the drab-colored female—such as northern cardinals, most species of ducks, pheasants, and robins—to increase his animal magnetism and attract a mate.

Bowers and Nests

- ◆ Sometimes, male birds rely on behavior rather than appearance to attract a mate. One of these behaviors is nest building.
- ◆ The golden bowerbird of northern Australia are small, olive-brown and golden birds who display near their bower, a decorative pile of sticks. They come in 2 forms: elaborate avenue bowers bordered by rows of twigs and maypole bowers made of stacks of twigs around a sapling.
- ◆ Males build their bowers and stay there for a mating period of several months, trying to lure multiple females. Females tend to like males that have the biggest or most elaborate bowers. Each drab-colored female will make the rounds to multiple bowers, not mating but inspecting each one over several weeks before she settles on a male.
- ◆ When she finally chooses a male, she flies to his bower, enters, and crouches down to invite the male to copulate. After the female bowerbird flies off, she doesn't see her mate again but incubates the eggs at her hidden nest and rears the chicks by herself.



DID YOU KNOW?

The golden bowerbird is the smallest of all bower-building species, yet it makes the largest bower.

- ◆ Bower quality correlates with male mating success, and it turns out that these males have fewer parasites than bowerbirds with lower-quality bowers. So, like the peacock's incredible tail, bowerbird bowers are signals of genetic quality and robust health of the male.
- ◆ Bowlers are different than nests. A bower's sole purpose is to attract a mate. A nest's purpose is to cradle the bird's eggs. The belief that birds live in nests is a myth, at least most of the time.
- ◆ A bird creates a nest solely for the purpose of laying and hatching their eggs. Many different factors help determine the type of nest a bird makes. The most obvious one is the size and number of her eggs. The vervain hummingbird of Jamaica lays an egg that is only half the diameter of a U.S. dime in a nest that is half the size of a walnut shell. The egg, weighing 0.37 grams, weighs about as much as a U.S. penny and is about 1/6 the weight of the tiny adult.

DID YOU KNOW?

Bowerbirds have unusually large brain size when compared to other birds, which may have something to do with their astounding building skills.



DID YOU KNOW?

Vervain and bee hummingbirds are the 2 smallest creatures living today in the entire bird world.



Flightless Bird Nests

- ◆ At the opposite end of the continuum, ostrich eggs are huge. They are at least 6 inches in diameter and can weigh up to 3 pounds. But they are only about 2% the size of the adult bird, making them the smallest eggs relative to adult size among almost 10,000 species of birds.
- ◆ They also have one of the simplest forms of nest: Female ostriches lay their eggs in shallow scrapes made by the adult male, and the large male can physically protect his eggs as he incubates them and also the precocial babies as they grow.
- ◆ The kiwi, which is roughly the size of a chicken, lays eggs 10 times the size of a chicken's egg. In contrast to ostriches, their close relatives, the kiwi lays one of the largest eggs in proportion to adult body size, about 1/5 to 1/4 of the female's body mass.



- ◆ Scientists in New Zealand and Australia have given us an interesting hypothesis for the huge kiwi egg: that kiwi chicks are born large and very precocial so that they are ready to outrun historical flying predators on their native islands. These chicks have a full internal yolk sac, which gives them enough nutrition to give them a good start in life until they can effectively feed for themselves several weeks after hatching.
- ◆ The kiwi is flightless, just like its big ratite cousin the ostrich. And like the ostrich, it lays its eggs on the ground—or, more accurately, in the ground. Kiwis dig a large enough hole to fit themselves inside and line it with vegetation. These birds spend their days inside this burrow, or a hollow log or something similar, and spend their nights foraging. So, even though the nest is on the ground, the burrow offers some protection to the eggs and hatchlings.
- ◆ The male kiwi incubates the eggs. Producing such a large egg is tough on the female kiwi, so the male takes over the parenting duties after the egg is laid, while the female recovers.



- ◆ While kiwis and ostriches make somewhat similar nests, they do have some differences in reproductive habits. Kiwis tend to mate for life, while ostriches are promiscuous.
- ◆ Still, it is the male who does most of the incubating and rearing of young. The tall, dark, and handsome male ostriches incubate the eggs of multiple females and raise the chicks in shallow scrapes in the ground.

Flighted Bird Nests

- ◆ Nesting ratites don't have much of a choice about making their nests on the ground. Flighted birds have more choices, and when we observe these birds, we get glimpses of the coevolution between nest and egg and how the form of one affects the form of the other.
- ◆ Common murres are diving seabirds that live most of their lives out at sea but pack themselves in on clifftops or in crevices in cliff faces during nesting season, nesting in huge groups of up to 1 million birds. The nesting cliffs are barren rocks that don't have much vegetation, but also don't have many ground predators, making them an ideal place to nest. But this is not what keeps eggs safe when they are just laid on the bare rock. The eggs have evolved into a pointy pear shape, and if one rolls, it simply rolls around in a circle rather than off the cliff.
- ◆ Pigeons are good breeders, and many pigeon species make loose nests that they build on cliffs or forks of tree branches, but they don't carry off their feces like other birds do, so the nest eventually builds up into something more substantial.
- ◆ The female pigeon lays one egg, then another about a day later, into this simple nest. The female and the male take turns incubating the eggs over each 24-hour period. When the pigeon chick hatches 2.5 weeks later, both male and female pigeons make a special cheesy substance called crop milk that they feed the chicks over the first

week or so. After that, they feed the chicks a special seed mixture that they regurgitate for the chicks.

- ◆ Robins are another very common bird in the Northern Hemisphere. Female American robins build their nests from the inside out, starting with feathers, grass, moss, and small twigs on the inside while forming it into a cup shape, and then using more small twigs and other sturdy materials along with some mud on the outside to reinforce the cup. Finally, the female robin will line the inside with more soft feathers and dry grass before she lays 3 to 5 bluish eggs. She incubates the eggs for about 2 weeks, and then the helpless altricial chicks are fed in the nest by both parents for the next 2 weeks before they fledge.
- ◆ Some birds build even more intricate nests. The bird family Icteridae includes the colorful Baltimore orioles of North America and oropendolas of South America. Baltimore orioles are smaller than their tropical relatives, and the Amazonian oropendola is the largest of the entire family at 20 inches long.
- ◆ Although nesting habits within the family are variable, the orioles and oropendolas make fascinating pendulous nests. The oriole makes its solitary hanging nest from a fork of a branch high in a tree, where the female weaves skinny fibers and animal hairs into the distinctive, predator-proof, sock-shaped nest. It takes her about a week to develop the nest, and then she lays 5 to 7 splotchy-colored eggs in the nest; these eggs hatch after 2 weeks, and then the parents spend 2 weeks feeding the chicks in the nest until they fledge.
- ◆ The Montezuma oropendola, a chestnut-colored bird with a bright yellow tail, lives in the Central American lowlands and nests in colonies of 30 to more than 150 individual pendulous nests woven from leaf fiber and vines. Each female in the colony has her own private nest and lays 2 whitish eggs that hatch in about 2 weeks.



Baltimore oriole nest

- ◆ Even more interesting is the sociable weaverbird of southern Africa that builds large apartment-style colonial nests for the flock. These huge, multi-chambered, haystack-like hanging nests of sticks and grass are built high in a tree to protect the birds from predators such as snakes.

Suggested Reading

Deeming and Reynolds, eds., *Nests, Eggs, and Incubation*.

Erickson and Read, *Into the Nest*.

Taking to the Sky: Bird Migration

Flight is the main mode of locomotion for most birds. Birds use their powers of flight for migrating, avoiding predators, and even feeding. As you will learn in this lecture, wing shape is different based on the needs of the birds. Furthermore, migration takes a lot of energy, and birds need to have good nutrition to be able to fly.

Bird Flight

- ◆ The peregrine falcons are the fastest birds, with aerial dives clocked at more than 175 miles per hour. A peregrine falcon's speed-designed wing has a fighter-jet's triangular wing shape, and the falcon can morph those wings as its dive accelerates into a tight vertical tuck. At top speed, the wings are held tightly against the torpedo-shaped body.
- ◆ Compare these to the slow-flight wings of owls, which are large, broad, and rounded for stealthy flight through forests. Owls' wings can also be slightly morphed to optimize wing shape at different speeds, and they are quiet due to fringed feathers around the wing margins.
- ◆ Each of these is drastically different from the non-flying wings of kiwis, rheas, and other flightless birds, which might be vestigial, used for balance when running, or, in the case of penguins, used for swimming.



Peregrine
falcon

- ◆ But no matter what type of wing a bird has, the basic physics of bird flight are the same as the physical rules that allow modern aircraft to fly and involve lift, drag, and gliding.
- ◆ Lift is produced by the action of airflow on a bird's wing, which is curved, like the airfoil-shaped wing of a jet.
- ◆ Drag is caused by a combination of the bird's weight, which tends to push the bird groundward; a frictional drag caused by friction on all body surfaces; a form of drag produced by the front-end shape of the bird; and a lift-induced drag. These drag effects are reduced by streamlining the shape of the birds' body and wings.
- ◆ Bird flight also requires specialized bone structure. Bird bones are hollow, with stiffening struts and air spaces that replace bone marrow found in other creatures. These pneumatic bones are particularly strong and light.
- ◆ Bird flight muscles are arranged on the breast and anchored on the breastbone, or keel, to keep the center of gravity low on the bird's body. Contraction of the bird's pectoralis muscle pulls the wing downward, while relaxation of that muscle allows the wing to be pulled upward as the supracoracoideus muscle contracts.

Migration by Flight

- ◆ Migratory birds—in particular, shorebirds—fly very long distances. Many of them migrate at night; some of them migrate during the day. That takes a lot of energy, so these birds have to eat all the time to build up their fat loads. The fat that they build up around their bodies during migration is the fat they use on their long flights.
- ◆ Every spring in the Delaware Bay, horseshoe crabs spawn billions of eggs, basically fat globules that the shorebirds stop and eat on their way to the Arctic to breed. The huge infusion of fat from the

horseshoe crab eggs provides important fuel in the form of energy to complete the birds' migration.

- ◆ These birds use a variety of methods to navigate back and forth between their breeding grounds—where many of them go every year, back to the same exact territory—and their non-breeding grounds. They use everything from the stars to landforms such as mountains, fields, and coastlines to navigate. They also use their memory to keep track of this information to remember it year after year.
- ◆ This is even true for small birds, such as hummingbirds, that only live a few years. It's advantageous for them to go back to the same breeding territory where they were successful the year before. It's too risky to go to an entirely new place. Over time, evolution and natural selection has allowed these animals to build memory banks or cues that they use to find their way back and forth between their breeding grounds and non-breeding grounds as well as to remember the routes they take on migration.
- ◆ More than 40% of the birds in North America, most of which are migratory, are declining significantly. The threats to migratory birds vary. The biggest threat currently is habitat destruction, both in North America on the breeding grounds and also in the tropics. One of the biggest threats in the future is climate change, which will most likely eliminate some bird species over the next 50 to 100 years. Another big threat is domestic cats. Outdoor cats kill between 1.3 and 4 billion birds per year in the United States alone. There are other threats as well, including buildings and wind turbines.
- ◆ To help with these issues, keep your cats, or your neighbor's cats, indoors. In addition, we need to replant, reforest, rehabilitat, and restore urban areas where people live into more native landscapes, versus having nonnative plants. Native plants have insects that have evolved to provide food for birds. Furthermore, put out water for birds in your backyard. Also, reduce the use of pesticides at home and at work.

DID YOU KNOW?

Cranes are among the world's oldest bird lineages, having been around since the end of the Eocene 34 million years ago. Sandhill cranes are the most common of all the cranes.

In one of the world's most amazing wildlife migrations, tens of thousands of sandhill cranes fly from the Gulf of Mexico and other southern wintering grounds north to the Platte River in Nebraska.

In the spring, more than 250,000 sandhill cranes may be seen along an 80-mile stretch of the Platte, where they fatten up alongside millions of migrating ducks, geese, and other birds in the almost-barren cornfields before their trip farther north to nesting grounds in the boreal forest and subarctic.

Cranes are highly social birds that react to one another's body posture and vocal cues, so when several lift off, many also take flight. Ornithologists have found that the cranes on the Platte may even fly to the same sandbar each year.

With climate change, cranes around the world are experiencing more flexibility in breeding season length, and sandhills may become resident around the Platte River area.



- ◆ Researchers at the Migratory Bird Center at Smithsonian's Conservation Biology Institute are dedicated to studying, appreciating, and educating the public about migratory birds. They study anywhere from 50 to 75 different species, mainly songbirds but also shorebirds, seabirds, and gulls. They track these birds throughout the year to study them throughout their full annual cycle.
- ◆ There is a large wild colony of black-crowned night herons at Smithsonian's National Zoo that has been nesting there for more than 100 years. They arrive in March and stay until August. Then, they disappear and travel all over the place, with some staying in Washington DC and others flying down to Florida.
- ◆ The Arctic tern is a waterbird species that migrates from the South Pole all the way up to the North Pole, migrating anywhere from 10,000 to 15,000 miles per year, twice a year, up and back.
- ◆ The blackpoll warbler is a small warbler that weighs about as much as a quarter, depending on its fat loads. This bird triples its body weight and then flies over the Atlantic Ocean for 2 or 3 days straight,



probably gliding for long periods of time to conserve energy, as opposed to making flapping movements that would use energy.

- ◆ Ruby-throated hummingbirds are migratory. They breed in Washington DC and spend the winter in Central America, which is a long-distance migration for a bird that weighs half a gram.

Flightless Birds

- ◆ Wings are about more than flying. Some birds, including penguins, evolved from flying ancestors but have lost the ability to fly because of different pressures in their ecological niche.
- ◆ For example, penguins' water-adapted wings let these flightless birds swim through the water at great speeds while they are fishing or avoiding predators. That's a much greater survival advantage for a large bird in the Antarctic environment than the advantage of flight that we observe in other birds.
- ◆ Penguins aren't the only birds to abandon the skies. The flightless ratites include extinct species such as the moa and living species such as the ostrich, along with a number of others. Although the chicken-sized South American tinamous are flighted members of this flightless bird group, all other birds in the ratite group do not fly.
- ◆ According to DNA analysis that examined the relationship between tinamous, rheas, ostriches, emus, and kiwis, tinamous are one of the most ancient members of the ratite group. The relationship analysis suggests that the common ancestor of the ostrich, rhea, and emu was like the tinamou and that each of the unflighted species lost its ability to fly independently and on several different occasions.
- ◆ Rheas and ostriches kept their wings and developed fluffy feathers and use their wings as rudders when running fast on the grasslands, where they are adapted to live with hooved mammals and other



Greater
rheas

grass eaters. Emus and cassowaries have reduced wings, suitable for large birds that live in forests.

- ◆ The wings of New Zealand's kiwis are vestigial, their feathers are the most hairlike of all the ratites' feathers, and these nocturnal birds that live in burrows are the most mammal-like of all birds. These amazing non-flighted birds evolved to occupy specialized niches that were vacant of mammals while all other birds were evolving to aerial niches.

Migratory Bird Conservation

- ◆ Birds began their evolution millions of years ago and have conquered the air, many watery habitats around the world, and all terrestrial habitats. They are magnificent flying animals, and we are constantly learning more about their flight anatomy, physiology, and biology.
- ◆ Some of our increased understanding can help humans create a better world for ourselves, and some of our increases in knowledge can help us make a more sustainable world for birds.
- ◆ If you want to participate in migratory bird conservation, learn more about your local gardens to increase your use of native plants and reduce or eliminate any pesticide use. And practice some mindfulness by slowing down and just watching the birds in your backyard, local park, or zoo.

Suggested Reading

Cramer, *The Narrow Edge*.

Newton, *The Migration Ecology of Birds*.

A close-up photograph of two brown monkeys, likely howlers, looking towards the camera. They have thick, shaggy brown fur and dark faces with prominent noses. The background is a soft, out-of-focus green, suggesting a natural habitat.

Lecture 14

What Makes a Mammal? Hair, Milk, and Teeth

Mammals are vertebrates—animals with a spinal cord and bony spine. Among the vertebrates, there are about 30,000 species of fish, more than 8000 species of reptiles, almost 10,000 species of birds, and only about 5400 species of mammals, according to Smithsonian’s Dr. Don Wilson and Bucknell University’s Dr. DeeAnn Reeder, who created the world’s most authoritative list of mammalian species in their 2-volume set *Mammal Species of the World*.

Mammals

- ◆ The fossil record tells us that mammals evolved almost 200 million years ago and lived as small creatures side by side with dinosaurs until the dinosaurs went extinct about 66 million years ago. Then, the mammals exploded onto the scene. Today's 5000-plus species are assembled in 26 orders, in dozens of families (about 30 families in the large rodent order alone).
- ◆ Our knowledge of the mammalian order is ever-changing and expanding because mammalogists continue to find exciting new information from modern molecular evidence, changing our understanding of many existing phylogenetic relationships.
- ◆ Modern phylogenetic analyses even give us new information about the most common and well-studied groups of mammals. Even skunks, which used to be placed in the carnivore order's weasel family, have now been placed in a new family by themselves, the Mephitidae. Meanwhile, new mammals are still being discovered through modern scientific exploration.
- ◆ Despite the fact that there are fewer species of mammals than birds, reptiles, and fish, we have studied many of the world's mammals



Skunk

more intensively than other creatures, perhaps because they are most like humans and our domestic farm livestock.

- ◆ Many things make our fellow mammals distinct from other animals, but the 2 unique traits of mammals are hair and milk.

Hair

- ◆ Hair is a filament made of keratin protein that grows from follicles in the skin. Keratin is a major structural protein in all vertebrates, found in skin and in claws, hooves, and nails, as well as in hair. Keratin protein is one of the toughest proteins an animal can produce.
- ◆ Hair is unique to mammals; although many groups of animals produce keratin, only mammals turn that keratin into hair. Hair is important to mammals for a number of reasons. They use its form and color patterns for displays and for camouflage, they use it for its insulating properties, for self-defense, and even as a sensory organ.
- ◆ We don't really know when hair evolved because it is rare in the fossil record. But zoologists think that hair coincides with the evolution of warm-bloodedness, or endothermy, the ability to produce our own body heat, because hair is a very good insulator.
- ◆ Arctic animals have a lot of hair for insulation against the cold.

DID YOU KNOW?

Zoologists have estimated that the Arctic fox has tens of thousands of hairs per square inch.



With a deep underfur and plentiful guard hairs on the outside, the small, nonmigratory Arctic fox may be the best adapted of all Arctic creatures for cold temperatures down to 40° below 0° or lower.

- ◆ Other Arctic animals, such as polar bears and caribou, have thick coats of hollow hairs. These insulate like human winter parkas that have synthetic hollow-fiber filling for efficient protection against deep cold.
- ◆ Arctic foxes also use their fur for camouflage. They are the only members of the Canidae family—that is, the doglike carnivores—whose fur changes color with the seasons. In the winter, it is pure white to blend in with the snow of its tundra habitat; for summer, it sheds its white fur and replaces it with a brownish or grayish coat that blends in with the tundra grasses. Its seasonal coloring disguises it from both predators and prey.
- ◆ Other times, an animal may use its fur for the opposite purpose: to be better seen. The classic example is the lion. Lions are the only members of the Felidae family—the catlike carnivores—that have visible sexual dimorphism. In other words, there’s an obvious visual difference between males and females: Male lions have manes.
- ◆ The mane is not just a signal of maleness. The color and size of a lion’s mane is actually influenced by its sex hormones, including testosterone. Research indicates that lions with darker, thicker manes have higher testosterone levels and that lionesses prefer males with big, dark manes. A mane gives a lioness information about a lion’s ability to survive and reproduce.
- ◆ Hair is unique to mammals, and all mammals have some form of hair. Although they look hairless, dolphins and whales have a few small, whiskery hairs on their chins. Elephants look hairless from a distance, but they do have hair, which is more obvious in juveniles than adults.
- ◆ Hair takes on many forms. Many mammals have defensive structures made entirely of hair. Porcupines may be the most famous example. All porcupine species are slow and lumbering, which might make them



vulnerable to a faster predator. But to make up for their lack of speed and agility, they have strong, barbed quills that are really enlarged, modified hairs.

- ◆ Specialized whiskers on cats, dogs, and other mammals are also modified hairs. Whiskers are technically called vibrissae, and they work as sensory receptors. Cats and mice use these sensitive whiskers in the same way that we use our fingertips to feel our way around in the dark, to find one another, or to avoid enemies.

DID YOU KNOW?

The spiny covering of hedgehogs and the horns of rhinoceros are made of keratin, the same substance that hair is made of.



Milk

- ◆ In addition to hair, the other identifying trait of a mammal is the ability of female mammals to produce milk. In mammals, milk is liquid and is only produced by the mother from specialized glands. The specialized glands that produce milk are called mammary glands, and female mammals invest a lot of energy providing extended care for their offspring with this special nutrient.
- ◆ Smithsonian's Olav Oftedal and colleagues performed major reviews of milk during the 1980s and 1990s and found that behavioral care, the environment, and additional traits such as body size influenced the composition of milk in different mammalian species.
- ◆ The composition of milk depends on multiple factors: whether the baby is born in a helpless altricial or more advanced precocial state; on the mother's physical condition and her current environment; and on whether young nurse on demand—as in marsupials, primates, or precocial hoofed animals—versus on a schedule, as in lions or deer, who park their babies while they search for food.
- ◆ Suckling patterns differ between mammal groups. A general rule is that suckling young on some schedule is typical for parents that separate from their young for extended periods. Often these periods of separation are thought to be an anti-predator adaptation.
- ◆ Tree shrews park their tiny babies in secluded nests for 2 days between feeding bouts, and their milk has a relatively

DID YOU KNOW?

A baby humpback whale drinks up to 130 gallons of milk each day.



high protein/fat content. Wild rabbits park their altricial babies in fur-lined nests and return only about once daily to suckle their young; rabbits have milk content of more than 10% milk protein and more than 12% fat. Rabbits and tree shrews are on one end of a parental contact spectrum that extends to the extensive contact of infant-carrying primates and nursing on demand.

- ◆ Milk production is incredibly expensive metabolically, even more so than pregnancy. Females with multiple infants or large, strong infants deplete their own body condition as they lactate, especially toward the time of weaning. It would be even more expensive if the milk in species with long maternal care and long lactation times was also high in protein and fat.
- ◆ Diet has a strong influence on the energetic density of milk. Carnivores make milk that is higher in protein and fats than milk of herbivores or omnivores. Atlantic grey seals, for example, feed on fish, and their milk has more than 11% protein, an incredible 53% milkfat. They suckle their young

DID YOU KNOW?

Scientists at Smithsonian's National Zoo have developed the largest milk repository in the world by working with other zoo professionals and gathering this remarkable substance from many species whenever the opportunity presented itself.

Much of our knowledge about the milk of other species was developed through studies of milk in zoo-based repositories, because the milk of different species is available during well-baby checks of zoo mothers and babies by zoo veterinarians.

The Smithsonian milk repository alone has almost 6000 milk samples, and nutritionists and veterinarians have analyzed it to help hand-raise baby animals.





for only 2 weeks after giving birth in seal rookeries in the subarctic during its cold spring. Young grey seals are able to quickly develop enough blubber to live on so that they can go to sea to feed on their own. The high protein, and especially the high fat content, are therefore an advantage to animals that live in cold seas and need to raise their large young quickly.

- ◆ Total milk synthesis, the volume produced during lactation, as well as how fat, proteins, sugars, and even hormones in the milk change over the duration of lactation are going to be important as zoologists research milk composition and lactation in the future. The results of these studies of milk synthesis will help us better understand ancestral relationships, behavior, and the ecology of mammalian species.

- ◆ Natural selection has shaped the milk production of mothers and the nursing behavior of infants, and these behaviors may be in conflict. The mother wants to grow her infants but needs to consider her lifetime reproductive success, so she needs to balance one infant's production and growth against the needs of the next infant. The infant cares about maximizing its own survival, so it will take as much as it can get, with little regard for its mother's own condition.
- ◆ How the mother makes milk using current body stores versus eating more varies across species, across individuals within species, and across seasons for each individual.
- ◆ Zoologists need to consider how mothers develop and deliver milk and how the infant ingests and uses this milk, especially because the goal is to properly nourish both mothers and babies in zoos. Zoologists need to consider the mother-infant behavior for frequency and duration of suckling as well as how infants grow and behave while in the nursing stage of their lives.
- ◆ Besides protein, fat, and sugar, there are other bioactive components in milk that help the infant develop, including hormones and minerals. Milk scientists continue to learn about the chemical components of milk, and we can look forward to more to come for this important mammalian product, because we haven't even yet analyzed the milk of thousands of species.
- ◆ We can learn a lot about evolution from studying milk. Species living in the same environment, with the same diet and other factors, may have different milk composition because they evolved from different ancestors. Or, different populations of a species may move into different environments, where they have different diets and different anti-predator needs or other factors, with important related changes in milk composition.
- ◆ So, milk composition is one good marker of the historical pressures faced by ancestors as well as current pressures faced by lactating females.

Teeth

- ◆ Zoologists believe that the evolution of lactation has facilitated a remarkable increase in the sophistication of mammalian teeth. Nutrition through a mother's milk and infant suckling postpones the time at which teeth need to erupt to handle adult food. Thus, lactation delays the need for teeth until much of the relatively rapid jaw growth is complete.
- ◆ So, this might have been a precondition for the complex occlusion of teeth in the upper and lower jaws that is necessary for chewing and that is so characteristic of mammals.
- ◆ Teeth are important structures that coevolve with our diet, whether we are herbivores, omnivores, or carnivores. Our adult teeth consist of an enamel covering over a relatively soft core of dentine, and in most mammal species, teeth stop growing once their owners are adults.



- ◆ Nursing and jaw growth are in delicate balance so that young mammals can receive nutrition and care from their mothers as they become physically independent and fend for themselves by eating solid food.

Extinction of Mammals

- ◆ Almost 1/4 of our world's mammals are considered to be threatened with extinction by the International Union for Conservation of Nature mammalogists, and more than 75 mammals have gone extinct in the last 500 years.
- ◆ Habitat loss now affects almost half of all mammals globally, while the second greatest threat to mammals has been poaching for parts and bushmeat.
- ◆ We have learned historically that endangered mammals—such as bison, wolves, and black-footed ferrets—can come back from the brink if we give them ample habitat and protection from overhunting.

Suggested Reading

Ben Shaul, "The Composition of the Milk of Wild Animals."

Brock, *Mammals*.

Power and Schulkin, *Milk*.

Herbivore Mammals: Ruminants and Runners

Of the 5400 species that make up the mammal class, fewer than 300 of these species are large herbivores, such as elephants, rhinoceroses, giraffes, horses, cows, and deer. There are many smaller herbivores, including more than 2000 species in the rodent order, which includes mice, rats, guinea pigs, beavers, chinchillas, capybaras, and the octodontids. Other smaller herbivores belong to the order Lagomorpha, which includes hares and rabbits, and the order Diprotodontia, which includes the Australian marsupial mammals, such as the koala and kangaroo. Finally, there are 4 living species of aquatic mammalian herbivore, the most famous of which is the manatee.

Mammalian Herbivores

- ◆ The mammalian herbivores are a large and diverse group, but they're united by their diet of plant foods, such as grass, fruits, nuts, seeds, and even wood. Each of the groups of mammalian herbivores has developed different strategies for chewing and digesting these materials.
- ◆ The most fascinating of these adaptations belong to the ungulate clade. There are even-toed ungulates—the Artiodactyls—the largest order of a little more than 200 species, in which we find the hippos, camels, llamas, deer, sheep, goats, cows, and many others. Many of these cloven-hooved animals have great cultural, dietary, and economic importance to humans.
- ◆ There is also an order called the Perissodactyls, or odd-toed ungulates. These include 8 species of horses, 4 species of tapirs, and 5 species of rhinoceroses.
- ◆ Despite the small number of species, ungulates are found all over the world, from Africa to Europe, Asia, and the Americas.
- ◆ While all the ungulates are plant eaters, different species eat different plants and plant parts—new grass, older grass, new bush and tree leaves, water plants near the shores of lakes, and so on.
- ◆ We primates also eat plant parts, but we also eat meat, so we are classified as omnivores, and that difference in diet is reflected in 2 places: our teeth

DID YOU KNOW?

The only places ungulates aren't found in the wild are Australia (Australia's mammals are mostly marsupials) and Antarctica, where an herbivore would have a hard time surviving because Antarctica has almost no plants.



and our gastrointestinal system. We humans have a generalized dental plan, meaning that our teeth aren't designed for one particular food. We see a similar dental plan in all primates, but especially our closest primate relatives, the Old World monkeys and great apes. Humans and other omnivores are also monogastric, meaning that we have a simple, single-chambered stomach.

- ◆ When you see an animal with this generalized kind of dentition and digestion, you can make some guesses about its diet. First, you know that the animal often eats easily digestible, high-sugar foods, such as fruits. We humans can also eat nuts, grains, and even meat, although unlike other primates, we tend to cook our grains and meat first, which starts the food breakdown process.
- ◆ Because we have simple teeth and simple stomachs, we have to eat relatively soft foods. On the other hand, most mammalian herbivores have diet-specific teeth and a more complicated digestive system to help them process and digest difficult-to-digest grass and leaves.

Ruminants

- ◆ The Artiodactyls are the even-toed ungulates. Most Artiodactyls belong to the ruminant suborder. These ruminants include cows, sheep, goats, giraffes, yaks, deer, camels, and antelopes. Ruminating animals have 4-chambered stomachs and rely on foregut fermentation via gut microflora to digest tough plant material. This adaptation evolved independently in several groups of mammals.
- ◆ The interesting features of the ruminant digestive system start with their teeth. Most ruminants do not have upper incisors like we do; instead, they have a tough upper palate called a dental pad. They use this pad, along with their tongue, to grasp the grasses, and then the lower incisors sever the grass against the dental pad—like a knife on a cutting board. At the back of the mouth, they have large molars to thoroughly chew these plant foods.

- ◆ Again, unlike humans, adult ruminant teeth have a different formation of enamel and dentine. This, too, demonstrates a relationship with their mostly grass diet.
- ◆ Grasses have silica spicules in them as a defense against herbivory. During grazing, the silica content in grasses causes abrasion of mammalian teeth. This tooth wear is partially compensated for by tooth structure, but the teeth still wear down throughout a ruminant's life.



- ◆ Ruminant molars also have a different form than human molars. These teeth show amazing diversity across mammalian species.
- ◆ Ruminants have 4-chambered stomachs, which are divided into the rumen, reticulum, omasum, and abomasum. The rumen is full of microbial flora, which coevolved with the animals. Digestion in the rumen is primarily carried out by these microflora, which include various bacteria, protozoan, yeast, and fungi species. The complicated process of foregut fermentation, or rumination, helps ruminants digest foods that other mammals cannot.
- ◆ Mammals lack the ability to digest cellulose on their own due to a lack of the enzyme cellulase. But the gut microflora can digest these long-chain carbon compounds, allowing ruminants access to the energy and nutrients stored in tough grasses and plants.
- ◆ While foregut fermentation is an efficient strategy for herbivores, there are other kinds of herbivore digestion. Horses, rabbits, and rhinos, among others, are monogastric hindgut fermenters. These animals have a single-chambered stomach that is much smaller than a ruminant's stomach.
- ◆ Instead of a large stomach, hindgut fermenters have much larger intestines than foregut fermenters, and that is where fermentation takes place. Because they do not ruminate— they do not maximize the extraction of nutrients through repeated bouts of chewing

DID YOU KNOW?

A horse's stomach volume is 2 to 4 gallons. In comparison, the rumen volume of a dairy cow is about 50 gallons.



and regurgitation—hindgut fermenters pass food through their systems much more quickly.

- ◆ Hindgut fermenters have developed a few strategies for making the most of their food. First, hindgut fermenters use a strategy of quantity over quality when it comes to eating. They need to eat a much greater daily volume of food than a ruminant of the same body size; in fact, many of them eat all day long.
- ◆ Even though their stomachs are smaller than a ruminant's, hindgut fermenters need large digestive tracts for processing those larger amounts of food. That's why, despite their relatively small stomachs, hindgut fermenters have proportionately larger intestines than other mammals.

- ◆ Some of the largest mammals on Earth are herbivorous hindgut fermenters, including elephants and rhinos. The *Indricotherium* rhinoceros, an extinct ancestor of today's rhinos, weighed almost 20 tons. It may have been the largest land mammal in Earth's history.
- ◆ But there are small hindgut fermenters, such as rabbits and rodents. That's not to say their digestive tracts are small; a rabbit's digestive tract is more than 10 times longer than its body.

DID YOU KNOW?

Horses graze for up to 17 hours a day, consuming as much as 2.5% of their body weight in grass. They also graze over larger ranges than ruminants of the same size. A horse's stomach is rarely empty, and food-retention time is shorter than it is in ruminants.

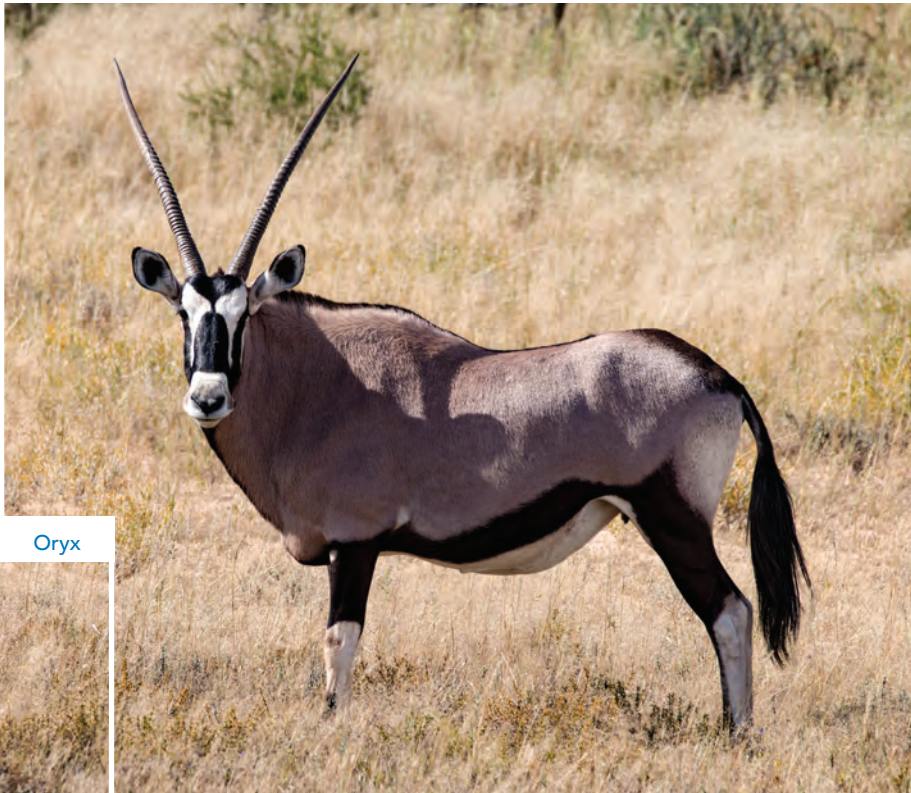




- ◆ These creatures have an alternate strategy for extracting extra nutrients from their food through a process called cecophagy. This is a specialized form of coprophagy—in other words, poop eating.
- ◆ Cecophages, such as rabbits, can create special types of pellets in the cecum called cecotropes. These pellets are not like normal feces; they are pellets of partially digested food that are coated in mucus in the cecum and passed through the large intestine intact. The animal consumes these pellets and puts the contents through a second round of digestion.
- ◆ Because of these 2 strategies for dealing with poor-quality food—large digestive systems for quantity consumption and cecophagy—hindgut fermenters can survive in conditions of scarce, poor-quality food where ruminants might not make it.

Runners

- ◆ Plant eaters are a critical part of the food chain. This food chain starts with the Sun's energy, which is then harnessed by the plants into sugars and starches and is thereby made available to other species as food. But herbivores are in the middle of the food chain; they are eaten in turn by carnivores—the meat eaters.
- ◆ Every animal that is some other animal's dinner needs an adaptive strategy to evade predation. The small herbivores, such as rats and rabbits, can hide in the tall plants that feed them, and the large herbivores, such as elephants and rhinos, can simply defend themselves against large predators.
- ◆ But the even- and odd-toed ungulates, such as the oryx and the horse, do not live in either one of these niches. Too big to hide well, the



Oryx

plant-eating ungulates need to be able to run from their predators. Speed and agility are a matter of life and death for these animals.

- ◆ All of these midsized herbivores have developed musculoskeletal and other adaptations for running and jumping that help them escape predators, including humans.
- ◆ The best runners are open-country antelopes, including the oryx. When walking, these animals move their legs in sequence of left front, right rear, and then right front, left rear. At a fast trot, each hoof is lifted off the ground before the one before it returns to the ground.
- ◆ In galloping, bounding, or other fast running, the motion is different. The front 2 legs leave the ground almost together, followed by the 2 back legs, which propel the body forward. Sometimes this motion is so fast that all 4 legs are off the ground at the same time.
- ◆ Ungulates have similar limb structures to ours, but the sizes and proportions of the bones are different. The changes vary a bit from species to species. Whether the animal is even- or odd-toed, there are similar leg and foot adaptations in ungulates, including horses, deer, antelope, sheep, goats, and giraffes—even rhinos and elephants.

Head Ornamentation

- ◆ Another adaptation that is common, although not universal, among mammalian herbivores is head ornamentation.
- ◆ Humans have long valued the antlers, tusks, and horns of large herbivorous animals both as ornamentation and as symbols of male prowess. We put animal horns on military helmets. We decorate kings' thrones with elephant tusks. That's probably because our ancestors recognized the weapon potential of these structures, and we associate them with the male members of these species.

- ◆ Horns and tusks are impressive, powerful structures that animals use for defense (and offense). But they're not exclusively male.
- ◆ In the Bovidae family, we see lots of variation in this. In cows, sheep, and goats, animals of both sexes have horns, although the males' horns may be larger for pre-mating combat.
- ◆ Among antelopes, horns might be carried by only the males, by both sexes, or not at all. Oryxes are among the antelope species where both sexes have horns—horns that are so magnificent that humans hunted the scimitar-horned oryx to extinction in the wild.
- ◆ Deer are the only mammals with the power to regenerate entire bones. The rest of us can only make minor repairs. That's why bone cancer and osteoporosis researchers are studying the growth of antler bone in the hope of understanding mammalian tissue regeneration in general. Perhaps if we discover how deer can regrow bone, human medical researchers can find a way to regenerate lost or damaged bone or even stop bone cancer.
- ◆ Maybe the only adaptation more visually impressive than deer antlers are elephant tusks. Unlike horns

DID YOU KNOW?

An average Burmese brow-antlered deer is only 3 to 4 feet high and weighs about 130 to 300 pounds, while their incredible antlers can be 3 feet long with only a few tines (or points) and can weigh 12 pounds each. Remarkably, these antlers grow this large in as little as 3 months.



made of hair or antlers made of bone, tusks are simply incisor teeth that have evolved into remarkable tools. Elephants are unique in this; in most other tusked animals, such as walrus and warthogs, the tusks are canine teeth.

- ◆ Just as deer use their antlers for mating challenges, elephants use their tusks as weapons. But unlike antlers, tusks are versatile tools. Elephants use tusks to dig, clear paths through dense undergrowth, and peel bark off of trees to eat.

DID YOU KNOW?

Elephants use their tusks a lot like we use our hands, and they are either right-tusked or left-tusked. You can tell an elephant's dominant tusk by looking for the tusk with more wear.



Suggested Reading

Castelló, *Bovids of the World*.

Demarquoy and Le Borgne, *Ruminant Physiology*.

Fritz, *A Journey through the Horse's Body*.

Carnivore Mammals: Feline, Canine, and Ursine

Among the 5400 species of mammals, fewer than 300 of these species are carnivores. Within the order Carnivora, there are 37 species of cats in 4 genera, 35 species of wild dogs in 10 genera, 4 species of hyenas each in their own genus, only 8 species of bears worldwide in 5 genera, 19 species of raccoons, 10 species of skunks, 70 species of civets and mongooses, and 55 species of weasels. These land-based carnivores have a worldwide distribution, except on Australia and Antarctica. There are also 34 species of seals, sea lions, and walruses—species that make up the clade Pinnipedia as part of the order Carnivora—distributed regionally in mostly marine ecosystems around the world.

Mammalian Carnivores

- ◆ While the mammalian herbivores have an unguligrade foot structure, among the carnivores, there are digitigrade animals that walk on their toes, such as cats and dogs, and plantigrade animals that walk on the soles of their feet, as humans and bears do. Both forms share an evolutionarily distant fusion of carpal and tarsal bones.
- ◆ In carnivores, perhaps this bony fusion to form the scapholunar bone provided a compromise: a solid basis but also a bit of movement in the midcarpal joint, which early carnivores needed to climb as well as to grapple with prey.
- ◆ Carnivores have relatively undeveloped clavicles, or collar bones. We omnivorous primates need a large clavicle to stabilize the lower part of the shoulder blade and to provide attachment for the muscles that control the side-to-side movement of our arms.
- ◆ Carnivores have a front-to-back swing of their limbs when running after prey, and the advantage of a long stride when running down their prey probably explains the clavicle that is free at both ends and lodged firmly within shoulder muscles. In other words, carnivores are adapted for running and have agile, powerful bodies no matter what their size.
- ◆ Carnivores are incredibly variable in lifestyle, and the remainder of their anatomy reminds us of this on a species-by-species basis.
- ◆ Cats have retractile claws, which are common to the whole Felidae family but are not common to all carnivores. Dogs and bears have digging-style claws, which are nonretractile and often blunter than cats' claws.
- ◆ Brown bears have incredibly long claws for digging up tubers, grubs, and even small mammal prey, while their closest relative, the polar bear, has sharp and more catlike claws for gripping their icy habitat and seal prey.



- ◆ The standard carnivore dental formula is 44 teeth: 3 incisors, 1 canine, 4 premolars, and 3 molars on each side, top and bottom. There are differences in this basic formula between carnivore families.
- ◆ The most likely ancestors of today's carnivores were probably forest-living animals with a tree-dwelling existence that arose somewhere between 50 and 60 million years ago. From these animals, called the Miacidae family, the modern carnivore families radiated quickly into 2 main branches, or suborders, during the Eocene and Oligocene periods 56 to 24 million years ago.
- ◆ One of these branches is the cat branch, with the cat, hyena, civet, and mongoose families, and the other is the dog branch, which includes not only dogs, wolves, and foxes, but also skunks, weasels, raccoons, and bears as well as sea lions, seals, and walruses.
- ◆ Within the dog branch, or Caniformia suborder, giant pandas are firmly established as members of the Ursidae, the bear family.



However, red pandas of the Himalayan mountains—a star at Smithsonian’s National Zoo—are not closely related to giant pandas, even though these species are both specialized for eating bamboo.

- ◆ The taxonomic position of red pandas has been debated since the early 19th century, and recent DNA analysis now places them in their own family, Ailuridae; this species is most closely related to the superfamily that contains raccoons, skunks, and weasels.
- ◆ Within the cat branch, the Feliformia suborder, is the cat family or Felidae. Bobcats, mountain lions, cheetahs, and other cats are also members of this family, including the domestic house cat.

Lions

- ◆ Lions, like other cats, have relatively short, powerful skulls that are adapted for killing and eating prey and, like other cats, rely on keen vision and hearing. Their snout is short relative to dog snouts, and this indicates that smell is less important to these species than is vision. Their jaws are still strong.

DID YOU KNOW?

Lions are one of the few carnivores that are able to take prey greater than their own weight.



- ◆ They are known to eat prey ranging in size from hares and rodents to wildebeest and water buffalo, even rhinos and elephants at times. Lions can take down healthy adult prey as well as young, old, and infirm animals, killing the prey animal with a suffocating throat bite. They sometimes kill other predators, such as hyenas and leopards, but rarely eat them.
- ◆ Cooperative hunting by lions in their social groups, or prides, is common when the lions are hunting very large animals or hunting in harsh environments. Hunts by single lions are more common when prey is relatively available and easy to capture.
- ◆ Lions can be extremely fast over short distances, but they lack the cardiac and pulmonary capacity to be long-distance runners. Because of this, lions are most successful at hunting when they sneak to within a short distance of the prey before launching their final sprint. Some pride members remain on the sidelines during these hunts and share in the meal, with dominant animals eating first.
- ◆ Male lions, like many cats, are much larger than females, and their size helps them dominate other members of the pride when feeding at the carcass. In turn, females dominate subadults and cubs, and there is a lot of squabbling at the carcass. Because of this squabbling, there is no guarantee that the cubs will be able to eat, and sometimes cubs

starve if food is not plentiful. After gorging themselves, lions may rest for up to a week before they try to hunt again.

- ◆ Large areas of land are necessary to support herds of lions' natural prey and the prides of lions themselves. This is the main reason that the long-term survival of lions is not assured. As human populations increase across Africa and agriculture spreads, native antelope and other prey decline, and lions are locally extirpated. Lions survive in national parks and local reserves, and we need to ensure that these areas are protected for the future of African wildlife.

Tigers

- ◆ The lion's closest relative is the tiger, although the savanna-dwelling lion has a simple tan coat and the tiger has its famous striped coat. Both provide camouflage in the species-preferred habitat. Tigers are silent, powerful, and agile hunters with powerful paws and claws, strong jaws, and sharp teeth. Amur tigers are the largest members of the cat family.
- ◆ Scientists from Smithsonian and elsewhere have classified tigers into several subspecies, from the southern tropical islands of Bali and Java; through Sumatra, Malaysia, and India; to the Amur (Siberian) region of the Russian Far East.
- ◆ The Siberian tiger's large body size and short legs help it retain body heat in its cold climate. The hoofed animals of Siberia are also relatively

DID YOU KNOW?

The tiger is the only big cat with striped fur, a camouflage coat that allows it to blend in remarkably well with its forest habitat.





larger than in other habitats, so large body size helps Amur tigers capture prey.

- ◆ Tiger habitat is characterized by thick forest cover, access to water, and good populations of large ungulate prey. Tigers used to roam areas of forested habitat and now are reduced to separated islands of habitat from India to the Russian Far East. They hunt around dawn and dusk and specialize in large game such as deer, boar, and other hoofed animals.

- ◆ Adult tigers defend large territories from other tigers of the same sex. The resource defended in female territories is primarily food, because a female needs to have enough prey to feed herself plus a litter of growing cubs. A male's territory overlaps multiple female territories, so he has the additional resource of multiple females to mate. Male territories are always larger than female territories, but territory size is always based on local prey base.
- ◆ Like their cousins the lions, tigers are under significant threat. Three of 9 tiger subspecies have already been declared extinct after tiger populations plunged by more than 90% during the last 100 years. Threats to tigers include traditional Chinese medicine, whose practitioners value tiger bone and other parts for a variety of medicinal uses.

Wolves

- ◆ All members of the canid family—including wild members, such as foxes, coyotes, and wolves, as well as the domestic dog—evolved for rapid, long-term pursuit of prey, which is evident in their long legs and digitigrade feet with nonretractile claws. The smallest canid, the fennec fox of Africa, is adapted for harsh desert environments where prey is scarce, while the largest canids, the wolves, are found in habitats with abundant prey.
- ◆ Archaeological evidence shows that dogs were domesticated long before any other animal, and even before humans developed plant agriculture. We suspect that hunter-gatherers started the domestication process by capturing young, wild wolves as pets, then deliberately using them as guards or as hunting partners. The result is the hundreds of domestic dog breeds on Earth now.
- ◆ While tame wolves—domestic dogs—have become our best friends, wild wolves have been hated and persecuted because they sometimes hunt farm animals and compete with humans for deer and other game species. Wolves can kill large numbers of domestic

animals, but their threats to humans are largely overrated.

- ◆ Like domestic dogs, wolves are social canids, and they travel in packs that can overcome animals as large as moose or bison with their sheer numbers.
- ◆ Wolves are found across the Northern Hemisphere and once had one of the largest ranges of any Northern Hemisphere animal. They are extremely adaptable and have been found in a variety of habitats, from deserts to wetlands to forests.
- ◆ By the mid-20th century, wolves were endangered in the lower 48 United States, and they were reintroduced into Yellowstone National Park and other large park areas starting in the 1990s. In the 20 years since wolves were reintroduced to the Yellowstone ecosystem, this national park went from no wolves to one of the highest densities of wolves in the world.

DID YOU KNOW?

The modern wolf species hasn't changed very much from the ancient wolf that is the most probable common ancestor of modern wolves and domestic dogs.



Bears

- ◆ There are 8 species of bears. They are adapted to a variety of habitats and diets, and their size shows it. The American and Asian black bears, brown bears, and South American Andean bears are all omnivores that eat plants, fruits, and small animals or bird eggs.

DID YOU KNOW?

Polar bears are the largest terrestrial carnivores on the planet.



- ◆ The polar bear evolved most recently from salmon-eating brown bears, and polar bears are seal specialists. The tropical Asian sun bear is the size of a retriever and is specialized for eating fruits of the forest. The Asian sloth bear is well adapted to eating insects, such as termites; it has evolved a space between its front teeth where its incisors were, so it can suck up insects like a vacuum cleaner. The giant panda is an herbivorous bear that is specialized for eating bamboo.
- ◆ Among all these species, polar bears are the largest, but their size and strength has not protected them from habitat loss. Polar bears are currently classified as vulnerable, with fewer than 20,000 remaining in the wild and declining relatively quickly. The loss of Arctic sea ice is the culprit.

Threats to Mammalian Carnivores

- ◆ Mammologists from the International Union for Conservation of Nature believe that almost 1/4 of our world's mammals are threatened with extinction, and carnivores such as black-footed ferrets, cheetahs, tigers, and polar bears are in the most trouble.

- ◆ Dwindling habitat due to habitat destruction by human actions, persecution as killers of domestic livestock, and exploitation for fur or bones for medicinal purposes are the main reasons that carnivores are threatened by humans.
- ◆ Thoughtful management in wild areas is the best conservation action for carnivores, because they need wild places and wild prey.
- ◆ The indiscriminate killing of predators by aerial gunning of wolves or indiscriminate poisoning of coyotes or foxes needs to be replaced with compassionate conservation and acknowledgement of the roles these animals play in our ecosystems.

Suggested Reading

Eisenberg, *The Carnivore Way*.

Nowak, *Walker's Carnivores of the World*.

Clark, Curlee, Minta, and Karevia, eds., *Carnivores in Ecosystems*.



Lecture 17

Primate Mammals: Diverse Forest Dwellers

Zoologists officially recognize more than 630 species of primates. The primate order includes lemurs, lorises, tarsiers, New World monkeys, Old World monkeys, lesser apes, and great apes, which includes us humans. This lecture will explore the ecology and behavior of our closest relatives in the animal kingdom, the primates.

Primates

- ◆ Zoologists consider primates to be generalist mammals, which means that they are able to survive in a wide variety of environments, not a narrow ecological niche. Within the order, primates show a wide range of adaptations and physical characteristics, but a few generalizations can be made.
- ◆ Primates have longer childhoods and longer life-spans than other mammals of a similar size. They also have larger brains relative to their body size than most other mammals.
- ◆ Primates rely more on sight and less on smell than other mammals. They eat a variety of diets, but almost all of them are capable of omnivory. A few, such as gorillas, are primarily herbivores, and tarsiers are the lone carnivorous exception—they survive mostly on insects.
- ◆ Many but not all of them have opposable thumbs, along with flat fingernails rather than claws and sensitive pads on each digit for gripping.
- ◆ The only trait that is common to all primates is an auditory bulla made of specialized temporal bone—in other words, an inner ear made of the side bone of the skull.

DID YOU KNOW?

Almost half of the world's primate species are threatened with extinction.



- ◆ Despite being generalists, most modern primates live in the subtropical and tropical forests of the world. Primates are natural forest dwellers; their adaptations are ideal for life in the trees.
- ◆ The modern primate group includes 2 suborders. The first is Strepsirrhini, or "wet-nosed" pre-monkeys, which includes lemurs, sifakas, and aye-aye, consisting of about 22 species in 12 genera of 4 distinct families that inhabit the island of Madagascar. Also included are bushbabies (or galagos) and lorises, with 33 species in several genera that inhabit Asia and Africa.
- ◆ The other suborder within the primates is suborder Haplorrhini, the "dry-nosed" primates, sometimes called higher primates. These include the infraorder Tarsiiformes, which consists of the 7 species of tarsiers, as well as the infraorder Simiiformes, which is basically everything else.
- ◆ The Simiiformes include the New World monkeys of Central and South America, 30 species in 11 genera, as well as a group of small animals without prehensile tails, the 25 species of New World marmosets and tamarins in 5 genera.
- ◆ Families in this suborder from the Old World—meaning Africa and Asia—include the Cercopithecidae, the baboons, macaques, and others, a family that includes 82 species in 14 genera.
- ◆ This suborder also includes 9 species of lesser apes, including all gibbons and the siamang, as well as the 4 species of great apes: the bonobo or pygmy chimp, the common chimpanzee, the orangutan, and the gorilla. Humans are considered dry-nosed primates.
- ◆ It is thought that Old and New World monkeys diverged when the continents of South America and Africa split about 120 million years ago. The Cebidae, or New World monkeys, have a distinctive platyrrhine, or broad-nosed shape with nostrils that are wide apart and face outward, appearing open. The Cercopithecidae, or Old World monkeys, have a catarrhine, or downward-nosed shape

with nostrils that are close together, narrowly spaced and pointing downward.

- ◆ Besides this distinction, several of the New World monkeys have prehensile tails that work like a fifth hand, while the tails of Old World monkeys are sometimes used as a balancing or rudder-like appendage that aids in leaping and climbing, not for grasping; at other times, they have much smaller tails, or a vestigial tail stub.
- ◆ As primates evolved from the doglike lemurs to great apes and humans, there was a flattening of our faces as the muzzle decreased in size. Although olfaction is the dominant sense in most mammals, we can no longer smell as well as dogs can, and our brain's olfactory lobe has also decreased in size.
- ◆ We have stereoscopic vision with our forward-facing eyes, and our optic lobe has increased in size. This trait was initially an adaptation to life in the trees; our primate ancestors needed stereoscopic vision to judge

DID YOU KNOW?

The New World monkeys include a competitor for the world's smallest primate, the common pygmy marmoset, which is only about 13 centimeters long and weighs just under 120 grams (about 4 ounces) on average.

The world's largest primate belongs to the great ape group. It's the gorilla, which weighs about 4 pounds at birth and reaches an adult weight of 160 to 215 pounds for females and more than 400 pounds for males.



distance as they leaped from branch to branch in the trees. Primates have also developed color vision as we have increased our reliance on our visual abilities.

- ◆ As primates advanced, they developed longer life-spans and time of maternal care, which gives infants a higher chance of survival and a time for social learning. This behavior is associated with delayed sexual maturity and a longer inter-birth interval, which also allowed an increase in the complexity of social behavior.
- ◆ The mating behavior of primates is very diverse. Primate breeding systems include monogamous pairs, single males that control harems (also called single-male polygyny, in which dominant males monopolize access to their harems), and even multi-male polygyny (for example, troops of baboons in which many breeding males associate in the same troop with multiple females).
- ◆ Many primates are sexually dimorphic, which includes body size, canine tooth size, and even coloration. All of these traits are noticeable in gorillas in which the dominant male is much larger than the females, has a silver back (and is called a silverback), and even has enlarged canines compared to female canines.
- ◆ As primates evolved and radiated into different environments, the sizes and shapes of their bodies changed to adapt to these environments. This explains the similar adaptations among diverse groups, from the terrestrial ring-tailed lemurs and baboons to the leaping sifakas, tail-swinging spider monkeys, and brachiating lesser apes.
- ◆ The quadrupedal primates tend to have narrow rib cages, long backs, and long pelvic blades. The leaping and brachiating primates tend to have a more vertical posture, more barrel-like chests, and shorter pelvic blades.
- ◆ Although the quadrupedal primates have arms and legs with similar lengths, the leaping sifakas tend to have better-developed hind limbs to provide power for long jumps. The brachiating lesser apes,

in contrast, have relatively longer and stronger arms and reduced legs. In humans, leg length has increased slightly because we are long-distance runners, and arms are relatively shorter.

- ◆ The type of locomotion primates use is also reflected in the feet and hands. The quadrupedal primates have a small, relatively divergent thumb, while brachiating apes and monkeys have thumbs that are greatly reduced as an adaptation for “clean” grabs of branches and vines. In our ape relatives, the thumb is well developed and gives us strong gripping ability and dexterity when we oppose it to our fingers.
- ◆ Primates have the greatest brain size relative to body size of almost all animals, and behavioral flexibility is related to both the relative and absolute brain size. The wrinkles—or, more accurately, folds—of the human brain are a way of fitting a greater brain volume and cognitive capacity into a smaller space. If we look at other primates, we see various levels of folding that are very consistent with the intelligence of the animal.

Lion Tamarins

- ◆ The golden lion tamarin is a New World monkey from South America that has a special place in Smithsonian’s National Zoo, because Smithsonian science, zoo breeding, and reintroduction programs are bringing this animal back from the brink of extinction.
- ◆ The 4 species of lion tamarins have colorful golden fur, lionlike manes surrounding their faces, and birdlike vocalizations. They live in family groups of 4 to 8 individuals, and adolescent golden lion tamarins participate in rearing the babies, so these groups are quite close-knit.
- ◆ All 4 species of lion tamarin are endangered: the golden lion tamarin, the golden-headed lion tamarin, the golden-rumped lion tamarin,

DID YOU KNOW?

Once critically endangered, the wild population of lion tamarins now numbers more than 3000 individuals.



and the black lion tamarin, all of which live in the coastal forests of Brazil that are now the most densely inhabited areas of the country.

- ◆ Like most primates, tamarins are omnivores, eating small vertebrates, insects, fruits, and flowers as well as plant gums or nectar whenever these food items are available.
- ◆ The deforestation of Brazil's Atlantic coasts, legal and eventual illegal trade in wild animals within the country, as well as local people eating these animals led to tamarins being listed as critically endangered in 1996. At the time, the U.S. Species Survival Plan population for golden lion tamarins was about 400 animals.
- ◆ Starting in the 1970s, when less than 20% of the tamarins' original habitat remained, Smithsonian and university scientists worked with Brazilian ecologists to restore lion tamarin habitat. At the same time, Smithsonian scientists worked with Brazilian scientists to plan and implement a reintroduction program to conserve these monkeys.
- ◆ By the turn of the millennium, the reintroduced population totaled about 200 individuals and became the model for reintroductions of other lion tamarins and even other species. The international lion tamarin conservation group, based largely in zoos, continues to monitor the habitat and conservation status of these amazing animals.

Gorillas

- ◆ At the other size extreme of the primate order is the gorilla, the largest of all primates. Its size, chest-beating display, and intense gaze has given it a reputation as one of the fiercest and most dangerous of all animals.
- ◆ Despite the King Kong myth and legend that portrayed gorillas as horrors, American scientist George Schaller closely studied gorilla troops more than 50 years ago, and these studies showed that these close relatives of humans are actually peaceful and family oriented.

DID YOU KNOW?

Gorilla infants have a white spot at the base of their spine, over the tail bone, that seems to signal to other gorillas that they are still kids.



- ◆ Deforestation and human encroachment into the gorilla's central African forest range has led to its current status as endangered. In fact, the western lowland gorilla is critically endangered in the wild.
- ◆ Decades ago, one of the main threats to gorillas were poachers who killed adults and captured infants to sell to zoos. Today, poachers hunt gorillas for food and to sell their skulls as tourist souvenirs. Even where these apes are protected by law, poaching still occurs frequently. And to add to the threats, the Ebola virus has devastated gorilla populations.
- ◆ Gorilla group size varies from 5 to 10 animals and includes a dominant silverback male who is the group leader, 3 adult females, and 4 or 5 offspring, sometimes including less-mature adult blackback males.
- ◆ Gorillas have huge, broad, strong hands. Perhaps surprisingly, these huge animals are primarily herbivores—or, more accurately, folivores. These creatures eat leaves and stems of plants, rather than the berries and even small vertebrates that their chimpanzee relatives consume.
- ◆ Gorillas, like chimps and humans, have high cognitive capacity that lets them solve complex problems, such as where and how to feed as well as how to sleep comfortably.

Endangered Primates

- ◆ Primates continue to be some of the most endangered animals on our planet. Primates around the world are threatened by local hunters who value bushmeat, by habitat loss due mostly to destruction of tropical forest as logging roads make access easier, and by the remaining illegal wildlife trade.
- ◆ The list of the most critically endangered species includes the eastern lowland gorilla and the golden lion tamarins. Golden lion

tamarins are making a comeback in Brazil, but gorillas have declined in some African countries by 50% in just 20 years.

- ◆ The future of these endangered species depends on the cultural and biological importance of these animals as recognized by their range countries and the efforts by governments and individuals to improve protections for the species. Failure to recognize biological importance and to provide conservation protections will surely result in extinction of lion tamarins, gorillas, and other endangered taxa and species by the end of the next century.

Suggested Reading

Montgomery, *Primates in the Real World*.

Petter, *Primates of the World*.

Redmond, *The Primate Family Tree*.

A photograph of three giraffes in a savanna setting. The giraffes have a characteristic brown and white reticulated pattern. They are standing in a line, with the largest one in the center, a smaller one to the left, and another to the right. The background is filled with lush green trees and foliage, suggesting a natural habitat. The lighting is bright, indicating a sunny day.

Lecture 18

Size, Structure, and Metabolism

This lecture will explore how an animal's size, whether large or small, helps it thrive on our planet. William Calder pointed out that the mass of 4-legged vertebrates, called quadrupeds, should determine the size and shape of their bodies and the thickness of their extremities, dictating general animal forms based on size. Body mass to limb length and other critical physical and physiological ratios are not linear, but scale in a number of different ways.

Sizes and Shapes of Animals

- ◆ The sizes and shapes of animals affect their interactions with their environment. There is amazing diversity of life on our planet, and all animals, from the smallest insect to the largest mammal, need to adapt to a common set of biological and physical problems. For example, all animals need to breathe or intake oxygen, find and process nourishment for themselves, excrete waste products, and move around their environments.
- ◆ Body size is a major factor for both determining an animal's daily requirements and for solving this set of biological and physical problems. The body plan of animals, large and small, results from development programmed by the genetic code. The unique DNA blueprint of each animal is the result of evolution over many generations of ancestors subjected to natural selection.
- ◆ Humans evolved via natural selection in our own environments, while smaller mammals, such as mice and their rodent relatives, evolved in their unique niches. Each species has its own form and function that is most adapted to its niche in the environment so that individuals survive and reproduce the next generation, making the species successful over time.
- ◆ When we study animals' form and function in our modern way, we're in the disciplines of anatomy and physiology. Anatomy is the study of the structure of organisms. Physiology is the study of the functions and activities performed by organisms.
- ◆ In terms of anatomy, all vertebrates have a similar body plan. A vertebrate, in short, is any animal with a backbone. At some point in their lives, all vertebrates share the earliest characteristics of primitive vertebrates. No matter what the adult looks like, the similarity of embryonic plan indicates a similarity of ancestry, somewhere back in the history of the planet.



- ◆ Despite the differences between frogs and humans, we are all vertebrates with unique physical and physiological challenges. And physiology differs according to body size: It is different if you're a tiny mouse or a giant elephant. This is called allometric scaling, which defines how differences in body size result in differences in physiology, such as faster heart or breathing rates in small creatures.
- ◆ Centuries ago, Galileo was one of the first people to think about allometry. He realized that increases in bone diameter needed to exceed increases in bone length, and he described this in a simple proportionality formula: Diameter is approximately equal to length squared. Allometric formulas ever since have been exponential or log-log expressions of body mass to metabolic rates, or bone length to bone mass and bone density or strength, and other features.

- ◆ Size affects metabolic rate. Taking into account the phylogeny of animals, the tested animals' digestive state, and body temperature, scientists generally agree that the basal metabolic rate of mammals scales, on average, with a body mass exponent of 0.68, or about $2/3$.
- ◆ Even so, when different species are compared on an equal-size basis within taxa, some require much less energy than others. For example, sloths, slow lorises, and some marsupials have standard metabolic rates below 40% of the minimum maintenance requirements for other mammals of the same size.
- ◆ Research continues to provide evidence for metabolic rate changes based on mass for adult mammals ranging in size and proportion from small mice to enormous elephants.
- ◆ Within the animal kingdom, a number of variables—including heart rate, breathing rate, and other physiological variables—scale down with increasing body mass.
- ◆ In general, as animals get larger, they have slower pulse rates and longer lives. This means that each individual life on this Earth has about 1 billion heartbeats before we die. It also means that animals behave differently at different body sizes.
- ◆ It turns out that biological outcomes such as population size, average time until reproduction, and average number of offspring also all scale to the quarter power of body mass for many kinds of animals. Scientists are still

DID YOU KNOW?

A mouse heart rate is about 300 to 800 heartbeats per minute, while an elephant has a heart rate of about 25 to 35 beats per minute.



working on the intricacies of this apparent biological law of scaling metabolism with body mass.

Physical Proportion of Body Structures

- ◆ For animals of different sizes, scientists have found that supporting the weight of the body is more dependent on position of the legs relative to the body, or what is called posture, than size of supporting limbs, at least in birds and mammals.
- ◆ For example, most mammals carry their bodies over 4 appropriately sized legs. Birds and humans are the only true bipedal animals. Because the other thousands of species of mammals are quadrupedal, it is apparently easier to support the weight of a body on 4 legs rather than 2 legs.
- ◆ Evolution has solved bipedal posture in 2 ways: Humans are plantigrade (we walk on our palms and soles), and birds are digitigrade (they walk on their toes).
- ◆ Part of the evolution toward large size is based on scaling of limbs in conjunction with posture and is simply a safety factor for the body.
- ◆ Zoo-based scientists in Germany have studied tall running birds and have discovered that they increase their stride and frequency of steps

DID YOU KNOW?

A half-ounce house mouse has a 21-day gestation period and therefore can have 5 or 10 litters of babies every year, with 4 to 5 babies per litter. In contrast, an elephant weighing 3 to 5 tons has a 22-month gestation period and can only have 1 baby every 5 years or so.



to run while supporting their relatively large bodies. The positioning of the muscle mass in the legs helps with support for these larger animals.

- ◆ When the legs' muscle mass is located close to the body, as in our human thigh muscles, the legs can swing faster, and this body plan also allows good bipedal support and allows humans and birds to move around efficiently on land in search of food or for other reasons.
- ◆ The flexibilities of human legs also allow us to climb trees and ride bicycles, and these greater flexibilities allowed humans to move to different habitats around the world. So, for humans, 2 legs work well.

DID YOU KNOW?

The largest bird ever known—the extinct elephant bird—could only support a body mass of about 1000 pounds on its 2 legs, much less than half the weight supported by 12,000-pound elephants, the largest quadrupedal mammals alive today.



- ◆ The 4 supportive legs of large mammals, such as elephants, act more like columns in their upright positioning when compared to the more flexible legs of small mammals, such as mice, which bend their legs while running and crouch when standing.
- ◆ For very large animals, such as extinct dinosaurs and modern elephants, their extreme weight means that limbs need to be fully upright for body support, and the mechanical advantage offered by bent limbs is not even possible. The amazingly robust and massive limb bones of larger creatures are thickened and cause relatively slower locomotion. This trade-off requires that the very large animals lose running speed and agility.
- ◆ Allometric characteristics of growth, metabolism, and reproduction suggest that there might be upper and lower limits to size as animals evolve, for both vertebrates and invertebrates.
- ◆ Two basic functions of the vertebrate skeleton are to give support to the body against the pull of gravity and to serve as a rigid framework for contracting muscles to accomplish articulated movement of the limbs. But that's not all a skeleton is for.
- ◆ Vertebrates have highly developed brains enclosed by a bony skull. They have well-developed sensory organs and supporting nervous systems, as well as respiratory

DID YOU KNOW?

Scientists have concluded that the infamous dinosaur Tyrannosaurus rex could not run, despite what movies suggest.



systems with either gills or lungs. And they have vertebrae to support their nerve cords, the main pathway for extensive nerve networks between muscles and the central nervous system.

- ◆ Invertebrates have no vertebrae—no spinal column. In fact, none of the animals we call invertebrates have internal skeletons at all. Invertebrates make up about 95% of the species on Earth. A large number of those—about 80%—are the arthropods. These include the insects and arachnids, among others.
- ◆ Instead of an internal, bony skeleton, arthropods have an exoskeleton for structural support and protection. Small arthropods have better support from the exoskeleton than they would from an endoskeleton.
- ◆ An arthropod's exoskeleton is made out of chitin, a biological polymer that is strong and is found as support in invertebrates and even in fungi, but it is not as strong as bone—another reason giant invertebrates can never be as large as giant vertebrates.
- ◆ Due to lack of a sturdy, internal supportive structure, most invertebrates are small. Conversely, the strong, internal bony support structure of vertebrates has resulted in the largest animals that have ever lived on Earth.



Metabolism

- ◆ An advantage of large size is that it may help animals escape predation. Larger animal body size may also be an adaptation for environmental fluctuations, and larger body size even permits a greater efficiency in metabolizing nutrients.
- ◆ For example, while mice use absolutely less oxygen than elephants, rhinos, or oryx, the metabolic cost of maintaining body temperature and homeostasis is less per ounce for elephants and other large mammals than for mice and other small mammals.
- ◆ This is because of the surface-to-volume-ratio effect on metabolism: The relatively smaller surface area of the large mammal body loses less heat energy than is lost from the relatively larger body surface area of a smaller mammal under similar conditions.
- ◆ Movement in large animals also requires less energy per unit weight than movement in small animals. The energy cost of moving each ounce of an elephant's body over 100 yards is only 1/30 of the metabolic cost of moving a mouse over the same distance, even though the elephant will use more oxygen in absolute terms than the mouse when running over that distance.
- ◆ One would think that high energy expenditure would relate to life-span as it does when we compare across species, where we know, for example, that mice have much shorter lives than elephants. But in recent intraspecific studies, high energy expenditure is positively correlated with longer life expectancy. Comparisons of metabolic rate against size and life-span across species still appear to trend in the opposite direction.
- ◆ Within the small family group of bears, the small tropical sun bears, which are the size of a German shepherd, are not even close to the size of the largest of bears, the Kodiak bears and polar bears that weigh 500 to 1000 pounds and eat salmon fat and seal blubber, respectively.

- ◆ These species of bears have similar evolutionary histories because they are bears, but the tropical bears have been separated for so long from other, more carnivorous bears that they have solved survival problems by adapting to different specific niches in the world's environments.
- ◆ With their small body size and relatively larger surface-to-volume ratio, as well as the sun bear's thin hair coat over that body surface, this tropical bear is well adapted to its warm, moist environments. Kodiak and polar bears have smaller surface-to-volume ratios, and their body surface is further protected by a thick internal layer of fat as well as a much thicker, more luxuriant hair coat to protect against the cold.
- ◆ So, even closely related animals can exhibit diverse characteristics as they evolve in different environments over time and solve different challenges to life.



Kodiak
brown bear

- ◆ An adaptive response to climate over the centuries has given rise to discreet changes in body-extremity proportions through natural selection. In this case, there is a displacement toward larger animal body size going from milder to colder environments, even within a species. This is called Bergmann's rule.
- ◆ This allometrically evolved geographic variation has adaptive significance that is found all over the animal kingdom, from small tropical bears and tropical tigers to large northern bears and Siberian tigers, and from relatively smaller temperate sparrows to larger arctic sparrows. Subpopulations of animals show larger individual animal size in colder environments, showing that this is a genetically determined trait.
- ◆ Physiological processes need to remain in balance to ensure stability of body temperature, hormone balance, and other properties following disturbance to an animal's body. The processes that rebalance the body systems are known collectively as homeostasis.
- ◆ All the activities of life, such as movement, respiration, and searching for food, require fuel. The study of how animals obtain and use fuel is called bioenergetics. An understanding of bioenergetics is also important as we seek to understand how animals maintain stable internal conditions in their bodies.

Suggested Reading

Bertram, *Understanding Mammalian Locomotion*.

Calder, *Size, Function and Life History*.

Johnson, "Of Mice and Elephants."

Lecture 19

Protection, Support, and Homeostasis

The diverse range of strength and movement abilities of animals is the result of a combination of their protective and supportive outer structure, their skeletal support, and the arrangement and abilities of their muscles, tissues, and internal organ systems. Among these features, animals have evolved an impressive number of forms and array of functions. This lecture will explore the diversity of adaptations that animals have developed for protection, support, and homeostasis.

Homeostasis

- ◆ Sea lions are mammalian carnivores, which means that they have a vertebrate body plan and have hair covering their bodies, that they bear live young and feed them with milk, and that they eat other animals—in this case, mostly fish.
- ◆ But sea lions, like their pinniped cousins the seals and walruses, are semiaquatic, so they have different needs than both the land dwellers, such as humans and dogs, and the other marine mammals, the whales and dolphins.
- ◆ Sea lions have to meet several challenges, one of which is the challenge of temperature regulation. Many of the pinnipeds prefer to live in subarctic zones, where the water ranges from around 50° or 60° Fahrenheit in the summer down to near freezing in the winter.



- ◆ On top of this, California sea lions spend part of their lives in water and part on land, in a region where air temperatures tend to peak in the 90s in summer and in many parts of the range below 0 in winter. So, a sea lion has to be able to adapt to dramatic ambient temperature shifts not only from season to season, but sometimes from hour to hour.
- ◆ To carry on the processes of life, a sea lion needs to maintain a constant body temperature under all ocean and air conditions. In other words, sea lions and other mammals need to maintain temperature homeostasis. Homeostasis refers to the process of maintaining a stable equilibrium in any physiological process.
- ◆ For sea lions, maintaining a stable body temperature means having fur and blubber. Sea lions have coarse, brownish fur that appears black when the animals are wet. Like their cousins the fur seals, they have guard hairs that overlay a coat of underhairs, which are waterproofed by oil from skin glands and are designed to trap air near the body when out of the water. The animal's body heat warms the air, and the trapped warm air keeps the animal cozy.
- ◆ However, their undercoat isn't as thick as a fur seal's undercoat, so it can only provide so much insulation. And it doesn't really insulate much at all when the animal is underwater.

DID YOU KNOW?

Blubber—which warms the body simply by being a poor conductor of heat—helps the warm-blooded sea lion maintain temperature homeostasis in the cold-water environment of the Pacific Ocean.



- ◆ Sea lions also have skin that is water-repellant and overlies a fat layer known as blubber. Almost all aquatic and semiaquatic mammals have some sort of blubber—otters are an exception. Sea lions have a relatively thin layer of blubber that helps keep them warm and adds to their hydrodynamic shape while swimming.
- ◆ Insulation is very poor in a flipper, but this is actually an advantage. Sea lions can hold their flippers up like sails to either absorb the Sun's heat when they are cold or to dissipate heat into the wind when they are hot. The cooled or heated blood from the flipper exchanges heat with other body structures as it circulates, helping to thermoregulate the entire body. If it's very cold and there's no sunlight to be had, the blood vessels in the flipper can constrict to minimize the loss of body heat.

Protection

- ◆ Thermoregulation is just one of the purposes of an animal's outer body covering, or integument. Skin is one type of integument, but this word can also refer to the membranes of small creatures or the cuticles of insects. Technically, the term refers to the protective body covering of a creature and any external attachments to that covering, such as scales, hair, or shells.
- ◆ The function of the integument layer is basically to keep the outside out and the inside in. It helps maintain the homeostasis of physiological processes and values, such as core body temperature and water balance. It is also a defense against invasion by foreign bodies and microorganisms as well as chemical and mechanical injuries, including sunburn, dehydration, and even physical blows.
- ◆ Integument comes in many different forms. Water-dwelling invertebrates such as clams, oysters, and other mollusks, have what zoologists call a mantle, an outer fold of skin covering an opening called the mantle cavity, which contains gills and excretory organs. The mantle also secretes parts of the shell to increase the size



and strength of the shell as the creature grows. This exterior shell supports and protects the soft inner parts of the animals.

- ◆ This arrangement is ideal for an invertebrate in a watery environment, but as invertebrates evolved from water living to land dwelling, they needed to develop a different kind of integument. To maintain their total body water balance, invertebrates now needed a water-retaining cuticle structure to function as a protective outer layer.
- ◆ The enormous phylum of invertebrates known as the arthropods have a cuticle: a protective covering with living and nonliving layers. The cuticle is secreted by a single-celled layer of epithelial tissue called the hypodermis, and it consists of a combination of chemicals, cellulose, fibers, and chitin and is a complex type of integument. The arthropod's muscles are attached to the inside of this external covering, which also serves as a supportive exoskeleton.
- ◆ In the vertebrates, we find another multilayered integument in sharks, rays, and other cartilaginous fishes. The skin of these animals

has several layers and contains mucous glands and sensory cells as well as small placoid scales that are dermal in origin. These placoid scales, also called denticles, almost resemble vertebrate teeth and are found within the skin layer. These placoid scales contain nerves and blood vessels, and as the body grows, the shark's skin area also increases its production of new denticles. When the denticles reach maturity, they are like vertebrate teeth because they do not grow; instead, they wear down and are lost.

- ◆ In amphibians such as salamanders, the epidermis is made up of several layers of cells. The amphibians are the first taxonomic group to have developed a dead, horny outer layer of skin, which zoologists call a stratum corneum. This layer is an early adaptation to life on land because it is protective and prevents loss of moisture from the body, and therefore this layer is most developed in amphibians that spend much of their time on land.
- ◆ In reptiles, the skin is thick and dry and contains hardly any glands (except maybe scent glands for sexual activity). The dry skin with few glands is an adaptation to prevent evaporation of water, which is what allowed the early reptiles to conquer the land. The stratum corneum of the reptile epidermis is well developed

DID YOU KNOW?

Pigment cells, known as chromatophores, are abundant in amphibians and reptiles and help in camouflage or as warning coloration.



and produces horny scales. Reptile scales often form crests or spines, so these creatures are protected and can also display to other creatures.

- ◆ Birds are considered avian reptiles and also have a thick, dry skin like the non-avian reptiles, which is how they have also been able to conquer the land. Birds probably own the most famous of the color pigments in their beautiful feathers. The colors of bird feathers and integumentary surface coverings in other animals are either structural colors (which are achieved by scattering light off molecules in the feathers or other integumentary coverings) or pigment colors (which are produced by pigments such as melanin that are produced in pigment cells).

DID YOU KNOW?

Of the approximately 10,000 bird species on Earth, all are thought to see in color.



Support

- ◆ Scales, feathers, hair, and even beaks, toenails, and horns are modifications of the integument. The protective integumental layer needs to be assisted by some other rigid support. Animals have 2 basic kinds of support—hydrostatic or rigid—and rigid support systems can be subdivided into endoskeletons and exoskeletons.

- ◆ Support can be offered by a fluid, hydrostatic skeleton. Many invertebrates have a hydrostatic skeleton, which is best understood as a closed compartment that holds fluid inside and under pressure to assist the body in remaining rigid. Some of the most amazing invertebrates have this kind of support, including soft sponges.
- ◆ But maybe the most familiar example is the earthworm. In this type of support, the muscles in the wall of the tubular body have no external or internal means of attachment but develop a solid muscular force by compressing against incompressible fluids. The earthworm can expand and contract against its body wall, and this provides movement to the creatures. Zoologists call this form of support a muscular hydrostat.
- ◆ Another muscular hydrostat is the trunk of an elephant. The elephant's trunk lacks any form of skeletal support because it is devoid of bones. But it does have more than 40,000 muscle fibers, and they work because they are made of incompressible tissues that are maintained at constant volume by the elephant's physiology.
- ◆ The amazing movements of the earthworm and elephant muscular hydrostats depend on muscles arranged in very complex patterns. The supportive tissue of invertebrates is a rigid exoskeleton.
- ◆ The supportive tissue of a vertebrate's internal skeleton, or endoskeleton, includes the cartilage derived from the mesoderm



germ layer and the bone itself. The vertebrates' internal skeleton gives the body physical support, protects the body's organs and organ systems, and is part of the musculoskeletal system that gives all vertebrates the potential for movement.

- ◆ Bone is a living tissue that surrounds an inner bone marrow, which helps with production of blood cells. On the outside of each bone is structural bone tissue, and between structural bone and the inner marrow is trabecular bone, which gives more support to the bone structure.
- ◆ Joint bones, ligaments, tendons, and muscles all work together to produce movement. The bones support animals' bodies and help define animal shape. The joints are where 2 bones meet and make the skeleton flexible and enable movement. Muscles are the stretchable masses of tissue that work with tendons and pull on our bones to make us move. The fibrous ligaments work together to attach from one bone to another.

Suggested Reading

Calais-Germain, *Anatomy of Movement*.

Durrani and Kalaugher, *Furry Logic*.

Schulkin, ed., *Allostasis, Homeostasis, and the Costs of Physiological Adaptation*.

DID YOU KNOW?

An elephant can use its muscular trunk—which lacks any form of skeletal support because it is devoid of bones—to maneuver a large tree trunk or even to pick up a tiny peanut.



Animal Energetics and the Giant Panda Problem

The processes of life burn fuel, so an animal has to take in about the same amount of fuel that it expends over a given period of time to keep its body functioning well. The ultimate source of the energy used by every living thing on Earth is the Sun. We can think of life as the process of converting the Sun's energy into food and back into energy again through creating and breaking chemical bonds. Although all of our energy ultimately comes from the same source, animal diets are as varied as the animals themselves.

How Energy Flows through an Ecosystem

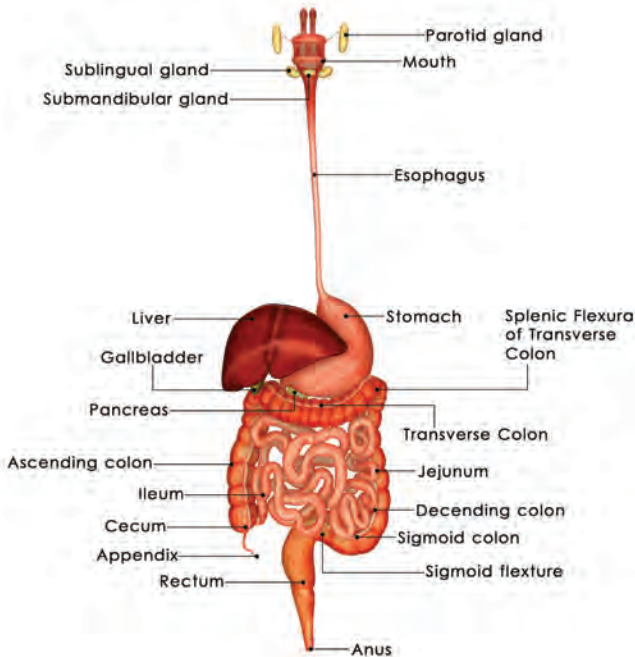
- ◆ Every living thing on Earth gets energy in 1 of 3 ways: It can be a producer, a consumer, or a decomposer.
- ◆ A producer, also known as an autotroph, is an organism that can make its own food. One familiar type of autotroph is green plants. But there are 2 other kinds of autotrophs. One of these is algae, which, like advanced plants, produces energy through photosynthesis. The third type of autotroph, called chemotrophs, are ancient forms of bacteria that live deep in the ocean near thermal vents, the heat of which is used to combine inorganic compounds with carbon dioxide to make food.
- ◆ The autotrophic producers not only produce their own food, but they produce food for the consumers within the food web. Consumers are heterotrophs—they are “other eaters.” All animals are heterotrophs.
- ◆ A consumer that feeds on plants or other primary producers is called a primary consumer. This group includes the mammalian herbivores, who ferment tough plant parts in their vat-like stomachs; other types of herbivores, such as some fish, amphibians, and birds that consume algae, so they are algivororus; primates that eat fruit or leaves, the frugivores and folivores; and bees, which are palynivores, or pollen eaters.
- ◆ A secondary consumer is a consumer that mostly eats other consumers, such as carnivorous mammals and omnivorous primates and bears.
- ◆ Tertiary consumers eat the secondary consumers, such as the carnivorous lion that hunts and kills its own food or the carrion-eating hyena that eats what other animals leave behind. Many of these are the animals we call apex predators because they eat other animals, even other carnivores, but there are very few animals that eat them.
- ◆ The last step in this trophic chain is the decomposers, the bacteria and fungi that eat the flesh of dead animals, plants, and animal



waste, breaking it back down into its chemical components so that the cycle can start all over again.

- ◆ This system is not very efficient. No organism on Earth gets 100% of the available energy out of the food it eats. In fact, while some plants are more efficient than others, on average they only convert about 1% of the energy they absorb into biomass—in other words, into their physical structures.

- ◆ Consumers at each level only convert about 10% of the available biomass in their food into their own biomass. So, from the producers on the bottom of the so-called trophic pyramid up to the apex predators at the top, massive amounts of energy are lost.
- ◆ Life on Earth cannot continue without the continuous influx of energy from the Sun. But the production of energy is really just the start of the process. From there, we have to ask how an animal obtains energy from the food it's eating.
- ◆ In an animal, metabolism involves everything from the cephalic phase to the defecation phase. The cephalic phase is the animal's initial response to some sort of food cue. Part of the human cephalic phase is the mouth watering when dinner is smelled. Many animals respond



to smells—to olfactory cues. Some respond to visual cues. Some respond to both.

- ◆ The cephalic phase primes the gastrointestinal tract for the work it's about to do, getting muscles and secretions ready to go. When food goes into the oral cavity, the digestive process may start immediately through salivary enzymes, or it may start with reduction in the size of food particles—in other words, chewing. In humans, it's both.
- ◆ Food then moves down the esophagus, which is basically just a muscular transport tube, and then passes into the stomach. At this point, the stomach adds gastric acid and pH-balancing enzymes that protect the stomach lining from the acid.
- ◆ The small intestine is where 90% of digestion takes place in humans and other primates. Food breakdown continues here, and nutrient absorption begins. Finally, food passes into the large intestine, where water is pulled out of the remaining digesta, and then the undigested food is passed out of the animal.
- ◆ These processes are different in mammalian herbivores versus mammalian carnivores, for example, and those differences from animal to animal help determine the most efficient diet for a particular species. In nature, we expect an animal's diet to reflect its physiology, and vice versa. And most of the time it does. But there are some exceptions, and those exceptions teach us many lessons.

Giant Pandas

- ◆ One of the most inefficient feeders on the planet is the giant panda. It has the physiology of a carnivore, but it eats a diet made almost entirely of tough, woody bamboo.
- ◆ Humans could probably survive our whole post-weaning life on a vegan diet of all plants or a carnivorous diet of all meat, fish, and

A giant panda is sitting on the ground in a naturalistic enclosure, eating a piece of bamboo. The panda is surrounded by bamboo stalks and green foliage. The background is slightly blurred, showing more of the enclosure.

DID YOU KNOW?

An adult panda weighing an average of 250 pounds consumes about 30 pounds of bamboo a day—sometimes more.

At Smithsonian's National Zoo, to ensure that the pandas get enough food, 100 pounds of bamboo per bear is put into their enclosure each day. They also sometimes get other treats, either food they might consume in the wild, such as tubers, or specially formulated panda snacks.

eggs. We are able to do this because we primates are omnivores. We eat plants, fungi, and animals in various forms.

- ◆ And our teeth are generalized for these activities: We can slice with our incisors, hold onto meat with our canines, and grind with our premolars and molars. We can digest fruits and juices, nuts, and meat in our relatively simple stomachs.
- ◆ Humans even developed fire and cooking, as well as external fermentation that we use when we make beer and yogurt. Cooking and fermentation break down protective cell walls of plants, the tough tissues of animals, and the complex biochemicals in both into more easily digestible nutrients.
- ◆ Bears can't make fires or beer, so they can't break down food before they eat it. They also have relatively short, simple digestive tracts, like most carnivores do. There's no place to slow down the passage of food and let gut microflora do its work, as you would expect in a typical herbivore. So, even though bears can eat plants, because they eat them raw, the plants are poorly digested when they pass through the gut.
- ◆ We can see the result of this minimal digestion in the bears' feces. Bears that eat a lot of plants will defecate in large, poorly digested piles, and the fecal matter may even have undigested food in it.
- ◆ Bamboo leaves a panda looking very much like it did just after it was chewed. Because pandas get such little nutrition out of their bamboo, they have to consume a lot of it.
- ◆ Once bamboo is eaten by a giant panda, the microorganisms that exist in the panda's gastrointestinal tract don't lend themselves to digesting fiber well. The panda gastrointestinal tract is probably better designed to handle the milk that it consumes as an infant than it is to handle the bamboo that it eats as an adult.
- ◆ The gut microbiome, the population of tiny symbiotic creatures living in each and every one of us, play a huge role in digestion—

DID YOU KNOW?

Pandas' masseter muscles, which connect the cheekbone area to the bottom of the jaw, are able to crack through pieces of bamboo that zookeepers have to use a chainsaw to cut.



- in determining how we get nutrients from our food—and that means they influence what we can and can't eat. The microbiome is an ongoing area of research in both human and animal studies, and it's sure to yield fascinating and important discoveries for years and decades to come.
- ◆ Although pandas have a typical carnivore skull shape and tooth plan, they have evolved a few special attributes to allow them to make the most of their bamboo. First, they have immensely powerful masseter muscles, which connect the zygomatic arch (the cheekbone area) to the bottom of the jaw.
 - ◆ The other adaptation pandas have is a sesamoid bone, which is a modified bone in the panda's wrist that looks like a thumb. In the human hand, the sesamoids are little bumps—about the size of a sesame seed, thus the name—on our first and second metacarpal bones. Our sesamoid bones are adaptations that allow our tendons to glide smoothly over the metacarpals.
 - ◆ In a panda, the sesamoid is enlarged into a thumb-like projection coming off the wrist. It looks like they have 6 digits. While not flexible or opposable like human thumbs, the modified sesamoid still allows them a better grip on their bamboo.

Suggested Reading

Eisenberg, *Trophic Cascades*.

Wenshi, *A Chance for Lasting Survival*.



Lecture 21

Ethology: Studying Animal Behavior

Watching animals behave, and understanding that behavior, has been incredibly important for human survival—for understanding our pets and domestic animals, for understanding game species, and for understanding and managing threatened species to save animals from extinction. For good management of both wild and domestic animals, we need to know about many kinds of animal behavior: where and why animals choose shelter, when and what animals eat, how and when animals reproduce, why animals live alone or in social groups, and how they communicate with one another. This lecture will cover some of the history and focus of animal behavior studies.

Ethology

- ◆ In the 1970s, 3 famous professors were awarded the Nobel Prize in Physiology or Medicine for developing the modern approach to objectively studying animal behavior under natural conditions, a field called ethology.
- ◆ Austrian zoologist Konrad Lorenz became famous for his studies of graylag geese and their instinctive behavior, especially imprinting, in which young animals instinctively bond with the first objects they see during some critical period after hatching or birth.
- ◆ Lorenz met Dutch zoologist Nikolaas Tinbergen in the 1930s, and they collaborated on these imprinting studies. Tinbergen dedicated many of his own studies to instinctive spontaneous behaviors that appear in full form the first time they are performed.
- ◆ Austrian Karl von Frisch was famous for his studies of honeybee sensory abilities and communication, including the fact that honeybees have color vision and that they perform “dances” to relay information about the location of flowers to other bees.

Graylag
goose



- ◆ Other zoologists, known as experimental psychologists, most often studied observable animal behavior in laboratory environments.
- ◆ In studying the digestive physiology of dogs, 19th century Russian scientist Ivan Pavlov needed to collect their saliva and soon noticed that the salivary response started not in response to the strong biological stimulus of food, but to a previously neutral stimulus paired with the food, a bell. This learning process, an apparently unconscious pairing of stimuli within the animal brain, is called classical conditioning.
- ◆ American scientist B. F. Skinner furthered our understanding of conditioning by studying how actions performed by animals resulted in consequences that were consciously understood by the animal—a situation called operant conditioning.
- ◆ That means the animal could increase a behavior in the presence of a desirable stimulus or decrease it in response to an undesirable stimulus. Skinner tested these ideas in a Skinner box, otherwise known as an operant conditioning chamber. In a Skinner box, an animal can be trained to perform a certain action by coupling the action with a reward. An animal's observable behavior was changed by these reinforcing rewards.
- ◆ Although Skinner's original studies were made with food rewards, reinforcers do not need to be limited to food. They can be social interactions, such as petting for a dog, or other rewards, such as more playtime, that are desirable to the animal. Application of this idea by animal trainers leads to a stronger human-animal bond as well as a greater understanding of the science of operant conditioning.
- ◆ Classical conditioning and operant conditioning together form the field of behaviorism in psychology and today influence how we study animal behavior and even the animal mind. Zookeepers around the world use this animal behavior theory to enhance the welfare of zoo animals every day.

- ◆ Niko Tinbergen was the first to suggest that we ask how questions (proximate questions about the immediate causes of a behavior) and why questions (about the evolutionary purpose and origin of a behavior) about animal behavior.
- ◆ Why questions ultimately help us study change in evolutionary time, because we can examine how the behaviors have changed over time in response to environmental pressures and how these behaviors indicate phylogenetic relationships. Understanding how behavior evolves in nature is central to studies of behavioral ecology and requires that we understand behavior, evolution, and ecology.
- ◆ We expect natural selection to allow survival of the fittest—that is, behaviors are favored if they enhance the ability of individuals to survive and subsequently reproduce. Linking behavior to ecology is important because ecology creates the environmental stage on which the behavior dramas play out. And understanding the behavioral ecology of a species is important for its management and conservation in nature.
- ◆ Behavior studies often start with keen observations of animals in zoos, where it is easy, and then moves on to studying the animals in nature, where observing may be more difficult. It sometimes takes one zoologist years of observing animals just to be able to ask good how and why questions about the species' ecology and behavior.
- ◆ Tinbergen was one of the first to use this kind of experimental approach when he and Lorenz tested the reaction of young, naïve turkey chicks to predator images to see if responses to predators are innate or learned behaviors.
- ◆ They found that if a cardboard silhouette of a bird is flown over the naïve prey birds in 2 directions, the prey birds flee if the dummy bird is flown in the direction in which it looks like a hawk and do not flee if the same dummy is flown in the direction in which it looks like a flying goose. These early studies supported the basic hypothesis that some anti-predator behavior is innate.

- ◆ Other animals are not born with the full complement of anti-predator behaviors and need to learn them. Smithsonian scientists who helped save black-footed ferrets from extinction used an applied version of the earlier Tinbergen-Lorenz study to train naïve black-footed ferrets to avoid predation.

Black-Footed Ferrets

- ◆ The greatest threat for black-footed ferrets is disease, and that's historically been the issue since the species was rediscovered in the early 1980s. The current disease that is threatening these animals is the sylvatic plague, an exotic disease that not only impacts black-footed ferrets, but also impact their prey, the prairie dog.



- ◆ Black-footed ferrets went extinct in the wild in 1987, and then zoos and breeding centers brought them back. Smithsonian's National Zoo first got black-footed ferrets in 1988; they were the first zoo in the country to have them in their collection.
- ◆ The Wyoming Game and Fish Department initiated the breeding program, and the work of researchers at the National Zoo in the areas of breeding, nutrition, and animal husbandry saved the species.
- ◆ The species was thought to be extinct in the late 1970s, and it was a dog that rediscovered a population in 1981. That population was studied in the wild, but due to disease the population declined, forcing researchers to rescue the remaining black-footed ferrets, 18 of which survived to form the foundation for the breeding program.
- ◆ Black-footed ferrets have now been reintroduced to Canada, the United States, and Mexico. The recovery plan from Fish and Wildlife Service calls for thousands of these ferrets at numerous locations within their home range. The black-footed ferret reintroduction has been one of the most successful conservation efforts ever.

Behavioral Ecology

- ◆ Zoologists who study animal behavior have made many of their richest discoveries by first observing and cataloging many behaviors in an ethogram, which is a full catalog of the animal's behaviors, during studies of zoo and aquarium animals. The researchers then take their improved techniques and methods to the field. Having an ethogram to help define field observations and analyze their importance to the animals is an efficient and effective way to begin studies of behavioral ecology.
- ◆ Take, for example, the work of Smithsonian National Zoo's research zoologist Devra Kleiman. There is a great deal of diversity in the ecological niches occupied and many differences in morphology among foxes, wolves, and other members of the dog family Canidae.

Kleiman's studies comparing different canid species to other wild dogs showed that despite this ecological and morphological diversity, social behaviors remain similar across canid species.

- ◆ She suggested that some specializations have occurred in group-living species, which help maintain cohesion within the group and reduce aggression among group members and across groups. Kleiman and her colleagues suggested that these changes in wild dog behaviors and dog postures have been changes of degree rather than in type of behavior.
- ◆ For example, the bat-eared fox and the wolf have developed different strategies to maintain group cohesion. The bat-eared fox uses social



grooming and other contact behaviors in conjunction with subtle postural changes, while the wolf has evolved overt postural changes. These are changes in degree of display. Kleiman concluded that these differences were related to the different evolutionary ecology of each species.

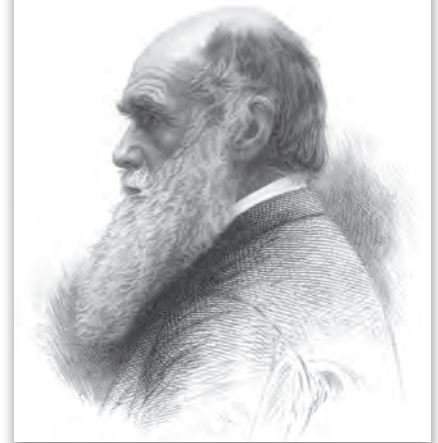
- ◆ Kleiman and her National Zoo colleague John Eisenberg later performed an analysis of differences between carnivorous mammals: the largely solitary and apparently unsocial wild cats and the largely social wild canids. They compared canids and felids in terms of their evolutionary histories, species and family distributions, habitat preferences, dog and cat morphology, and differences in behavior.
- ◆ Felids are obligatory carnivores, and canids have omnivorous habits. Dogs and cats hear in the same frequency ranges but have different visual and olfactory senses.



- ◆ Wild cats have the largest eyes of any carnivore and therefore may have better visual acuity at close range, while dogs have a wider field of vision. Dogs can smell at least 4 times better than cats based on the numbers of olfactory receptors.
- ◆ While cats use their olfactory abilities to find one another and examine other environmental scents up close, wolves and other wild dogs use their keen sense of smell to avoid predators and find prey from a greater distance. Kleiman and Eisenberg suggested that the type of stalking hunting that is performed by mostly solitary cats with the sharp, retractile felid claws are winning traits for the solitary felids.
- ◆ An increase in body size occurred in tigers, leopards, lions, and other cats as an adaptation to hunting large prey such as deer, antelope, and other herbivores, in a solitary way. In a separate niche in which many canids hunted slightly larger prey, the wild dogs kept a relatively moderate body size, and several species evolved well-developed pack-hunting techniques.
- ◆ Because of these adaptations, Kleiman and Eisenberg suggested that group structure in canids is based on long-term affiliations between a mated adult pair and their offspring, while felid group structure is based on the core group of a mother and her maturing daughters. Canids therefore develop a strong pair bond

DID YOU KNOW?

Charles Darwin studied barnacles and earthworms most of his life because he found them to be incredibly interesting for answering the questions he had about natural selection and the beneficial nature of these creatures.



DID YOU KNOW?

When Immanuel Kant was writing about early educational theories, he commented on how house sparrows needed to learn their song and how they could learn canary song if left with canary foster parents, which would appear to be a case of social learning, as opposed to instinct.



- not observed in the felids due to their ecological niche and evolutionary history, and canids have even evolved the behavior wherein males provision their young.
- ◆ Research biologists at Smithsonian's National Zoo used the common song sparrow to study its diversity of size, color, and song. They found that song sparrows in different regions have regional dialects across subpopulations and subspecies.
 - ◆ Smithsonian's animal behavior scientists and their colleagues have studied the songs of song sparrows to understand many behavioral questions, including whether individual sparrows recognize neighbors (they do); how sparrows communicate aggressive intent (apparently, singing very softly is a good indicator of this intent); and how nutrition during the early life of sparrows influences song learning and complexity (a better diet results in better songs).
 - ◆ Behavioral studies in a common species with a wide range provide a model for understanding how and why animal behavior evolves and is different across space and time.

Suggested Reading

Ackerman, *The Genius of Birds*.

Cheng, *How Animals Think and Feel*.

Marzluff and Agnell, *Gifts of the Crow*.

Safina, *Beyond Words*.

Think! How Intelligent Are Animals?

Thinking is mental flexibility: the ability to create a plan B if plan A doesn't work. If an animal reacts to a stimulus not with a pre-programmed, unchanging set of behaviors, but instead can figure out a fundamentally different way to reach its goal, then we can say that the animal is thinking. This lecture will examine the behaviors of different animals to determine whether they can be said to think.

Mental Flexibility

- ◆ Think about a time when you acquired a new way of dealing with a problem. Maybe it was dealing with software on your computer, or a cooking technique, or the best driving route between point A and point B. Whatever it was, you probably acquired that flexibility through 1 of 2 methods: Either you discovered it yourself through repeated trial and error, or someone showed you a new way.
- ◆ Trial and error is a relatively simple kind of learning that we not only perform ourselves, but that we can observe in animals. Trial and error simply requires repeated, different attempts at a task over a certain amount of time. You (or the animal) then associate behaviors with the consequences they produce.
- ◆ Pleasant consequences tend to reinforce and increase behaviors. If a dog is cued to sit, does as he's asked, and receives a biscuit, that is a pleasant consequence for the dog performing the correct behavior. The dog will have a tendency to increasingly do the behavior that he expects will result in a reward.
- ◆ Animals also learn by trial and error in nature, without human interference. For example, a young osprey may dive during multiple



early attempts to catch a fish and probably misses several fish, even though fish hunting may be a partially innate behavior in these birds. Finally, the osprey dives at just the right speed and catches a fish, which is a pleasant consequence of a well-timed dive. Then, plunging into the ocean after fish in the most accurate and successful way is a learned behavior that tends to continue.

- ◆ When we're in the lab looking at animal learning, a very common skill researchers utilize is maze navigation. Researchers use T-shaped mazes, called T-mazes, with no food reward to determine whether rats have a right- or left-handed turn preference. Once preference has been established, food rewards are added to see if the rats can change their preferences and how quickly that happens.
- ◆ More complex, timed mazes determine how fast the rats learn by trial and error. In these mazes, the pleasant consequence of a food reward is placed in some arm of the maze to see how many trials it takes for the rat to choose the food end of the maze consistently.
- ◆ If we move the rat's cheese, we can see how long it takes the rat to change his preference to the new food location—a measure of mental flexibility.
- ◆ Some rats are slower and some are faster, but the conclusion is that a rat's behavior is not entirely instinctive. Rats can learn by trial and error.
- ◆ And through more and more sophisticated versions of this simple experiment, it has been shown that mice can use internal cues, such as the scent of food, as well as external cues, such as landmarks, to increase their probabilities of finding food in

DID YOU KNOW?

Rats have been tested in mazes for more than 100 years.



mazes over time. This is called spatial learning, the acquisition and later use of knowledge about the spatial environment.

- ◆ Animals with higher cognitive abilities may learn by trial and error, and they may also learn from watching adult animals—and this is called social learning.
- ◆ We know that we primates learn socially. In addition to occurring in mammal carnivores such as cats and dogs, zoologists have recorded instances of social learning among fish, reptiles, and birds.

Tool Use

- ◆ For a long time, we were taught that only humans use tools—that only humans manipulated objects specifically for the purpose of achieving a mechanical advantage. However, zoologists observing animals carefully over a long period of time have found many examples of tool use in the animal kingdom.
- ◆ In the 1870s, Darwin specifically mentions baboon tool use in his book *The Descent of Man*, but it was probably animal behavior pioneer Jane Goodall's studies of chimpanzees in the 1960s that really brought serious scientific attention to the subject of animal tool use.
- ◆ The first instance of tool use that Dr. Goodall observed is the behavior called ant dipping. She noticed a chimpanzee pushing a long stalk of grass into a hole in the ground and

DID YOU KNOW?

Chimpanzees are our closest living relatives, sharing more than 98% of our DNA.



then pulling it out covered with termites. The chimpanzee followed this behavior by sticking the grass in his mouth and pulling the grass through his lips. Later, she saw chimps selecting twigs and stripping the leaves off them specifically for use as ant-dipping sticks. The chimps were deliberately creating tools, not just grabbing some object that was handy at the time.

- ◆ Later, the great ethologist Frans de Waal observed bonobos using leaves for cupping water, among other simple tools. Then, ethologist Christophe Boesch recorded instances of chimpanzees using tools. What's more, mother chimpanzees will show their offspring how to use stone tools to break hard-to-reach foods, such as nuts.
- ◆ To study how flexible chimp tool use was, researchers looked at geographically separate groups of chimpanzees: one in Taï National Park in Côte d'Ivoire and others in Mahale Mountains National Park and near the Gombe Stream in Tanzania. These groups have the entire continent of Africa between them, so there's no chance of cross-breeding or social contact in the wild. However, these territories have similar environmental features, such as the same types of climate and food sources.
- ◆ Scientists found that the different populations used their tools differently. There were differences in frequency of tool use and in modifications. Researchers concluded that chimps not only had learning, but also had "culture"—different approaches to problem solving among different geographic groups, differences that couldn't be explained by genetics or environment.
- ◆ But it's not just our closest relatives, the chimps, that use tools. Sea otters dive deep into kelp gardens and gather rocks. Then, while floating on their backs, they place the rocks on their chests and use the rocks to break abalone mollusks. Scientists at Monterey Bay Aquarium have studied this behavior and confirmed that young otters must be taught this shell-breaking behavior by their mothers or, if hand-raised, by keepers.



DID YOU KNOW?

Most otters store their favorite rocks in their left armpit.

- ◆ Animal behavior researchers agree that this is a clear example of tool use, not only because the rocks fit the definition of tools, but because otters will keep their favorite rocks, storing them in a pouch of flesh under their armpits.

Mirror Use

- ◆ We humans use mirrors because we are aware of our self. That's why this phenomenon is called mirror self-recognition (MSR).
- ◆ Human children do not use a mirror as adults do until they are about 18 to 24 months old, just around the age they can pass tests about the thoughts and feelings of others—tests that, together, show that children are self-aware and possess empathy.
- ◆ When dogs see themselves in a mirror, they treat the image as if it's another dog. They might growl at the mirror image of this "new dog," or go around to the back of the mirror to find the "other dog," or even just look at the mirror without any reaction because the "dog in the mirror" provides no feedback. Dogs may use the mirror to help them examine their surroundings, but they don't stand in front of the mirror examining parts of themselves.



- ◆ Monkeys do the same thing as dogs when presented with a mirror. Despite repeated testing, they have not recognized themselves in a mirror.

- ◆ Because of this, MSR was once thought to be another uniquely human quality. What about our closest relatives the great apes? Shouldn't our closest relatives be able to recognize themselves in a mirror, just as they can use tools like we can?
- ◆ In the 1970s, psychologist Gordon Gallup tested this by giving chimps a full-length mirror. The chimps grimaced menacingly at their image at first, but after a while, the chimps moved back and forth in front of the mirror to see what the mirror image would do. This phase of understanding a mirror is called contingency testing.
- ◆ When Gallup's chimps finally recognized their image in the mirror as themselves, they began checking their mouths and teeth as well as their nostrils. In subsequent studies, they even checked their rumps. These are parts of their body they could not normally see. They would even blow bubbles at themselves.
- ◆ To confirm that this was true MSR, Gallup developed the mark test. Marks of ink were placed on the foreheads of anesthetized chimps to see if chimps would use the mirror to examine and touch the mark when they woke—and they did. Then, some moved the hand that touched the ink to their nose or mouth to inspect the mark, so they clearly recognized their own face and hand in the mirror.
- ◆ The fact that chimps could show MSR was more evidence that animal and human self-awareness is on a continuum. It makes us wonder about other animals and their abilities for self-recognition.
- ◆ Dolphins are social, big-brained animals, just like chimps. But do they show MSR? Diana Reiss of the City University of New York showed mirrors to dolphins at the New York Aquarium to see what they would do. The dolphins performed different activities in front of the mirror, including blowing bubbles and doing cartwheels, suggesting that they were aware that the dolphins in the mirror were images of themselves.

DID YOU KNOW?

Asian elephants are known to break off leafy branches and swat at pesky biting flies. This is an example of tool use.



- ◆ Diana needed to use the classic mark test to test this experimentally. When she marked a male dolphin while he was in a training session, he swam immediately to the mirror and positioned himself to see what the scientists had done near his tail. When she marked a dolphin near its tail with a visible mark and a sham mark that could not be seen, the dolphin went to the mirror and flexed while viewing the visible mark over and over again—clear proof that dolphins have MSR.

- ◆ Asian elephants are another big-brained, social animal. Scientist Joshua Plotnik, along with Frans de Waal and Diana Reiss, studied MSR in elephants at the Bronx Zoo. With the assistance of the Bronx Zoo's curators, they built an 8-foot-by-8-foot, steel-framed, indestructible mirror to be placed in an elephant exercise yard.

- ◆ One of the elephants, named Happy, was marked with a visible mark and a sham mark. She examined her visible mark in the mirror much more frequently than the sham mark or any other place on her body. Happy was thus the first elephant to show human scientists that elephants also have the capacity for MSR.

Suggested Reading

De Waal, *Are We Smart Enough to Know How Smart Animals Are?*
Reiss, *The Dolphin in the Mirror.*

Combating Disease in the Animal Kingdom

Human diseases that are caused by microbes that originate in animals include human immunodeficiency virus (HIV), severe acute respiratory syndrome (SARS), influenzas, Ebola, and Zika virus. Several of these have spread extensively in human populations to cause a global epidemic, also known as a pandemic. This lecture will explore the biology of emerging diseases and how we use our understanding of wildlife disease to improve public health and to conserve wildlife for the future of the animal kingdom.

Plagues

- ◆ The most historically impactful disease for our species is the Black Death, the plague of the mid-14th century. Most cases of Black Death were likely of the bubonic type, or started that way. The term “bubonic” means that large boils appeared on the victim’s body from infection of lymph nodes.
- ◆ Some victims likely died of pneumonic plague, a form either transmitted by sputum or progressing from the bubonic form and infecting the lungs.
- ◆ Finally, some victims likely succumbed to septicemic plague, where the blood was directly infected. This could occur either as a progression from bubonic or pneumonic, or as a primary infection.
- ◆ Once the Black Death took hold in a community, it spread rapidly. This epidemic probably arrived in Europe via the Black Sea in October of 1347, brought by rats on trading ships to the Sicilian port of Messina. Then, it crossed to Vienna, Italy, and by the winter of 1348, it had reached England. After England, it cut its way east across the continent, moving through Scandinavia and eastern Europe between 1348 and 1350 and finally reaching the western edges of Russia in 1351.
- ◆ At the same time, other ships brought the disease to Alexandria in Egypt, and from there, it spread throughout the Near East, through the areas that are now Lebanon, Syria, Israel,

DID YOU KNOW?

A popular belief during the 17th century was that the bubonic plague was caused by dogs and cats. But the disease is actually carried by rat fleas.



Saudi Arabia, Iraq, and Yemen. Along the way, the plague killed somewhere between 75 and 200 million people.

- ◆ This outbreak was not the only time this disease hit Europe, although it was the biggest single outbreak. The disease had a resurgence every decade or 2 from the 14th through the 19th centuries.
- ◆ Bubonic plague is caused by the bacteria *Yersinia pestis*, which is carried by rat fleas. The bubonic plague mostly affects rats, but it can “jump” to humans, and humans with plague often have many flea bites.
- ◆ The form of plague known as primary pneumonic plague can be spread by droplet transmission—that is, coughing up transmissible infection from the lungs.
- ◆ Plague did not die out with the sanitation and medical advances of the 19th century. A few cases per year continue to be reported around the world, even though we know that rat and flea control is the answer to limiting spread. Plague is still a big problem in prairie dog populations, which in turn adversely affects nearby endangered species, such as black-footed ferrets.

Zoonotic Diseases

- ◆ A zoonotic disease is a disease that can be spread between animals and humans. Zoonotic diseases can be caused by viruses, bacteria, parasites, and fungi. These diseases are very common. Scientists estimate that more than 6 out of every 10 infectious diseases in humans are spread from animals.
- ◆ For example, pregnant women should not handle kitty litter because the tiny, parasitic toxoplasma organism that can be spread from cats to people may be present there. In nonpregnant adults with healthy immune systems, toxoplasmosis typically causes flu-like symptoms, but pregnant women can transmit the disease to their unborn

offspring, who may experience loss of vision, mental retardation, loss of hearing, and even death. The most common source of toxoplasmosis in humans is poor food safety in handling raw meat and even unwashed vegetables.



- ◆ Diseases that common household pets, livestock, or pest animals can transmit to humans include rabies from bats or dogs. Raccoons and skunks are the major source in the United States for infections in dogs and cats. While infection from dogs is common worldwide, in the United States dogs are less important in the transmission of disease to humans than are bats.
- ◆ Lyme disease from deer ticks carried by deer and field mice is common, and diseases such as West Nile, Zika, and malaria are transmitted by mosquitos.

Elephant Endotheliotropic Herpesvirus

- ◆ Unlike one of the common human herpesviruses, herpes simplex, which resides in nerve tissue and may cause blisters but is almost never fatal, elephant endotheliotropic herpesvirus (EEHV) is a unique herpesvirus that resides in blood tissue and causes death in elephants.
- ◆ Although this disease was first discovered in captive Asian elephants, it has now been identified from Asian elephants in range countries—India and Cambodia. Cooperative, multi-institutional research efforts have been ongoing for more than a decade to study EEHV, to identify multiple strains of the virus, to learn about transmission, to develop and improve treatments for young elephants, and to find a vaccine.
- ◆ Researchers first discovered that there are different viruses that attack Asian and African elephants, but so far these viruses only cause mortality in Asian elephants. This virus is suspected of causing the deaths of more than half of the young Asian elephants in zoos, and we still do not know how many wild elephant calves may have died historically from this disease.
- ◆ Smithsonian’s National Zoo veterinary and genetics teams have helped to set up regional laboratories in range countries and can identify the virus in sick elephants within hours so medication can be started to save the elephants’ lives. And Smithsonian’s EEHV diagnostic team has helped to build capacity of in-country teams, so there is a global effort to prevent future Asian elephant deaths from this devastating disease.
- ◆ To save wild animals like elephants, scientists need regular access to them, and captive elephants are key to these studies. There are only about 40,000 Asian elephants remaining in nature, a number equivalent to the number of African elephants that are killed each year for their ivory.

DID YOU KNOW?

- ◆ National Zoo's elephants and other captive elephants from across North America have contributed regular blood samples and trunk wash samples to Smithsonian's herpesvirus research efforts as part of the all-out effort to help save Asian elephants from extinction.
- ◆ More than 12 different kinds of elephant herpesvirus have now been identified, and 5 are known to cause hemorrhagic disease. Smithsonian's Global Health Program is working with other zoos and a biotech company to develop a treatment for the critical hemorrhagic phase of the disease. This treatment is aimed at stopping the bleeding so that the elephant can survive the most dangerous effect of the infection.

Zoo pathology labs are where some of the detectives of the wildlife profession work, and pathologists at Smithsonian's National Zoo and Conservation Biology Institute are at the leading edge of finding, identifying, and characterizing emerging wildlife diseases.

These pathologists, heroes for conservation and endangered animal health, spend hours each day cutting into tissues or peering at fecal samples, blood, or other cells and tissues through the lens of a microscope. Their job is to try to identify what has made animals sick or has killed animals, for the health of other animals and even people.



Canine Distemper Virus

- ◆ The International Union for Conservation of Nature estimates that there are fewer than 2500 adult tigers left in nature, a decline in range and number of 50% from only 20 years ago and a decline of more than 90% compared to only 100 years ago. The threats they face today include habitat loss because of our rising human population,

poaching for traditional Chinese medicine, and retaliatory persecution after the cats take livestock.

- ◆ But now, a new threat to tigers has reared its ugly head: canine distemper virus (CDV). Veterinarians and wildlife managers have known for years that CDV affects domestic dogs and other species, but recently the virus has been spreading to new regions and new species. The virus has been found in many large cats, such as lions and tigers, as well as raccoons, skunks, foxes, wolves, coyotes, and even ferrets and seals.
- ◆ Most often, the virus is transmitted to these other species due to dogs coming into contact with wildlife—which itself is an effect of habitat loss, because people and their pets are now occupying these traditional wilderness areas. But once it gets into the population, CDV spreads from wild animal to wild animal as well.



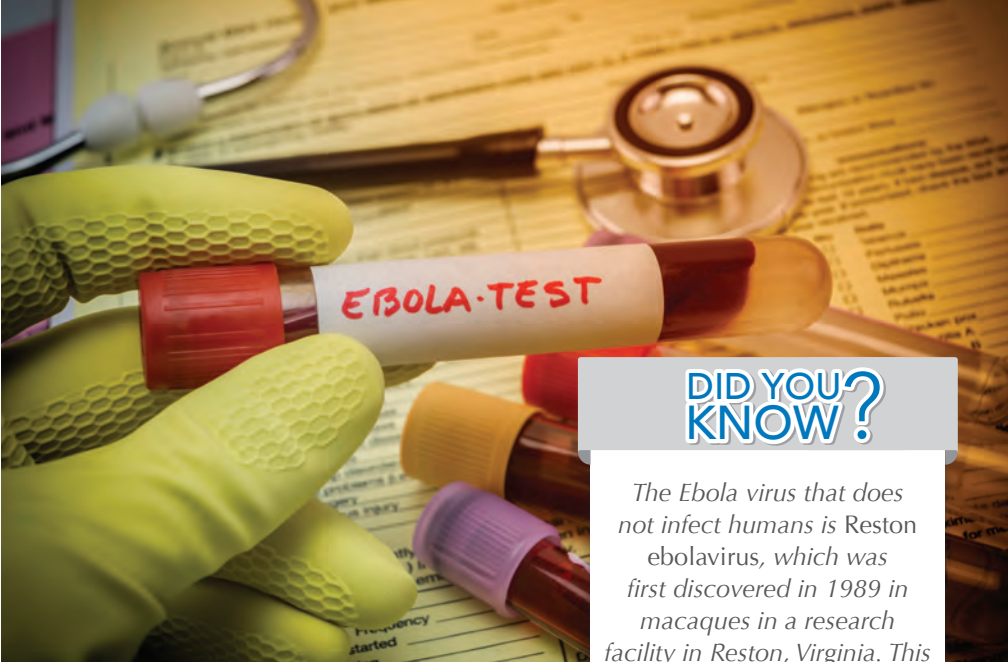
DID YOU KNOW?

The name “canine distemper virus” may be a misnomer, given the diversity of species we now know it impacts.

- ◆ CDV causes fever, digestive problems, respiratory problems, dehydration, and seizures in Amur tigers. Infected tigers often appear malnourished, are disoriented, and are unable to hunt. CDV could cause the extinction of tigers.
- ◆ Vaccination of big cats might be an answer. But there are at least 2 challenges for wildlife managers. Delivery of the vaccine is difficult when it is nearly impossible to find these animals, who want to remain hidden from human view. And efficacy of the vaccine outside of those domestic species it is designed for is questionable; it may not work for the wild species. Experts are encouraging people to vaccinate their dogs and other captive carnivores in hopes of reducing the rate at which the disease enters the wild population.
- ◆ Another key to combating canine distemper is to protect as many natural areas as possible. If the animals have larger ranges, they will be less likely to come into contact with infected domestic animals and other infected populations. Persistence of endangered animals is dependent on the persistence of multiple subpopulations.

Ebola

- ◆ Ebola first came on the human scene in the 1970s. Two outbreaks happened at about the same time: one in what is now South Sudan and the other near the Ebola River in the Congo—giving the disease its name. Ebola is actually a genus containing 5 viruses, 4 of which can infect humans and the fifth of which only infects nonhuman primates.
- ◆ Like the Black Death, Ebola is a zoonotic disease. Its favorite host is believed to be bats, but it can also be hosted by apes, monkeys, antelope, and porcupines. There are very likely some undiscovered hosts, and one of these may turn out to be the most important one for future human spillover events.
- ◆ Ebola enters a human host when a human comes into contact with infected blood, organs, or bodily fluids of the animal—which can



DID YOU KNOW?

*The Ebola virus that does not infect humans is Reston ebolavirus, which was first discovered in 1989 in macaques in a research facility in Reston, Virginia. This incident was made famous by the sensationalist nonfiction thriller *The Hot Zone*.*

happen through hunting or simply through stumbling across a dead animal in the rainforest. Once a human is infected, Ebola travels through direct contact with blood and secretions of an infected person or by objects that have been contaminated with secretions, such as sheets and clothing.

- ◆ The 2014 West African outbreak was the largest outbreak since 1976. The outbreak was eventually contained because of disease management practices that the World Health Organization had been developing since the original outbreak in the 1970s: Reducing human-to-human transmission through the use of protective clothing, through safe handling of the deceased, and through good quarantine of the infected and those who had unprotected contact with the infected.
- ◆ Because the Red Cross kept such good records of who died during the 2014 outbreak and where, scientists from Nuffield College, University of Oxford, discovered that a mere 3% of people were

responsible for the majority of the disease's spread—more than 60% of the rest of the cases. So, in future outbreaks, if health-care workers can quickly identify and quarantine these so-called superspreaders, they might be able to keep an outbreak from becoming an epidemic.

Zika Virus

- ◆ Although Zika was first identified in Uganda in the 1940s, only about 2 dozen human cases were documented before 2007. But in 2015, outbreaks began occurring around the world. They were especially prevalent in Brazil, Central America, the Caribbean, and Florida.
- ◆ The 2015 outbreak coincided with a surge in cases of Guillain-Barré syndrome, which often follows a viral or bacterial infection and is an autoimmune disease that can lead to paralysis, and a surge in

Protecting Yourself from Zoonotic Diseases

According to the Centers for Disease Control, there are many ways you can protect yourself and your family from zoonotic diseases.

- ◆ Always wash your hands and follow proper hygiene. Zoo professionals wash hands, often while singing “Happy Birthday” twice, when using the restroom.
- ◆ Handle your food safely. Use multiple cutting boards for meat, veggies, and breads; be sure that meats are cooked to safe temperatures; and always wash veggies well. Make sure that your dairy products are pasteurized.
- ◆ Prevent bites from mosquitoes and ticks by wearing extra clothing and using chemical repellents.
- ◆ Know the simple things that you can do to stay safe around your pets, and make sure that they are vaccinated.
- ◆ Be aware of zoonotic diseases both at home and especially when you travel, and how you can prevent infection by those diseases.

reports of severe neonatal microcephaly, a birth defect marked by decreased brain tissue.

- ◆ Most people who are infected with Zika show no symptoms; many people just have mild flu-like symptoms such as fever, headache, and joint ache. The symptoms that differentiate Zika from the flu are conjunctivitis and rashes. Until Zika got so much publicity in 2015 and 2016, many people may have had Zika and never realized it.
- ◆ As previously temperate zones become warmer, they become more inviting to *Aedes* mosquitos, allowing them to come into contact with a larger number of humans. Greater human mobility brings humans to more mosquitoes and brings the disease to previously uninfected *Aedes* populations, speeding the spread of the disease. As with malaria and the Black Death, our best hope for controlling the disease is in controlling the insects that spread it.

Biological Monitoring Programs

- ◆ To minimize the impact of pandemic threats such as Ebola and Zika on human health and economic and social stability, the U.S. Agency for International Development (USAID) has launched the Emerging Pandemic Threats program.
- ◆ The goals of this program are to prevent the emergence of new zoonotic diseases, to ensure early detection of new threats when they do emerge, and to control emerging diseases in a timely and effective way. This program aims to bring heightened focus to places and practices around the world that enable not just spillover of new microbial threats, but that also allow their amplification and spread.
- ◆ The USAID program will also invest in One World, One Health policies that connect public health, domestic animal and plant agriculture, the environment, regional and global economic growth, and public education—an extensive interdisciplinary approach

that is now required for the prevention and control of our world's emerging disease threats.

- ◆ Modern zoo and aquarium veterinarians are engaged at the forefront of these biological monitoring programs as they help to strengthen real-time biosurveillance by necropsying (that is, autopsying animals) both zoo animals and wild animals that die around zoos.
- ◆ Your local zoo veterinarian is often part of a global team of wildlife veterinarians developing a longitudinal dataset that will allow us to understand the biological and behavioral drivers of new disease threats emerging from animals in nature. They are also experts in understanding how to reduce risk to wildlife, to our domestic animal populations, and to human life itself.



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Johnson, ed., *The Role of Animals in Emerging Viral Diseases*.

Quammen, *Spillover*.



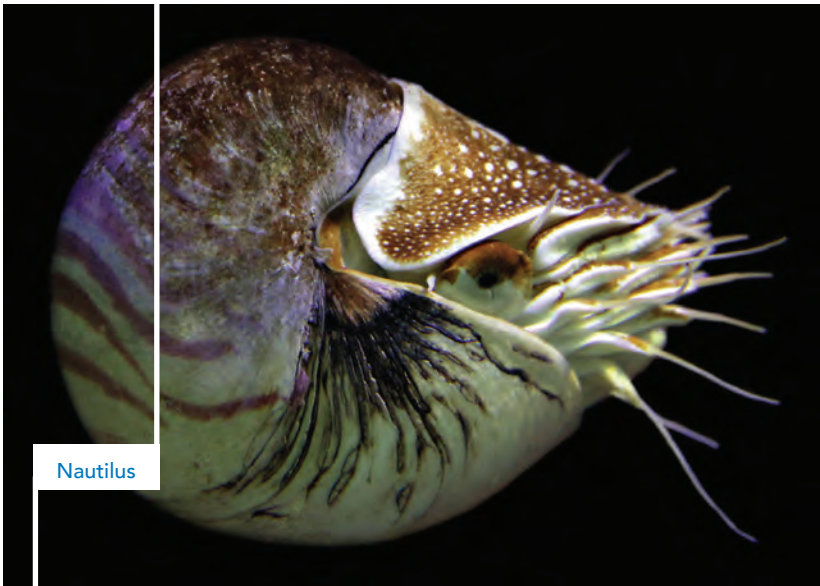
Lecture 24

Animal Futures: Frontiers in Zoology

Smithsonian's National Zoo and Conservation Biology Institute is part of a network of zoos and institutions that is dedicated to the conservation and wellbeing of our planet's wildlife. This course has only scratched the surface on what institutions like these are doing to help animals all around the world, and there's so much more to learn in the area of wildlife conservation. Visit your local park or zoo and get engaged in helping sustain our planet for future generations.

Studying the Natural World

- ◆ There have been 5 extinctions on Earth so far, and now we're in the middle of the sixth extinction. This particular extinction is caused by humans. Smithsonian's National Zoo and other zoos accredited by the Association of Zoos & Aquariums (AZA) are trying to make a difference in saving animals from extinction by restoring animals and plants to their natural habitats and restoring environmental systems.
- ◆ Smithsonian's National Zoo conservation biologists are very good at making community-based conservation models that have a benefit to human society. They have been able to rally the public around endangered species, and zoos and their collaborators have helped to bring the condor, red wolf, black-footed ferret, and golden lion tamarin back from the brink of extinction.
- ◆ Humans are the biggest threat to wildlife. The human population has been growing for hundreds of thousands of years. With that



Nautilus

population growth comes habitat change, climate change, poaching, and unsustainable harvesting of animals.

- ◆ As we encroach on these wild habitats with our domestic animals, there is an opportunity for the spread of disease. About 75% of the diseases affecting human health now are zoonotic. Smithsonian's Global Health Program and its collaborators are working around the world to discover these emerging diseases.

- ◆ Because they have been around for so long, some animals are called living fossils, such as the nautilus, cockroach, and horseshoe crab.
 - › The nautilus has been around for hundreds of millions of years. It is successful because even though humans have had an impact on oceans, especially on estuarine areas, the nautilus lives in the deep ocean, and we haven't had much of an impact there.
 - › The cockroach has remained pretty much unchanged for millions of years. It's a generalist species that can live around humans, like raccoons and rats.
 - › The horseshoe crab is also a very ancient species. Horseshoe crab populations were declining, but individuals and medical communities wanted to protect horseshoe crabs, so they are making a comeback.

DID YOU KNOW?

The blue blood of horseshoe crabs is used to test for impurities in some medicines.



- ◆ Scientific studies of natural history have only been going on for about 200 years. We still don't know a lot about animals that are on land, especially in deep forests; in the harsh Arctic or Antarctic environments, where it's dark for 6 months out of the year; or in

the deep blue sea, where the pressure of the water makes it almost impossible for us to explore. But we are making inroads into these types of scientific studies.

- ◆ Smithsonian's Conservation Biology Institute (SCBI) scientists are great collaborators with others around the world and operate on 6 continents and 25 countries. In the last 15 years, Smithsonian's environmental scientists have worked on human/elephant conflict in Myanmar and Sri Lanka. They have also worked in China and Mongolia with Przewalski's horses, which were extinct in the wild but were brought back through captive breeding programs and were reintroduced.
- ◆ The SCBI has had some great successes in these collaborations. About 30 years after the scimitar-horned oryx was driven to extinction in northern Africa, scientists are able to reintroduce this species because of the success of captive breeding programs.
- ◆ At Smithsonian's National Zoo, scientists at Robert Fleischer's genetics lab are able to take old DNA or fresh DNA and tell what species it's from. They worked with DNA materials from ostriches in northern Uganda and identified them as a totally separate subspecies from the southern ostrich. The genetics lab is also helping to identify conservation needs in the wild for ostriches, giraffes, and other animals that live in northern Africa.
- ◆ The SCBI's headquarters in Front Royal, Virginia, has been spearheading research for more than 20 years. They do a lot of breeding there because they have about 20 different endangered species, but they also have an ecosystem lab, a telemonitoring lab, and an endocrinology lab. They look at hormonal processes for reproduction as well as animal metabolism and health.
- ◆ Tucked into the hills of Virginia, the SCBI does a lot of behind-the-scenes work for Smithsonian's National Zoo, which sends samples taken from species at the zoo to the SCBI for analysis. The goal is to learn more about the species, whether it's to determine timing

of breeding or to answer questions about the welfare of the species kept at the zoo.

Smithsonian's Museum Support Center

- ◆ Smithsonian's Museum Support Center houses storage pods in Suitland, Maryland, that contain 55 million specimens—about 40% of the entire Smithsonian collection—that can't fit in the museums.
- ◆ The frozen pod, or cryo-pod, contains frozen biological materials such as gametes, embryos, tissues, blood, and DNA from threatened species. There are more than 2500 samples of frozen sperm or embryos from more than 100 species, 8000 serum samples from 80 species, and 108,000 tissue samples from 1500 species. The idea is to rescue the genome, move that genetic material inexpensively later on, and provide insurance for the future.
- ◆ For example, cryo-preserved sperm was used to reproduce a black-footed ferret, resulting in more genetic diversity. In addition, SCBI scientists worked with other veterinarians in 2017 to produce the first clouded leopard cub from artificial insemination.

Condors

- ◆ Condors are the only Pleistocene giant left. The mastodon, mammoth, giant saber-toothed cat, and giant bear are all extinct. Condors remain as the world's largest vulture. They're in their relic habitat in California, but scientists are trying to reintroduce them into other parts of California, Utah, Arizona, and Oregon, their original habitat.
- ◆ Biologists on different continents and in different countries are helping bring the condor back from the brink of extinction. Smithsonian conservation biologists on the West Coast have developed small models that help with population modeling for condors, island foxes off of California, and butterflies along the West Coast.



- ◆ Condors went to almost extinction in the early 1980s and were brought to the San Diego and Los Angeles Zoos. Since then, AZA-accredited zoos have helped breed condors in captivity, usually in off-site facilities that are not open to the public. Now, there are 200 condors in zoos and more than 200 condors back in the wild.
- ◆ Condors still have a problem with lead in the environment, so zoos and their collaborators are doing lead-free ammunition education around the West Coast so that when condors are brought back into the skies of Oregon or California, they can have a sustainable population.
- ◆ When a hunter hits a game animal with a lead slug that is about the size of your thumb or smaller, the slug breaks into 250 micropieces in the muscle of the game animal. If the hunter doesn't get that game animal back, or if he does and those pieces are in the animal's gut contents, those meats are back in the environment. Condors, as the

world's cleaners of the environment, eat that meat and ingest that lead. To get condors back into a sustainable population status, we need to work on getting lead out of the environment.

How Can You Help Conservation Efforts?

- ◆ There are about 180 million visits to AZA-accredited zoos and aquariums every year. You can go to your local zoo or aquarium and learn about the endangered animals in your own backyard and around the world. You can get up close and personal with those animals to see what conservation needs they have and how you can help.
- ◆ Think globally and act locally. Think about biodiversity in your own backyard. If you have a garden in Maryland or Virginia, for example, the water and everything else that you put on that garden, including pesticides, go into the watershed and down into the Chesapeake Bay. You can wash your car less in your driveway to help not send soap down into the watershed. You can use less pesticide in your backyard, and you can help pollinators and migratory birds by planting native plants in your backyard.
- ◆ You can think about threats to wildlife outside your backyard around the world, such as palm oil. Millions of acres of tropical forests are taken down to plant palm oil, which takes away homes from orangutans, elephants, tigers, and other animals. Using sustainable palm oil helps.
- ◆ You can think about the oceans and use biosustainable seafood. To do that, you can use a sustainable seafood app, available from the Monterey Bay Aquarium, through Smithsonian's National Zoo, and others.
- ◆ You can take legislative action with your elected congressmen and others, and you can help charities—nongovernmental organizations such as Smithsonian's National Zoo and Conservation Biology Institute or your home zoo or aquarium—take conservation action.

- ◆ Save the Golden Lion Tamarin is a charitable organization in the United States that is working to raise money for their sister organization in Brazil, which is working on corridors and habitat protection for the golden lion tamarin. For these animals to be sustainable and survive, they need 25,000 hectares of continuous forest that's protected. There are currently 3000 golden lion tamarins in 10,000 hectares of forest, and some of it's not protected, so improvements need to be made in this area.

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The IUCN Red List of Threatened Species. <http://www.iucnredlist.org/>.

Citizen Science Opportunities

BeeCampus USA. <http://www.beecityusa.org/bee-campus-usa.html>.

eMammal. <http://emammal.si.edu/>.

FrogWatch USA. <https://www.aza.org/frogwatch-usa-volunteers>.

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