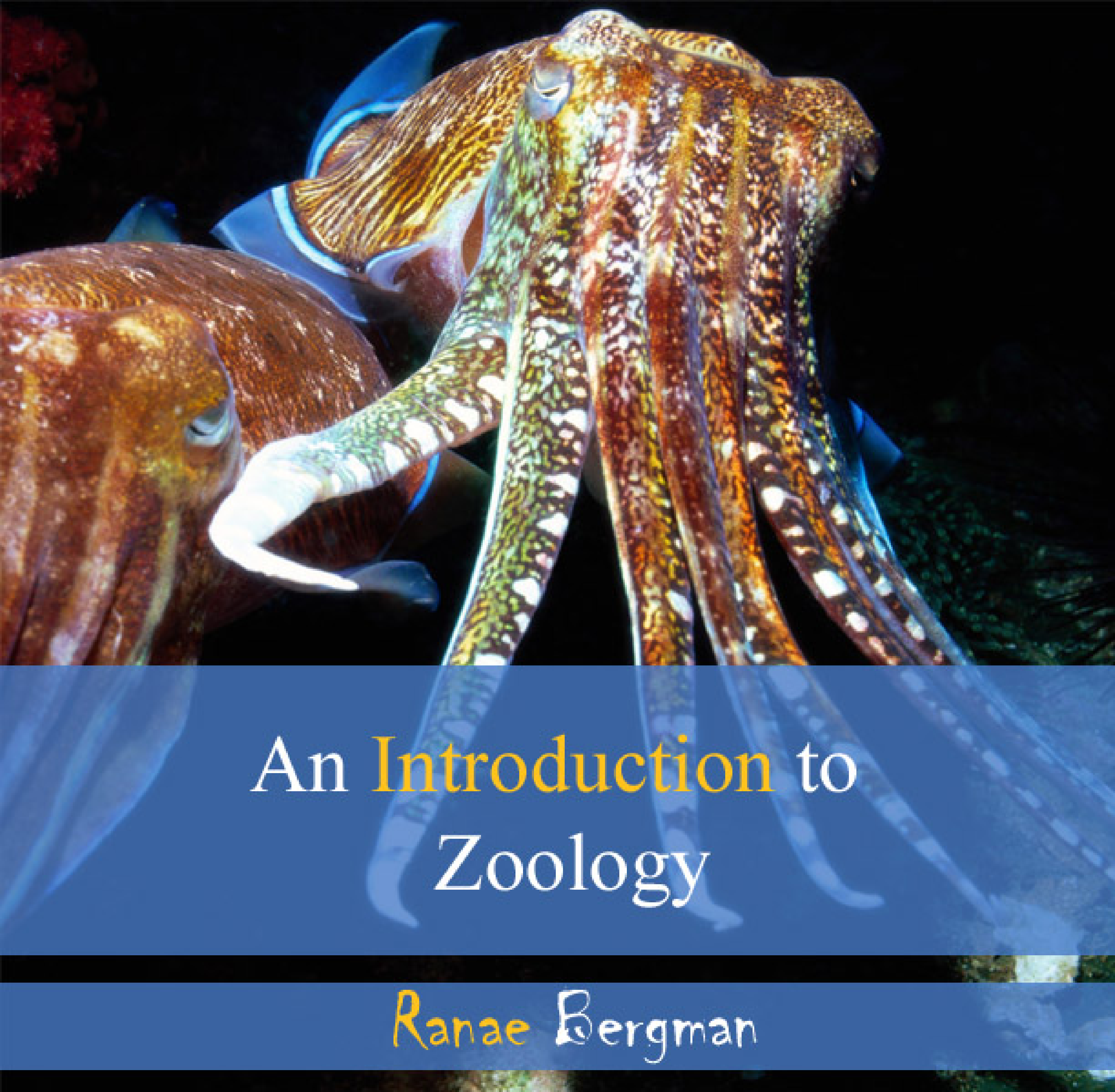

An Introduction to Zoology

Ranae Bergman

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Chapter- 1

Zoology

Conrad Gesner (1516–1565). His *Historiae animalium* is considered the beginning of modern zoology.

Zoology occasionally also spelt **zoölogy**, is the branch of biology which relates to the animal kingdom, including the structure, embryology, evolution, classification, habits, and distribution of all animals, both living and extinct. The term is derived from Ancient Greek ζῷον (zōon, "animal") + λόγος (logos, "knowledge").

Ancient history to Darwin

The history of zoology traces the study of the animal kingdom from ancient to modern times. Although the concept of *zoology* as a single coherent field arose much later, the zoological sciences emerged from natural history reaching back to the works of Aristotle and Galen in the ancient Greco-Roman world. This ancient work was further developed in the Middle Ages by Muslim physicians and scholars such as Albertus Magnus. During the Renaissance and early modern period, zoological thought was revolutionized in Europe by a renewed interest in empiricism and the discovery of many novel organisms. Prominent in this movement were Vesalius and William Harvey, who used experimentation and careful observation in physiology, and naturalists such as Carl Linnaeus and Buffon who began to classify the diversity of life and the fossil record, as well as the development and behavior of organisms. Microscopy revealed the previously unknown world of microorganisms, laying the groundwork for cell theory. The growing importance of natural theology, partly a response to the rise of mechanical philosophy, encouraged the growth of natural history (although it entrenched the argument from design).

Over the 18th and 19th centuries, zoology became an increasingly professional scientific discipline. Explorer-naturalists such as Alexander von Humboldt investigated the interaction between organisms and their environment, and the ways this relationship depends on geography—laying the foundations for biogeography, ecology and ethology. Naturalists began to reject essentialism and consider the importance of extinction and the mutability of species. Cell theory provided a new perspective on the fundamental basis of life.

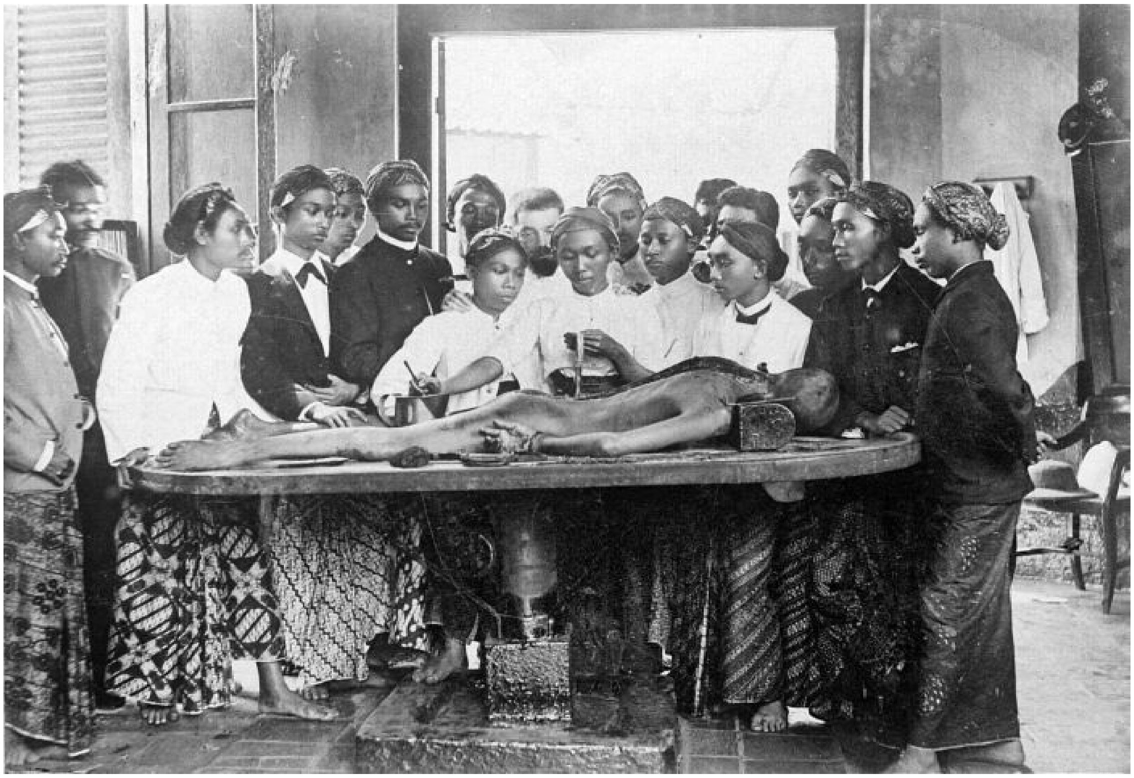
Since Darwin

These developments, as well as the results from embryology and paleontology, were synthesized in Charles Darwin's theory of evolution by natural selection. In 1859, Darwin placed the theory of organic evolution on a new footing, by his discovery of a process by which organic evolution can occur, and provided observational evidence that it had done so.

Darwin gave new direction to morphology and physiology, by uniting them in a common biological theory: the theory of organic evolution. The result was a reconstruction of the classification of animals upon a genealogical basis, fresh investigation of the development of animals, and early attempts to determine their genetic relationships. The end of the 19th century saw the fall of spontaneous generation and the rise of the germ theory of disease, though the mechanism of inheritance remained a mystery. In the early 20th century, the rediscovery of Mendel's work led to the rapid development of genetics by Thomas Hunt Morgan and his students, and by the 1930s the combination of population genetics and natural selection in the "neo-Darwinian synthesis".

Research

Structural



Anatomy lesson carried out in Java, Dutch East Indies, date unknown.

Cell biology studies the structural and physiological properties of cells, including their behaviors, interactions, and environment. This is done on both the microscopic and molecular levels, for single-celled organisms such as bacteria as well as the specialized cells in multicellular organisms such as humans. Understanding the structure and function of cells is fundamental to all of the biological sciences. The similarities and differences between cell types are particularly relevant to molecular biology.

Anatomy considers the forms of macroscopic structures such as organs and organ systems.

Physiological

Physiology studies the mechanical, physical, and biochemical processes of living organisms by attempting to understand how all of the structures function as a whole. The theme of "structure to function" is central to biology. Physiological studies have traditionally been divided into plant physiology and animal physiology, but some principles of physiology are universal, no matter what particular organism is being studied. For example, what is learned about the physiology of yeast cells can also apply to human cells. The field of animal physiology extends the tools and methods of human physiology to non-human species. Physiology studies how for example nervous, immune, endocrine, respiratory, and circulatory systems, function and interact.

Evolutionary

Evolutionary research is concerned with the origin and descent of species, as well as their change over time, and includes scientists from many taxonomically oriented disciplines. For example, it generally involves scientists who have special training in particular organisms such as mammalogy, ornithology, or herpetology, but use those organisms as systems to answer general questions about evolution.

Evolutionary biology is partly based on paleontology, which uses the fossil record to answer questions about the mode and tempo of evolution, and partly on the developments in areas such as population genetics and evolutionary theory. In the 1980s, developmental biology re-entered evolutionary biology from its initial exclusion from the modern synthesis through the study of evolutionary developmental biology. Related fields often considered part of evolutionary biology are phylogenetics, systematics, and taxonomy.

Systematics

Scientific classification in zoology, is a method by which zoologists group and categorize organisms by biological type, such as genus or species. Biological classification is a form of scientific taxonomy. Modern biological classification has its root in the work of Carolus Linnaeus, who grouped species according to shared physical characteristics. These groupings have since been revised to improve consistency with the Darwinian principle of common descent. Molecular phylogenetics, which uses DNA sequences as data, has driven many recent revisions and is likely to continue to do so. Biological classification belongs to the science of zoological systematics.


CAROLI LINNÆI REGNUM ANIMALE.

I. QUADRUPEDIA. | II. AVES. | III. AMPHIBIA. | IV. PISCES. | V. INSECTA. | VI. VERMES.

PARADOXA

Linnaeus's table of the Animal Kingdom from the first edition of *Systema Naturae* (1735).

Many scientists now consider the five-kingdom system outdated. Modern alternative classification systems generally begin with the three-domain system: Archaea (originally Archaebacteria); Bacteria (originally Eubacteria); Eukaryota (including protists, fungi, plants, and animals) These domains reflect whether the cells have nuclei or not, as well as differences in the chemical composition of the cell exteriors.

Further, each kingdom is broken down recursively until each species is separately classified. The order is: Domain; Kingdom; Phylum; Class; Order; Family; Genus; Species. The scientific name of an organism is generated from its genus and species. For example, humans are listed as *Homo sapiens*. *Homo* is the genus, and *sapiens* the species. When writing the scientific name of an organism, it is proper to capitalize the first letter in the genus and put all of the species in lowercase. Additionally, the entire term may be italicized or underlined.

The dominant classification system is called the Linnaean taxonomy. It includes ranks and binomial nomenclature. The classification, taxonomy, and nomenclature of zoological organisms is administered by the International Code of Zoological Nomenclature, and International Code of Nomenclature of Bacteria for animals and bacteria, respectively. The classification of viruses, viroids, prions, and all other sub-viral agents that demonstrate biological characteristics is conducted by the International Code of Virus classification and nomenclature. However, several other viral classification systems do exist.

A merging draft, BioCode, was published in 1997 in an attempt to standardize nomenclature in these areas, but has yet to be formally adopted. The BioCode draft has received little attention since 1997; its originally planned implementation date of January 1, 2000, has passed unnoticed. However, a 2004 paper concerning the cyanobacteria does advocate a future adoption of a BioCode and interim steps consisting of reducing the differences between the codes. The International Code of Virus Classification and Nomenclature (ICVCN) remains outside the BioCode.

Ethology

Kelp Gull chicks peck at red spot on mother's beak to stimulate regurgitating reflex.

Ethology studies animal behavior (particularly that of social animals such as primates and canids), and is sometimes considered a separate branch of study. Ethologists have been particularly concerned with the evolution of behavior and the understanding of behavior in terms of the theory of natural selection. In one sense, the first modern ethologist was Charles Darwin, whose book, *The Expression of the Emotions in Man and Animals,* influenced many ethologists to come.

Biogeography studies the spatial distribution of organisms on the Earth, focusing on topics like plate tectonics, climate change, dispersal and migration, and cladistics.

Branches of zoology

Although the study of animal life is ancient, its scientific incarnation is relatively modern. This mirrors the transition from natural history to biology at the start of the nineteenth century. Since Hunter and Cuvier, comparative anatomical study has been associated with morphography shapins the modern areas of zoological investigation: anatomy, physiology, histology, embryology, teratology and ethology. Modern zoology first arose in German and British universities. In Britain, Thomas Henry Huxley was a prominent figure. His ideas were centered on the morphology of animals. Many consider him the greatest comparative anatomist of the latter half of the nineteenth century. Similar to Hunter, his courses were composed of lectures and laboratory practical classes in contrast the previous format of lectures only. This system became widely spread.

Gradually zoology expanded beyond Huxley's comparative anatomy to include the following sub-disciplines:

- Zoography, also known as *descriptive zoology*, describes animals and their habitats.
- Comparative anatomy studies the structure of animals.
- Animal physiology
- Behavioral ecology
- Ethology is the study of animal behavior.
- The various taxonomically oriented disciplines such as mammalogy, herpetology, ornithology and entomology identify and classify species and study the structures and mechanisms specific to those groups.

Related fields:

- Evolutionary biology: Development of both animals and plants is considered in the articles on evolution, population genetics, heredity, variation, Mendelism, reproduction.
- Molecular Biology studies the common genetic and developmental mechanisms of animals and plants
- Palaeontology
- Systematics, cladistics, phylogenetics, phylogeography, biogeography and taxonomy classify and group species via common descent and regional associations.

Chapter- 2

History of Zoology

This chapter considers the **history of zoology** up to the year 1859, when the theory of evolution by natural selection was proposed by Charles Darwin. The **history of zoology** traces the study of the animal kingdom from ancient to modern times. Although the concept of *zoology* as a single coherent field arose much later, the zoological sciences emerged from natural history reaching back to the works of Aristotle and Galen in the ancient Greco-Roman world. This ancient work was further developed in the Middle Ages by Muslim physicians and scholars such as Albertus Magnus. During the European Renaissance and early modern period, zoological thought was revolutionized in Europe by a renewed interest in empiricism and the discovery of many novel organisms. Prominent in this movement were Vesalius and William Harvey, who used experimentation and careful observation in physiology, and naturalists such as Carl Linnaeus and Buffon who began to classify the diversity of life and the fossil record, as well as the development and behavior of organisms. Microscopy revealed the previously unknown world of microorganisms, laying the groundwork for cell theory. The growing importance of natural theology, partly a response to the rise of mechanical philosophy, encouraged the growth of natural history (although it entrenched the argument from design).

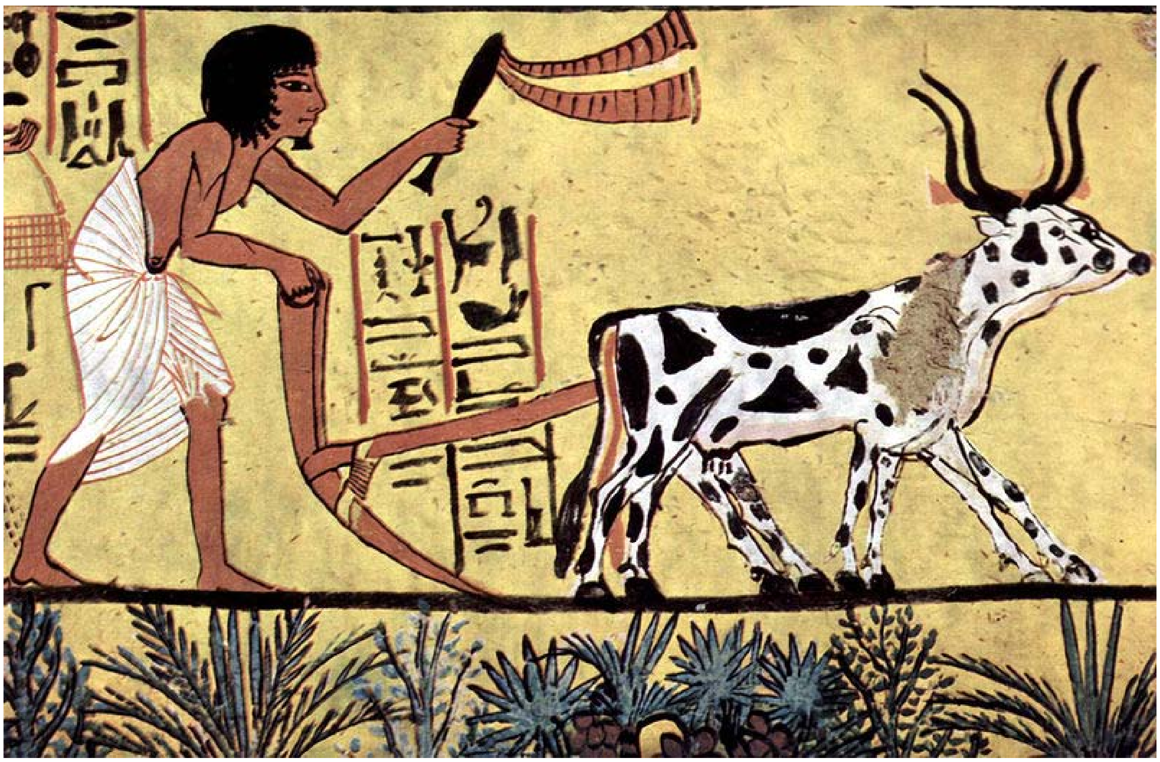
Over the 18th and 19th centuries, zoology became increasingly professional scientific disciplines. Explorer-naturalists such as Alexander von Humboldt investigated the interaction between organisms and their environment, and the ways this relationship depends on geography—laying the foundations for biogeography, ecology and ethology. Naturalists began to reject essentialism and consider the importance of extinction and the mutability of species. Cell theory provided a new perspective on the fundamental basis of life. These developments, as well as the results from embryology and paleontology, were synthesized in Charles Darwin's theory of evolution by natural selection. In 1859, Darwin placed the theory of organic evolution on a new footing, by his discovery of a process by which organic evolution can occur, and provided observational evidence that it had done so.

Pre-scientific zoology

Early cultures

The earliest humans must have had and passed on knowledge about animals to increase their chances of survival. This may have included knowledge of human and animal anatomy and aspects of animal behavior (such as migration patterns). However, the first major turning point in zoological knowledge came with the Neolithic Revolution about 10,000 years ago. Humans domesticated livestock animals to accompany the resulting sedentary societies.

Animals in Ancient Egypt



An ancient Egyptian plows his fields with a pair of oxen, used as beasts of burden and a source of food.

The Egyptians believed that a balanced relationship between people and animals was an essential element of the cosmic order; thus humans, animals and plants were believed to be members of a single whole. Animals, both domesticated and wild, were therefore a critical source of spirituality, companionship, and sustenance to the ancient Egyptians. Cattle were the most important livestock; the administration collected taxes on livestock in regular censuses, and the size of a herd reflected the prestige and importance of the estate or temple that owned them. In addition to cattle, the ancient Egyptians kept sheep, goats, and pigs. Poultry such as ducks, geese, and pigeons were captured in nets and bred on farms, where they were force-fed with dough to fatten them. The Nile provided a plentiful source of fish. Bees were also domesticated from at least the Old Kingdom, and they provided both honey and wax.

The ancient Egyptians used donkeys and oxen as beasts of burden, and they were responsible for plowing the fields and trampling seed into the soil. The slaughter of a fattened ox was also a central part of an offering ritual. Horses were introduced by the Hyksos in the Second Intermediate Period, and the camel, although known from the New Kingdom, was not used as a beast of burden until the Late Period. There is also evidence to suggest that elephants were briefly utilized in the Late Period, but largely abandoned due to lack of grazing land. Dogs, cats and monkeys were common family pets, while more exotic pets imported from the heart of Africa, such as lions, were reserved for royalty. Herodotus observed that the Egyptians were the only people to keep their animals with them in their houses. During the Predynastic and Late periods, the worship of the gods in their animal form was extremely popular, such as the cat goddess Bastet and the ibis god Thoth, and these animals were bred in large numbers on farms for the purpose of ritual sacrifice.

Eastern ancient cultures

The ancient cultures of Mesopotamia, the Indian subcontinent, and China, among others, produced renowned surgeons and students of the natural sciences such as Susruta and Zhang Zhongjing, reflecting independent sophisticated systems of natural philosophy. Taoist philosophers, such as Zhuangzi in the 4th century BC, expressed ideas related to evolution, such as denying the fixity of biological species and speculating that species had developed differing attributes in response to differing environments. The ancient Indian Ayurveda tradition independently developed the concept of three humours, resembling that of the four humours of ancient Greek medicine, though the Ayurvedic system included further complications, such as the body being composed of five elements and seven basic tissues. Ayurvedic writers also classified living things into four categories based on the method of birth (from the womb, eggs, heat & moisture, and seeds) and explained the conception of a fetus in detail. They also made considerable advances in the field of surgery, often without the use of human dissection or animal vivisection. One of the earliest Ayurvedic treatises was the *Sushruta Samhita*, attributed to Sushruta in the 6th century BC. It was also an early materia medica, describing 700 medicinal plants, 64 preparations from mineral sources, and 57 preparations based on animal sources. However, the roots of modern zoology are usually traced back to the secular tradition of ancient Greek philosophy.

Ancient Greek traditions

The pre-Socratic philosophers asked many questions about life but produced little systematic knowledge of specifically zoological interest—though the attempts of the atomists to explain life in purely physical terms would recur periodically through the history of zoology. However, the medical theories of Hippocrates and his followers, especially humorism, had a lasting impact.

The philosopher Aristotle was the most influential scholar of the living world from classical antiquity. Though his early work in natural philosophy was speculative, Aristotle's later biological writings were more empirical, focusing on biological causation and the diversity of life. He made countless observations of nature, especially the habits and attributes of animals in the world around him, which he devoted considerable attention to categorizing. In all, Aristotle classified 540 animal species, and dissected at least 50. He believed that intellectual purposes, formal causes, guided all natural processes.

Aristotle, and nearly all Western scholars after him until the 18th century, believed that creatures were arranged in a graded scale of perfection rising from plants on up to humans: the *scala naturae* or Great Chain of Being. Pliny the Elder was also known for his knowledge of animals and nature, and was the most prolific compiler of zoological descriptions.

A few scholars in the Hellenistic period under the Ptolemies—particularly Herophilus of Chalcedon and Erasistratus of Chios—amended Aristotle's physiological work, even performing experimental dissections and vivisections. Claudius Galen became the most important authority on medicine and anatomy. Though a few ancient atomists such as Lucretius challenged the teleological Aristotelian viewpoint that all aspects of life are the result of design or purpose, teleology (and after the rise of Christianity, natural theology) would remain central to biological thought essentially until the 18th and 19th centuries. The ideas of the Greek traditions of zoology survived, but they were generally taken unquestioningly in medieval Europe.

Medieval and Islamic knowledge

De arte venandi, by Frederick II, Holy Roman Emperor, was an influential medieval natural history text that explored bird morphology.

The decline of the Roman Empire led to the disappearance or destruction of much knowledge, though physicians still incorporated many aspects of the Greek tradition into training and practice. In Byzantium and the Islamic world, many of the Greek works were translated into Arabic and many of the works of Aristotle were preserved.

Medieval Muslim physicians, scientists and philosophers made significant contributions to zoological knowledge between the 8th and 13th centuries during what is known as the "Islamic Golden Age" or "Muslim Agricultural Revolution". The Afro-Arab scholar al-Jahiz (781–869) described early evolutionary ideas such as the struggle for existence. He also introduced the idea of a food chain, and was an early adherent of environmental determinism.

The Arabian physician Ibn al-Nafis (1213–1288) was an early adherent of experimental dissection and autopsy, who in 1242 discovered pulmonary circulation and coronary circulation, which form the basis of the circulatory system. He also described the concept of metabolism, and discredited the incorrect Galenic and Avicennian theories on the four humours, pulsation, bones, muscles, intestines, sensory organs, bilious canals, esophagus and stomach.

During the High Middle Ages, a few European scholars such as Hildegard of Bingen, Albertus Magnus and Frederick II expanded the natural history canon. Magnus' *De animalibus libri XXVI* is not the only volume of his commentaries on natural history, but it was one of the most extensive studies of zoological observation published before modern times. The rise of European universities, though important for the development of physics and philosophy, had little impact on zoological scholarship.

Zoology as a science

Renaissance and early modern developments

Conrad Gesner (1516–1565). His *Historiae animalium* is considered the beginning of modern zoology.

Prior to the Renaissance, accounts of animals were often apocryphal and creatures were often described as "legendary." This period was succeeded by the age of collectors and travellers, when many of the stories were actually demonstrated as true when the living or preserved specimens were brought to Europe. Verification by collecting of things, instead of the accumulation of anecdotes, then became more common, and scholars developed a new faculty of careful observation. The Renaissance brought expanded interest in both empirical natural history and physiology. In 1543, Andreas Vesalius inaugurated the modern era of Western medicine with his seminal human anatomy treatise *De humani corporis fabrica*, which was based on dissection of corpses. Vesalius was the first in a series of anatomists who gradually replaced scholasticism with empiricism in physiology and medicine, relying on first-hand experience rather than authority and abstract reasoning. Bestiaries—a genre that combines both the natural and figurative knowledge of animals—also became more sophisticated. Conrad Gessner great zoological work, *Historiae animalium*, appeared in four volumes, 1551-1558, at Zürich, a fifth being issued in 1587. His works were the starting-point of modern zoology. Other major works were produced by William Turner, Pierre Belon, Guillaume Rondelet, and Ulisse Aldrovandi. Artists such as Albrecht Dürer and Leonardo da Vinci, often working with naturalists, were also interested in the bodies of animals and humans, studying physiology in detail and contributing to the growth of anatomical knowledge.

In the 17th century, the enthusiasts of the new sciences, the investigators of nature by means of observation and experiment, banded themselves into academies or societies for mutual support and discourse. The first founded of surviving European academies, the Academia Naturae Curiosorum (1651) especially confined itself to the description and illustration of the structure of plants and animals; eleven years later (1662) the Royal Society of London was incorporated by royal charter, having existed without a name or fixed organisation for seventeen years previously (from 1645). A little later the Academy of Sciences of Paris was established by Louis XIV, later still the Royal Society of Sciences in Uppsala was founded. Systematizing, naming and classifying dominated zoology throughout much of the 17th and 18th centuries. Carl Linnaeus published a basic taxonomy for the natural world in 1735 (variations of which have been in use ever since), and in the 1750s introduced scientific names for all his species. While Linnaeus conceived of species as unchanging parts of a designed hierarchy, the other great naturalist of the 18th century, Georges-Louis Leclerc, Comte de Buffon, treated species as artificial categories and living forms as malleable—even suggesting the possibility of common descent. Though he was opposed to evolution, Buffon is a key figure in the history of evolutionary thought; his work would influence the evolutionary theories of both Jean-Baptiste Lamarck and Charles Darwin.

Before the Age of Exploration, naturalists had little idea of the sheer scale of biological diversity. The discovery and description of new species and the collection of specimens became a passion of scientific gentlemen and a lucrative enterprise for entrepreneurs; many naturalists traveled the globe in search of scientific knowledge and adventure.

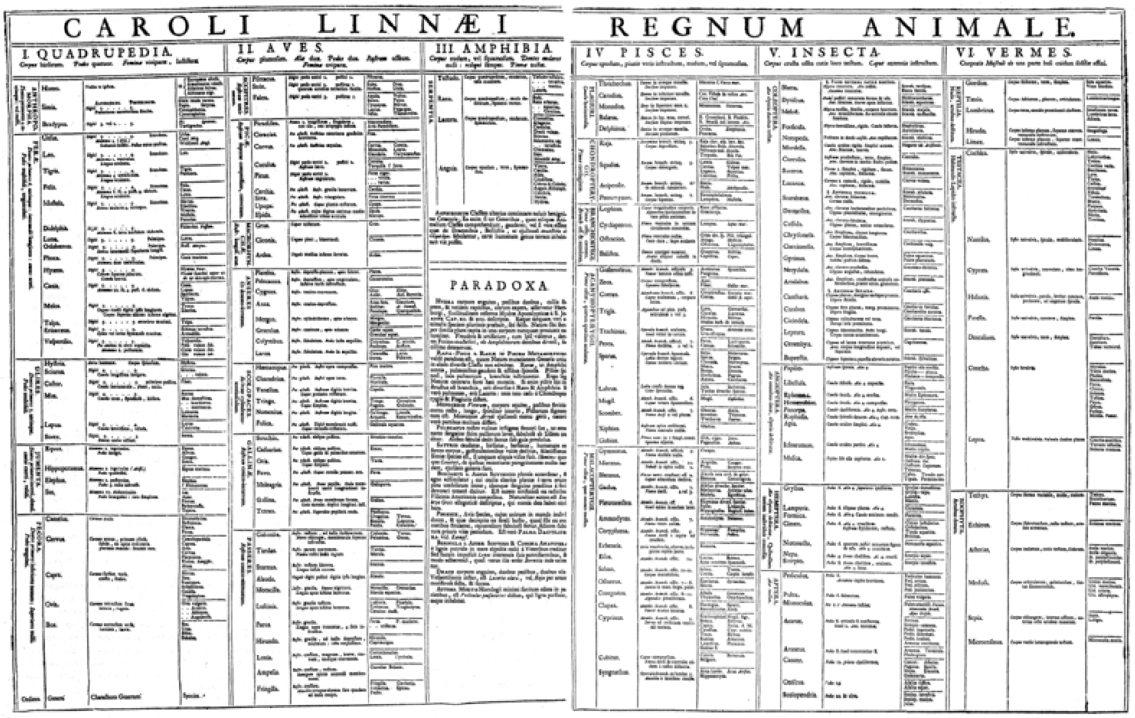


Table of the Animal Kingdom ("Regnum Animale") from the 1st edition of Linnaeus' *Systema Naturae* (1735).

Extending the work of Vesalius into experiments on still living bodies (of both humans and animals), William Harvey and other natural philosophers investigated the roles of blood, veins and arteries. Harvey's *De motu cordis* in 1628 was the beginning of the end for Galenic theory, and alongside Santorio Santorio's studies of metabolism, it served as an influential model of quantitative approaches to physiology.

Impact of the microscope

In the early 17th century, the micro-world of zoology was just beginning to open up. A few lensmakers and natural philosophers had been creating crude microscopes since the late 16th century, and Robert Hooke published the seminal *Micrographia* based on observations with his own compound microscope in 1665. But it was not until Antony van Leeuwenhoek's dramatic improvements in lensmaking beginning in the 1670s—ultimately producing up to 200-fold magnification with a single lens—that scholars discovered spermatozoa, bacteria, infusoria and the sheer strangeness and diversity of microscopic life. Similar investigations by Jan Swammerdam led to new interest in entomology and built the basic techniques of microscopic dissection and staining.

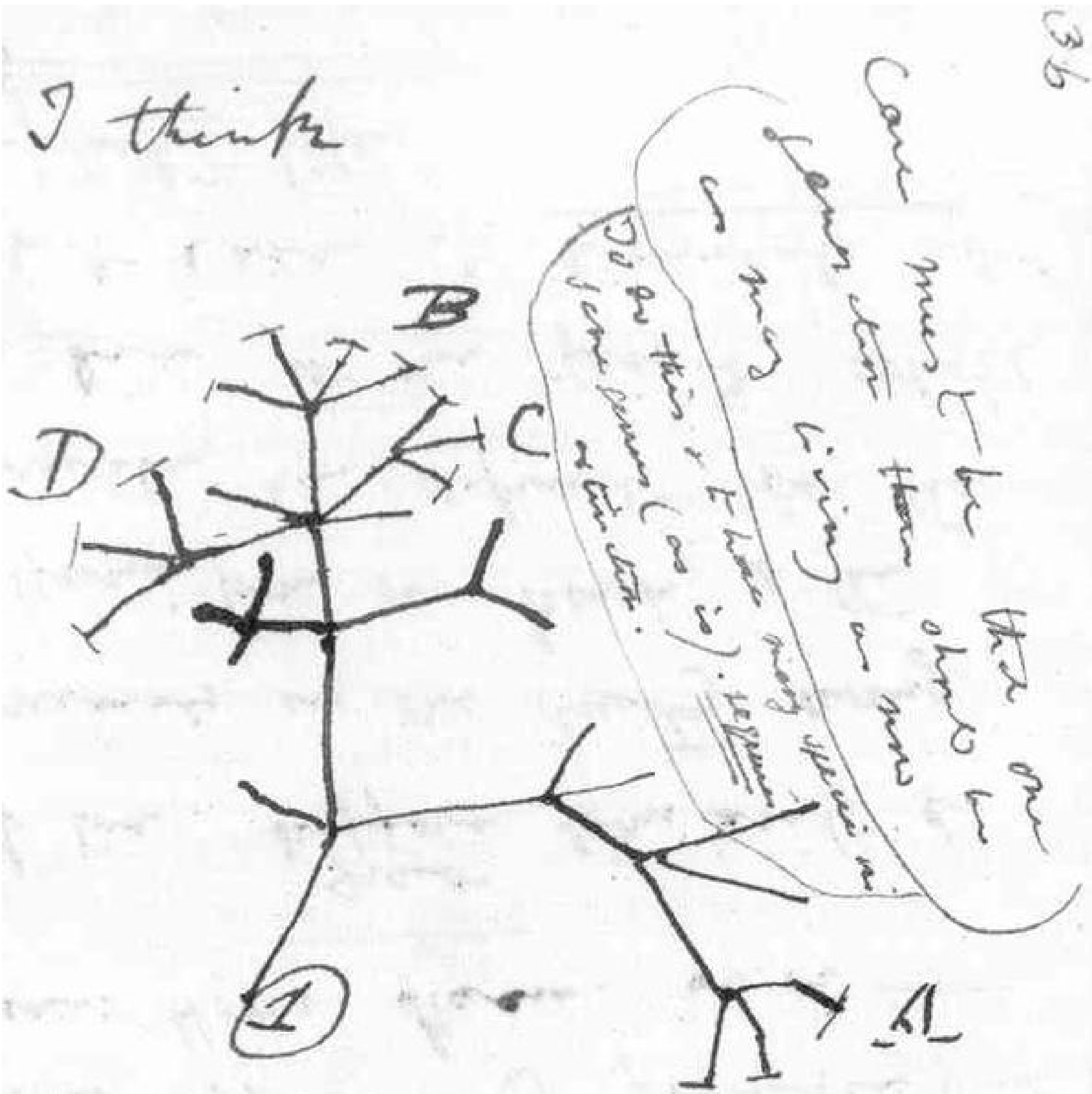
Debate over the flood described in the Bible catalyzed the development of paleontology; in 1669 Nicholas Steno published an essay on how the remains of living organisms could be trapped in layers of sediment and mineralized to produce fossils. Although Steno's ideas about fossilization were well known and much debated among natural philosophers, an organic origin for all fossils would not be accepted by all naturalists until the end of the 18th century due to philosophical and theological debate about issues such as the age of the earth and extinction.

18th century microscopes from the Musée des Arts et Métiers, Paris.

Advances in microscopy also had a profound impact on biological thinking. In the early 19th century, a number of biologists pointed to the central importance of the cell. In 1838 and 1839, Schleiden and Schwann began promoting the ideas that (1) the basic unit of organisms is the cell and (2) that individual cells have all the characteristics of life, though they opposed the idea that (3) all cells come from the division of other cells. Thanks to the work of Robert Remak and Rudolf Virchow, however, by the 1860s most biologists accepted all three tenets of what came to be known as cell theory.

In advance of On the Origin of Species

Up through the 19th century, the scope of zoology was largely divided between physiology, which investigated questions of form and function, and natural history, which was concerned with the diversity of life and interactions among different forms of life and between life and non-life. By 1900, much of these domains overlapped, while natural history (and its counterpart natural philosophy) had largely given way to more specialized scientific disciplines—cytology, bacteriology, morphology, embryology, geography, and geology. Widespread travel by naturalists in the early-to-mid-19th century resulted in a wealth of new information about the diversity and distribution of living organisms. Of particular importance was the work of Alexander von Humboldt, which analyzed the relationship between organisms and their environment (i.e., the domain of natural history) using the quantitative approaches of natural philosophy (i.e., physics and chemistry). Humboldt's work laid the foundations of biogeography and inspired several generations of scientists.



Charles Darwin's first sketch of an evolutionary tree from his *First Notebook on Transmutation of Species* (1837)

The emerging discipline of geology also brought natural history and natural philosophy closer together; Georges Cuvier and others made great strides in comparative anatomy and paleontology in the late 1790s and early 19th century. In a series of lectures and papers that made detailed comparisons between living mammals and fossil remains Cuvier was able to establish that the fossils were remains of species that had become extinct—rather than being remains of species still alive elsewhere in the world, as had been widely believed. Fossils discovered and described by Gideon Mantell, William Buckland, Mary Anning, and Richard Owen among others helped establish that there had been an 'age of reptiles' that had preceded even the prehistoric mammals. These discoveries captured the public imagination and focused attention on the history of life on earth.

The most significant evolutionary theory before Darwin's was that of Jean-Baptiste Lamarck; based on the inheritance of acquired characteristics (an inheritance mechanism that was widely accepted until the 20th century), it described a chain of development stretching from the lowliest microbe to humans. The British naturalist Charles Darwin, combining the biogeographical approach of Humboldt, the uniformitarian geology of Lyell, Thomas Malthus's writings on population growth, and his own morphological expertise, created a more successful evolutionary theory based on natural selection; similar evidence led Alfred Russel Wallace to independently reach the same conclusions. Charles Darwin's early interest in nature led him on a five-year voyage on HMS *Beagle* which established him as an eminent geologist whose observations and theories supported Charles Lyell's uniformitarian ideas, and publication of his journal of the voyage made him famous as a popular author. Puzzled by the geographical distribution of wildlife and fossils he collected on the voyage, Darwin investigated the transmutation of species and conceived his theory of natural selection in 1838. Although he discussed his ideas with several naturalists, he needed time for extensive research and his geological work had priority. He was writing up his theory in 1858 when Alfred Russel Wallace sent him an essay which described the same idea, prompting immediate joint publication of both of their theories. Darwin's *On the Origin of Species*, published on 24 November 1859, a seminal work of scientific literature, was to be the foundation of evolutionary biology.

Chapter- 3

Ornithology

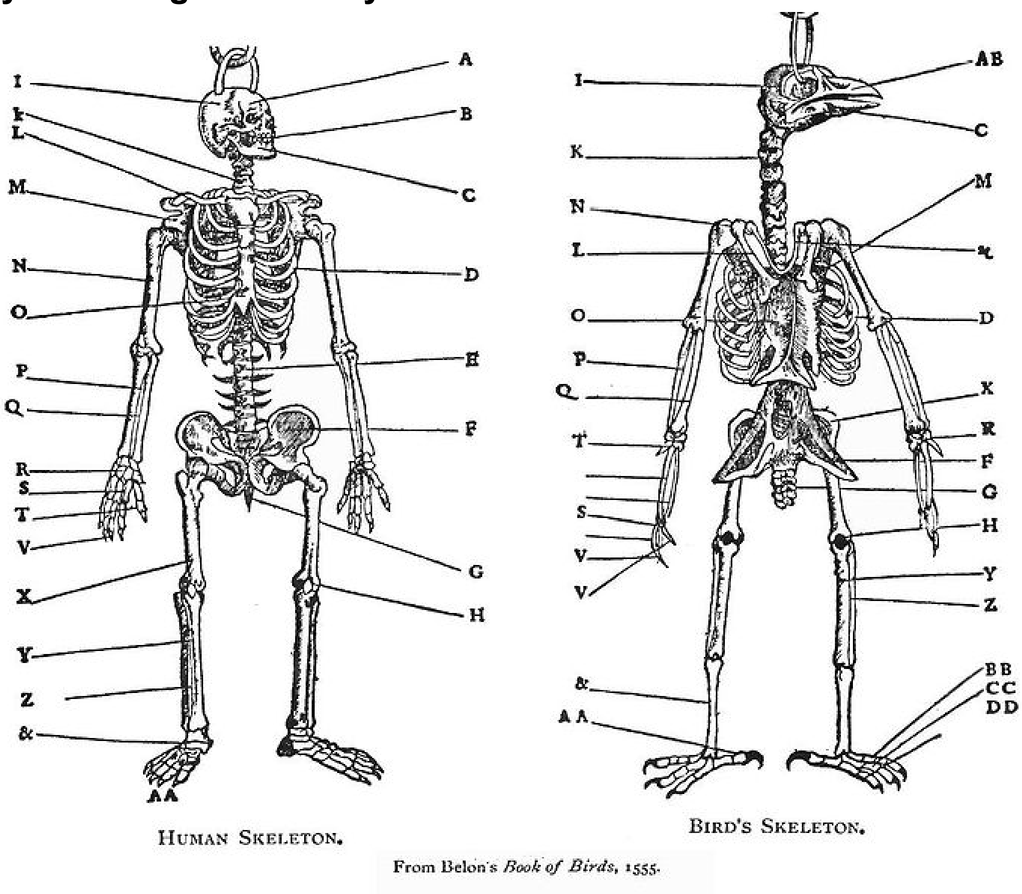
Ornithology (from Greek: ὄρνις, ὄρνιθος, *ornis*, *ornithos*, "bird"; and λόγος, *logos*, "knowledge") is a branch of zoology that concerns the study of birds. Several aspects of ornithology differ from related disciplines, due partly to the high visibility and the aesthetic appeal of birds. Most marked among these is the extent of studies undertaken by amateurs working within the parameters of strict scientific methodology.

The science of ornithology has a long history and studies on birds have helped develop several key concepts in evolution, behaviour and ecology such as the definition of species, the process of speciation, instinct, learning, ecological niches, guilds, island biogeography, phylogeography and conservation. While early ornithology was principally concerned with descriptions and distributions of species, ornithologists today seek answers to very specific questions, often using birds as models to test hypotheses or predictions based on theories. Most modern biological theories apply across taxonomic groups and the number of professional scientists who identify themselves as "ornithologists" has therefore declined. A wide range of tools and techniques are used in ornithology and innovations are constantly made.

History

The history of ornithology largely reflects the trends in the history of biology. Trends include the move from mere descriptions to the identification of patterns and then towards elucidating the processes that produce the patterns.

Early knowledge and study



Belon's comparison of birds and humans in his *Book of Birds*, 1555

Humans must have observed birds from the earliest times, and stone age drawings are among the oldest indications of an interest in birds. Birds were perhaps important as a food source, and bones of as many as 80 species have been found in excavations of early Stone Age settlements.

Cultures around the world have rich vocabularies related to birds. Traditional bird names are often based on detailed knowledge of the behaviour, with many names being onomatopoeic, many still in use. Traditional knowledge may also involve the use of birds in folk medicine and knowledge of these practices are passed on through oral traditions. Hunting of wild birds as well as their domestication would have required considerable knowledge of their habits. Poultry farming and falconry were practised from early times in many parts of the world. Artificial incubation of poultry was practised in China around 246 BC and around at least 400 BC in Egypt. The Egyptians also made use of birds in their hieroglyphic scripts, many of which, though stylized, are still identifiable to species.

Cover of Ulisse Aldrovandi's Ornithology, 1599

Early written records provide valuable information on the past distributions of species. For instance Xenophon records the abundance of the Ostrich in Assyria (Anabasis, i. 5); this subspecies from Asia minor is extinct and all extant Ostrich races are today restricted to Africa. Other old writings such as the *Vedas* (1500-800 BC) demonstrate the careful observation of avian life histories and includes the earliest reference to the habit of brood parasitism by the Asian Koel (*Eudynamys scolopacea*). Like writing, the early art of China, Japan, Persia and India also demonstrate knowledge, with examples of scientifically accurate bird illustrations.

Aristotle in 350 BC in his *Historia Animalium* noted the habit of bird migration, moulting, egg laying and life spans. He however introduced and propagated several myths, such as the idea that swallows hibernated in winter although he noted that cranes migrated from the steppes of Scythia to the marshes at the headwaters of the Nile. The idea of swallow hibernation became so well established that, even as late as in 1878, Elliott Coues could list as many as 182 contemporary publications dealing with the hibernation of swallows and little published evidence to contradict the theory. Similar misconceptions existed regarding the breeding of Barnacle geese. Their nests had not been seen and it was believed that they grew by transformations of goose barnacles, an idea that became prevalent from around the 11th century and noted by Bishop Giraldus Cambrensis (Gerald of Wales) in *Topographia Hiberniae* (1187).

The origins of falconry have been traced to Mesopotamia and the earliest record comes from the reign of Sargon II (722–705 BC). Falconry made its entry to Europe only after AD 400, brought in from the East after invasions by the Huns and Allans. Frederick II of Hohenstaufen (1194–1250) learnt about Arabian falconry during wars in the region and obtained an Arabic treatise on falconry by Moamyn. He had this work translated into Latin and also conducted experiments on birds in his menagerie. By sealing the eyes of vultures and placing food nearby, he concluded that they found food by sight, and not by smell. He also developed methods to keep and train falcons. The studies that he undertook over nearly 30 years, were published in 1240 as De Arte Venandi cum Avibus (The Art of Hunting with Birds), considered one of the earliest studies on bird behaviour.

Several early German and French scholars compiled old works and conducted new research on birds. These included Guillaume Rondelet who described his observations in the Mediterranean and Pierre Belon who described the fish and birds that he had seen in France and the Levant. Belon's Book of Birds (1555) is a folio volume with descriptions of some two hundred species. His comparison of the skeleton of humans and birds is considered as a landmark in comparative anatomy. Volcher Coiter (1534–1576), a Dutch anatomist made detailed studies of the internal structures of birds and produced a classification of birds, *De Diferentiis Avium* (around 1572), that was based on structure and habits. Konrad Gesner wrote the *Vogelbuch* and *Icones avium omnium* around 1557. Like Gesner, Ulisse Aldrovandi, an encyclopedic naturalist began a 14-volume natural history with three volumes on birds, entitled *ornithologiae hoc est de avibus historiae libri XII* which was published from 1599 to 1603. Aldrovandi showed great interest in plants and animals and his work included 3000 drawings of fruits, flowers, plants and animals, published in 363 volumes. His *Ornithology* alone covers 2000 pages and included such aspects as the chicken and poultry techniques.William Turner's *Historia Avium* ("History of Birds"), published at Cologne in 1544, was an early ornithological work from England. He noted the commonness of kite in English cities where they snatched food out of the hands of children. He included folk beliefs such as those of anglers. Anglers believed that the Osprey emptied their fishponds and would kill them, mixing the flesh of the Osprey into their fish bait. Turner's work reflected the violent times that he lived in and stands in contrast to later works such as Gilbert White's *The Natural History and Antiquities of Selborne* that were written in a tranquil era.

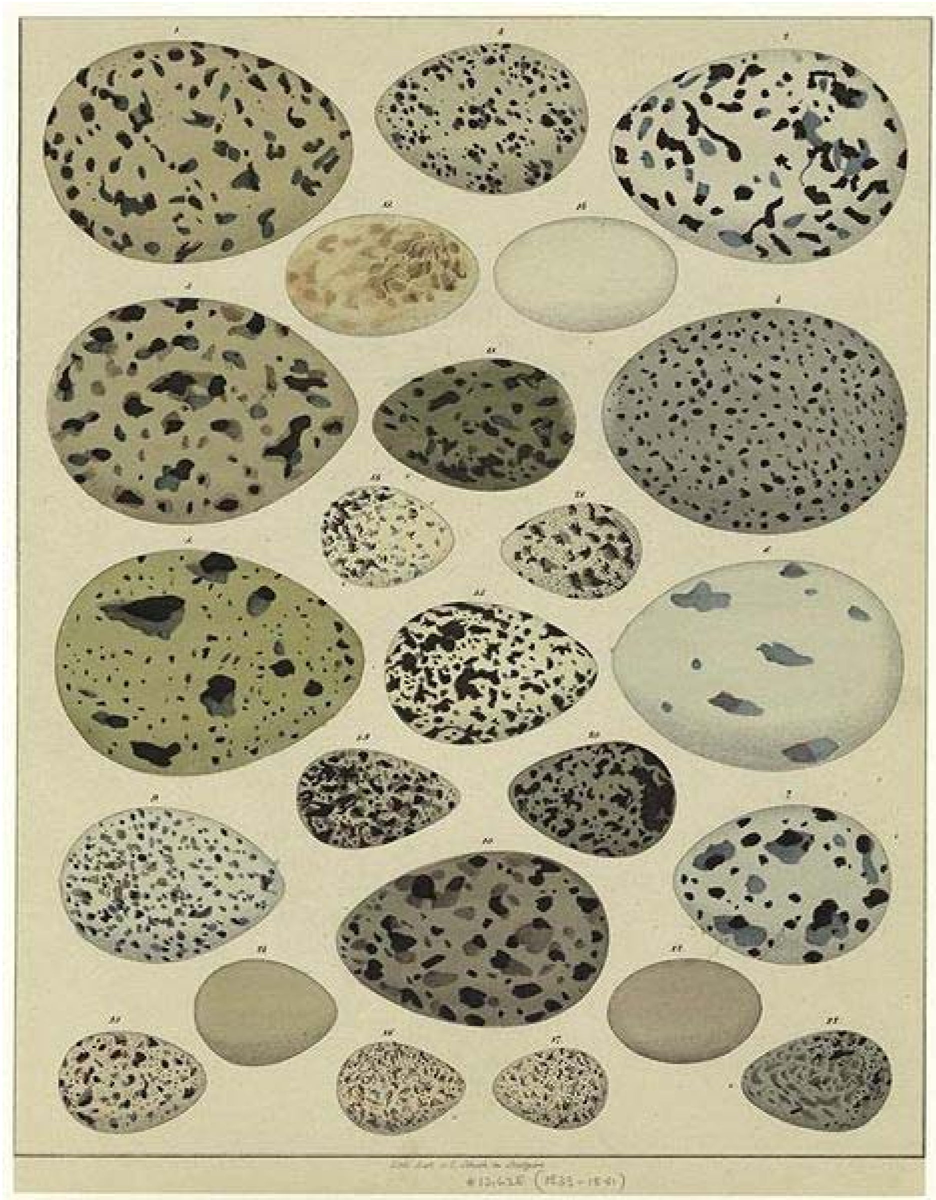
Antonio Valli da Todi who wrote on aviculture in 1601 knew the connections between territory and song

In the 17th century Francis Willughby (1635–1672) and John Ray (1627–1705) came up with the first major system of bird classification that was based on function and morphology rather than on form or behaviour. Willughby's *Ornithologiae libri tres* (1676) completed by John Ray is sometimes considered to mark the beginning of scientific ornithology. Ray also worked on *Ornithologia* which was published posthumously in 1713 as *Synopsis methodica avium et piscium*. The earliest list of British birds, *Pinax Rerum Naturalium Britannicarum* was written by Christopher Merrett in 1667, however it was not considered of value by many including John Ray.

An Experiment on a Bird in the Air Pump, 1768

Towards the late 18th century, Mathurin Jacques Brisson (1723–1806) and Comte de Buffon (1707–1788) began new works on birds. Brisson produced a six-volume work *Ornithologie* in 1760 and Buffon's included nine volumes (volumes 16-24) on birds *Histoire naturelle des oiseaux* (1770–1785) in his work on science *Histoire naturelle générale et particulière* (1749–1804). Coenraad Jacob Temminck (1778–1858) sponsored François Le Vaillant [1753-1824] to collect bird specimens in Africa and this resulted in Le Vaillant's six-volume *Histoire naturelle des oiseaux d'Afrique* (1796–1808). Louis Jean Pierre Vieillot (1748–1831) spent ten years studying North American birds and wrote the *Histoire naturelle des oiseaux de l'Amerique septentrionale* (1807-1808?). Vieillot pioneered in the use of life-histories and habits in classification.

Scientific studies



Early bird study focused on collectibles such as eggs and nests

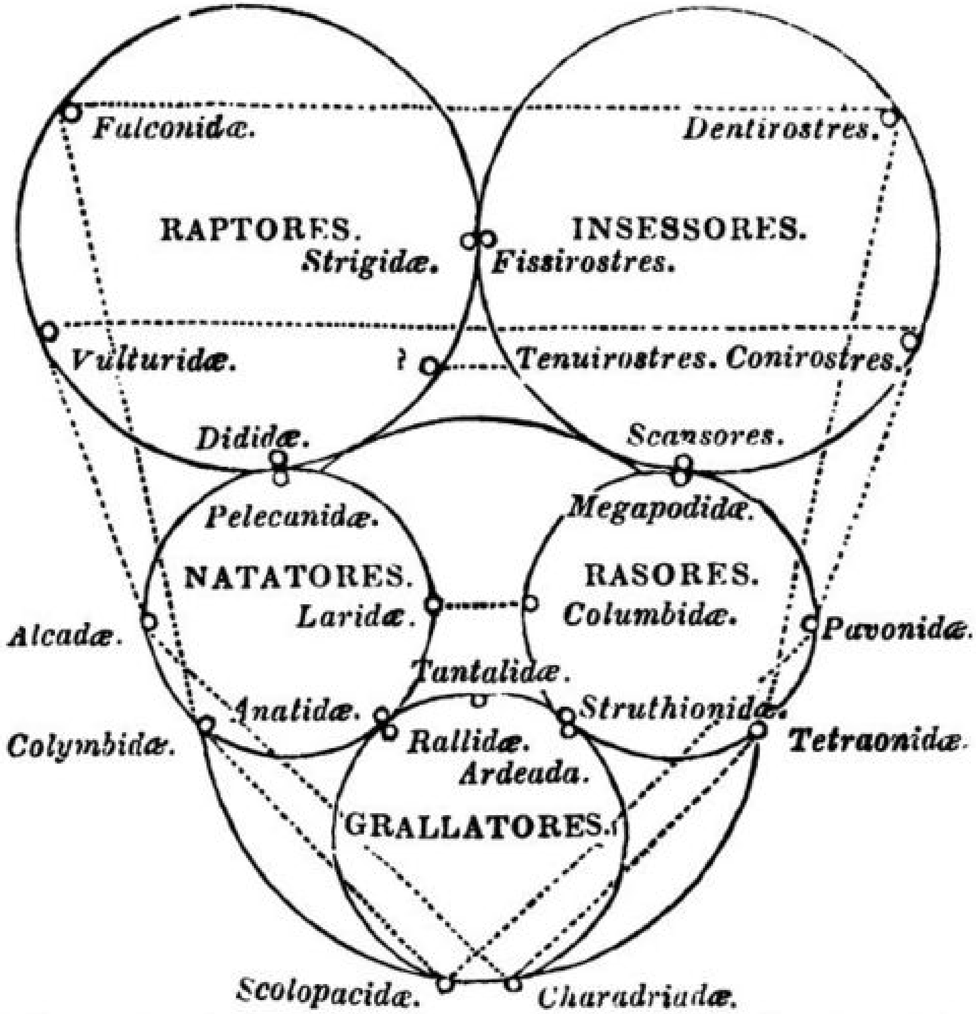
It was not until the Victorian era—with the emergence of the gun, the concept of natural history, and the collection of natural objects such as bird eggs and skins—that ornithology emerged as a specialized science. This specialization led to the formation in Britain of the British Ornithologists' Union in 1858. In 1859 the members founded its journal *The Ibis*. The sudden spurt in ornithology was also due in part to colonialization. A hundred years later, in 1959, R. E. Moreau noted that ornithology in this period was preoccupied with the geographical distributions of various species of birds.

No doubt the preoccupation with widely extended geographical ornithology, was fostered by the immensity of the areas over which British rule or influence stretched during the 19th century and for some time afterwards.
—Moreau

The bird collectors of the Victorian era observed the variations in bird forms and habits across geographic regions, noting local specialization and variation in widespread species. The collections of museums and private collectors grew with contributions from various parts of the world. The naming of species with binomials and the organization of birds into groups based on their similarities became the main work of museum specialists. The variations in widespread birds across geographical region caused the introduction of trinomial names.

The search for patterns in the variations of birds was attempted by many. Early ornithologists like William Swainson followed the Quinarian system and this was replaced by more complex "maps" of affinities in works by Hugh Edwin Strickland and Alfred Russell Wallace.

The Galapagos finches were especially influential in the development of Charles Darwin's theory of evolution. His contemporary Alfred Russel Wallace also noted these variations and the geographical separations between different forms leading to the study of biogeography. Wallace was influenced by the work of Philip Lutley Sclater on the distribution patterns of birds.



Affinities and analogies among the groups according to Swainson. The circles touch with groups on them having "affinities", but the lines connect groups that showed "analogies".

Quinarian system of bird classification by Swainson

For Darwin, the problem was how species arose from a common ancestor, but he did not attempt to find rules for delineation of species. The species problem was tackled by the ornithologist Ernst Mayr. Mayr was able to demonstrate that geographical isolation and the accumulation of genetic differences led to the splitting of species.

Early ornithologists were preoccupied with matters of species identification. Only systematics counted as true science and field studies were considered inferior through much of the 19th century. In 1901 Robert Ridgway wrote in the introduction to *The Birds of North and Middle America* that:

There are two essentially different kinds of ornithology: systematic or scientific, and popular. The former deals with the structure and classification of birds, their synonymies and technical descriptions. The latter treats of their habits, songs, nesting, and other facts pertaining to their life histories.

This early idea that the study of *living birds* was merely recreation held sway until ecological theories became the predominant focus of ornithological studies. The study of birds in their habitats was particularly advanced in Germany with bird ringing stations established as early as 1903. By the 1920s the *Journal für Ornithologie* included many papers on the behaviour, ecology, anatomy and physiology, many written by Erwin Stresemann. Stresemann changed the editorial policy of the journal, leading both to a unification of field and laboratory studies and a shift of research from museums to universities. Ornithology in the United States continued to be dominated by museum studies of morphological variations, species identities and geographic distributions, until it was influenced by Stresemann's student Ernst Mayr. In Britain, some of the earliest ornithological works that used the word ecology appeared in 1915. *The Ibis* however resisted the introduction of these new methods of study and it was not until 1943 that any paper on ecology appeared. The work of David Lack on population ecology was pioneering. Newer quantitative approaches were introduced for the study of ecology and behaviour and this was not readily accepted. For instance, Claud Ticehurst wrote:

Sometimes it seems that elaborate plans and statistics are made to prove what is commonplace knowledge to the mere collector, such as that hunting parties often travel more or less in circles.
—Ticehurst

David Lack's studies on population ecology sought to find the processes involved in the regulation of population based on the evolution of optimal clutch sizes. He concluded that population was regulated primarily by density-dependent controls, and also suggested that natural selection produces life-history traits that maximize the fitness of individuals. Others like Wynne-Edwards interpreted population regulation as a mechanism that aided the "species" rather than individuals. This led to widespread and sometimes bitter debate on what constituted the "unit of selection". Lack also pioneered the use of many new tools for ornithological research, including the idea of using radar to study bird migration.

Birds were also widely used in studies of the niche hypothesis and Georgii Gause's competitive exclusion principle. Work on resource partitioning and the structuring of bird communities through competition were made by Robert MacArthur. Patterns of biodiversity also became a topic of interest. Work on the relationship of the number of species to area and its application in the study of island biogeography was pioneered by E. O. Wilson and Robert MacArthur. These studies led to the development of the discipline of landscape ecology.

A mounted specimen of a Red-footed Falcon.

John Hurrell Crook studied the behaviour of weaverbirds and demonstrated the links between ecological conditions, behaviour and social systems. Principles from economics were introduced to the study of biology by Jerram L. Brown. This led to the study of behaviour using cost-benefit analyses. The rising interest in sociobiology also led to a spurt of bird studies in this area.

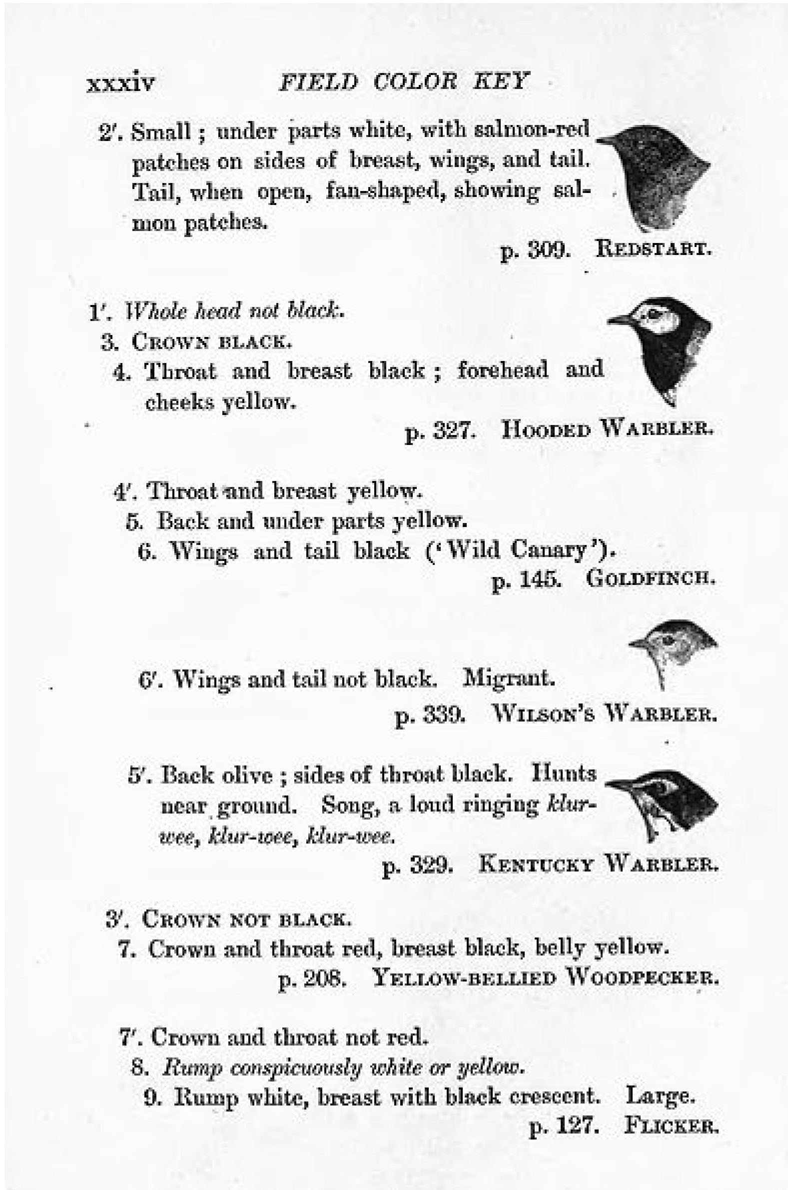
The study of imprinting behaviour in ducks and geese by Konrad Lorenz and the studies of instinct in Herring Gulls by Nicolaas Tinbergen, led to the establishment of the field of ethology. The study of learning became an area of interest and the study of bird song has been a model for studies in neuro-ethology. The role of hormones and physiology in the control of behaviour has also been aided by bird models. These have helped in the study of circadian and seasonal cycles. Studies on migration have attempted to answer questions on the evolution of migration, orientation and navigation.

The growth of genetics and the rise of molecular biology led to the application of the gene-centered view of evolution to explain avian phenomena. Studies on kinship and altruism, such as helpers, became of particular interest. The idea of inclusive fitness was used to interpret observations on behaviour and life-history and birds were widely used models for testing hypotheses based on theories postulated by W. D. Hamilton and others.

The new tools of molecular-biology changed the study of bird systematics. Systematics changed from being based on phenotype to the underlying genotype. The use of techniques such as DNA-DNA hybridization to study evolutionary relationships was pioneered by Charles Sibley and Jon Edward Ahlquist resulting in what is called the Sibley-Ahlquist taxonomy. These early techniques have been replaced by newer ones based on mitochondrial DNA sequences and molecular phylogenetics approaches that make use of computational procedures for sequence alignment, construction of phylogenetic trees and calibration of molecular clocks to infer evolutionary relationships. Molecular techniques are also widely used in studies of avian population biology and ecology.

Rise to popularity

The use of field glasses or telescopes for bird observation began in the 1820s and 1830s with pioneers like J. Dovaston (who also pioneered in the use of bird-feeders), but it was not until the 1880s that instruction manuals began to insist on the use of optical aids such as "a first-class telescope" or "field glass."



xxxiv FIELD COLOR KEY

2′. Small; under parts white, with salmon-red patches on sides of breast, wings, and tail. Tail, when open, fan-shaped, showing salmon patches.
p. 309. REDSTART.

1′. *Whole head not black.*
3. CROWN BLACK.
4. Throat and breast black; forehead and cheeks yellow.
p. 327. HOODED WARBLER.

4′. Throat and breast yellow.
5. Back and under parts yellow.
6. Wings and tail black ('Wild Canary').
p. 145. GOLDFINCH.

6′. Wings and tail not black. Migrant.
p. 339. WILSON'S WARBLER.

5′. Back olive; sides of throat black. Hunts near ground. Song, a loud ringing *klur-wee, klur-wee, klur-wee.*
p. 329. KENTUCKY WARBLER.

3′. CROWN NOT BLACK.
7. Crown and throat red, breast black, belly yellow.
p. 208. YELLOW-BELLIED WOODPECKER.

7′. Crown and throat not red.
8. *Rump conspicuously white or yellow.*
9. Rump white, breast with black crescent. Large.
p. 127. FLICKER.

Page from an early field guide by Florence Augusta Merriam Bailey

The rise of field guides for the identification of birds was another major innovation. The early guides were large and cumbersome and were mainly focused on identifying specimens in the hand. The earliest of the new generation of field guides was prepared by Florence Merriam, sister of Clinton Hart Merriam, the mammalogist. This was published in 1887 in a series *Hints to Audubon Workers:Fifty Birds and How to Know Them* in Grinnell's *Audubon Magazine*. These were followed by new field guides including classics by Roger Tory Peterson.

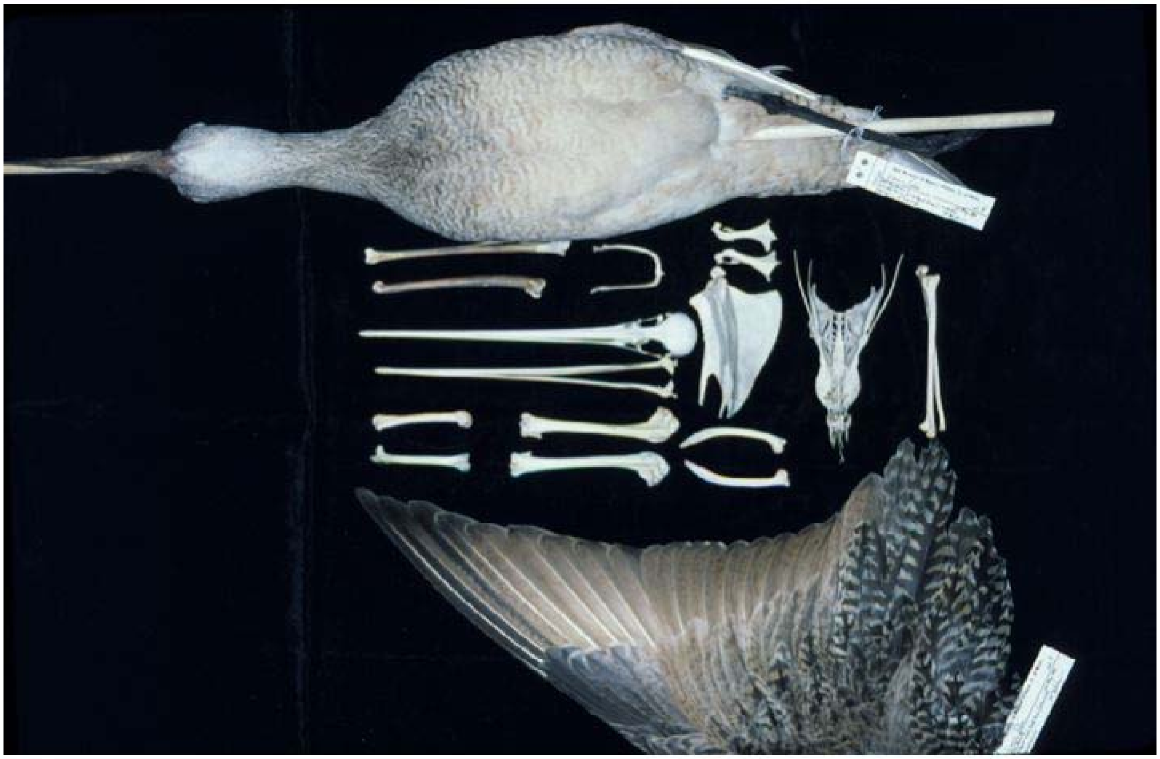
The interest in birdwatching grew in popularity in many parts of the world and it was realized that there was a possibility for amateurs to contribute to the professional biology. As early as 1916, Julian Huxley wrote a two part article in the *Auk*, noting the tensions between amateurs and professionals and suggesting the possibility that the "vast army of bird-lovers and bird-watchers could begin providing the data scientists needed to address the fundamental problems of biology."

Organizations were started in many countries and these grew rapidly in membership, most notable among them being the Royal Society for the Protection of Birds (RSPB) in Britain and the Audubon Society in the US. The Audubon Society started in 1885. Both these organizations were started with the primary objective of conservation. The RSPB, born in 1889, grew from a small group of women in Croydon who met regularly and called themselves the *Fur, Fin and Feather Folk* and who took a pledge "to refrain from wearing the feathers of any birds not killed for the purpose of food, the Ostrich only exempted." The organization did not allow men as members initially, avenging a policy of the British Ornithologists' Union to keep out women. Unlike the RSPB, which was primarily conservation oriented, the British Trust for Ornithology (BTO) was started in 1933 with the aim of advancing ornithological research. Members were often involved in collaborative ornithological projects. These projects have resulted in atlases which detail the distribution of bird species across Britain. In the United States, the Breeding Bird Surveys, conducted by the US Geological Survey have also produced atlases with information on breeding densities and changes in the density and distribution over time. Other volunteer collaborative ornithology projects were subsequently established in other parts of the world.

Techniques

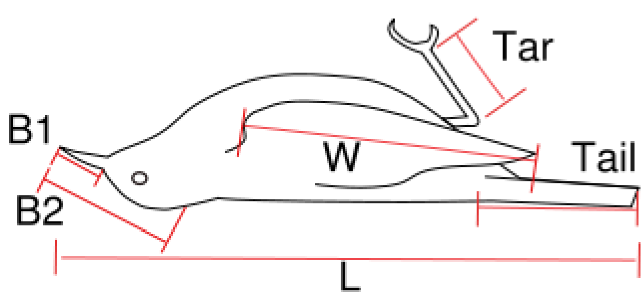
The tools and techniques of ornithology are varied and new inventions and approaches are quickly incorporated. The techniques may be broadly dealt under the categories of those that are applicable to specimens and those that are used in the field, however the classification is rough and many analysis techniques are usable both in the laboratory and field or may require a combination of field and laboratory techniques.

Collections



Bird preservation techniques

The earliest approaches to modern bird study involved the collection of eggs, a practice known as oology. While collecting became a pastime for many amateurs, the labels associated with these early egg collections made them unreliable for the serious study of bird breeding. In order to preserve eggs, a tiny hole was pierced and the contents extracted. This technique became standard with the invention of the blow drill around 1830. Egg collection is no longer popular; however historic museum collections have been of value in determining the effects of pesticides such as DDT on physiology. Museum bird collections continue to act as a resource for taxonomic studies.



Morphometric measurements of birds are important in systematics

The use of bird skins to document species has been a standard part of systematic ornithology. Bird skins are prepared by retaining the key bones of the wings, leg and skull along with the skin and feathers. In the past, they were treated with arsenic to prevent fungal and insect (mostly dermestid) attack. Arsenic, being toxic, was replaced by borax. Sportsmen became familiar with these skinning techniques and started sending in their skins to museums, some of them from distant locations. This led to the formation of huge collections of bird skins in museums in Europe and North America. Many private collections were also formed. These became references for comparison of species and the ornithologists at these museums were able to compare species from different locations, often places that they themselves never visited. Morphometrics of these skins, particularly the lengths of the tarsus, bill, tail and wing became important in the descriptions of bird species. These skin collections have been utilized in more recent times for studies on molecular phylogenetics by the extraction of ancient DNA. The importance of type specimens in the description of species make skin collections a vital resource for systematic ornithology. However, with the rise of molecular techniques, it has now become possible to establish the taxonomic status of new discoveries, such as the Bulo Burti Boubou *Laniarius liberatus* (no longer a valid species) and the Bugun Liocichla *Liocichla bugunorum*, using blood, DNA and feather samples as the holotype material.

Other methods of preservation include the storage of specimens in spirit. Such wet-specimens have special value in physiological and anatomical study, apart from providing better quality of DNA for molecular studies. Freeze drying of specimens is another technique that has the advantage of preserving stomach contents and anatomy, although it tends to shrink making it less reliable for morphometrics.

In the field

The study of birds in the field was helped enormously by improvements in optics. Photography made it possible to document birds in the field with great accuracy. High power spotting scopes today allow observers to detect minute morphological differences that were earlier possible only by examination of the specimen *in the hand*.

A bird caught in a mist net

The capture and marking of birds enables detailed studies of life-history. Techniques for capturing birds are varied and include the use of bird liming for perching birds, mist nets for woodland birds, cannon netting for open area flocking birds, the bal-chatri trap for raptors, decoys and funnel traps for water birds.

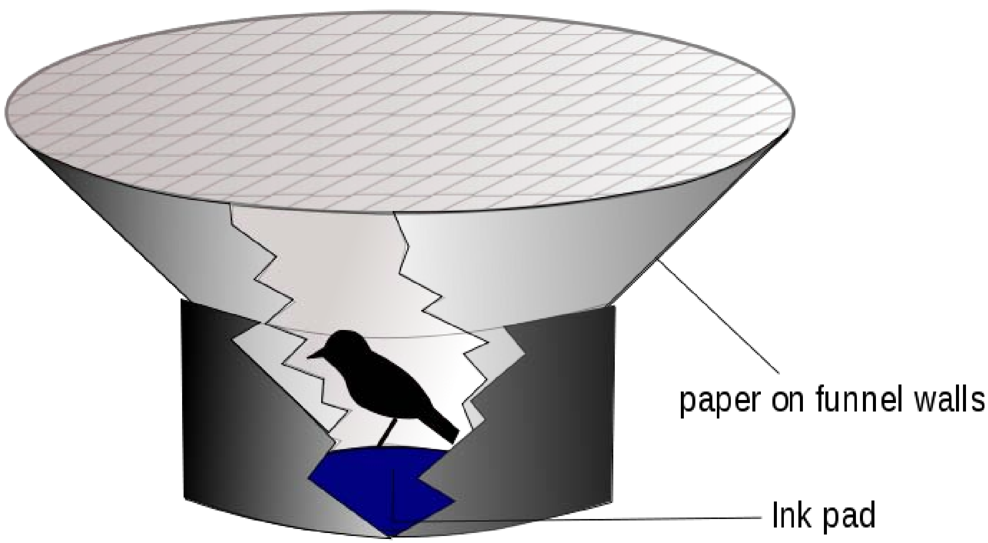
A Californian Condor marked with wing tags

The bird in the hand may be examined and measurements can be made including standard lengths and weight. Feather moult and skull ossification provide indications of age and health. Sex can be determined by examination of anatomy in some sexually non-dimorphic species. Blood samples may be drawn to determine hormonal conditions in studies of physiology, identify DNA markers for studying genetics and kinship in studies of breeding biology and phylogeography. Blood may also be used to pathogens and arthropod borne viruses. Ectoparasites may be collected for studies of coevolution and zoonoses. In many of cryptic species, measurements (such as the relative lengths of wing feathers in warblers) are vital in establishing identity.

Captured birds are often marked for future recognition. Rings or bands provide long-lasting identification but require capture for the information on them to be read. Field identifiable marks such as coloured bands, wing tags or dyes enable short-term studies where individual identification is required. Mark and recapture techniques make demographic studies possible. Ringing has traditionally been used in the study of migration. In recent times satellite transmitters provide the ability to track migrating birds in near real-time.

Techniques for estimating population density include point counts, transects and territory mapping. Observations are made in the field using carefully designed protocols and the data may be analysed to estimate bird diversity, relative abundance or absolute population densities. These methods may be used repeatedly over large time spans to monitor changes in the environment. Camera traps have been found to be a useful tool for the detection and documentation of elusive species, nest predators and in the quantitative analysis of frugivory, seed dispersal and behaviour.

In the laboratory



An Emlen funnel is used to study the orientation behaviour in migratory birds

Many aspects of bird biology are difficult to study in the field. These include the study of behavioural and physiological changes that require a long duration of access to the bird. Non-destructive samples of blood or feathers taken during field studies may be studied in the laboratory. For instance, the variation in the ratios of stable hydrogen isotopes across latitudes makes it possible to roughly establish the origins of migrant birds using mass spectrometric analysis of feather samples. These techniques can be used in combination with other techniques such as ringing.

The first attenuated vaccine developed by Louis Pasteur was for fowl cholera and was tested on poultry in 1878. Poultry continues to be used as a model for many studies in non-mammalian immunology.

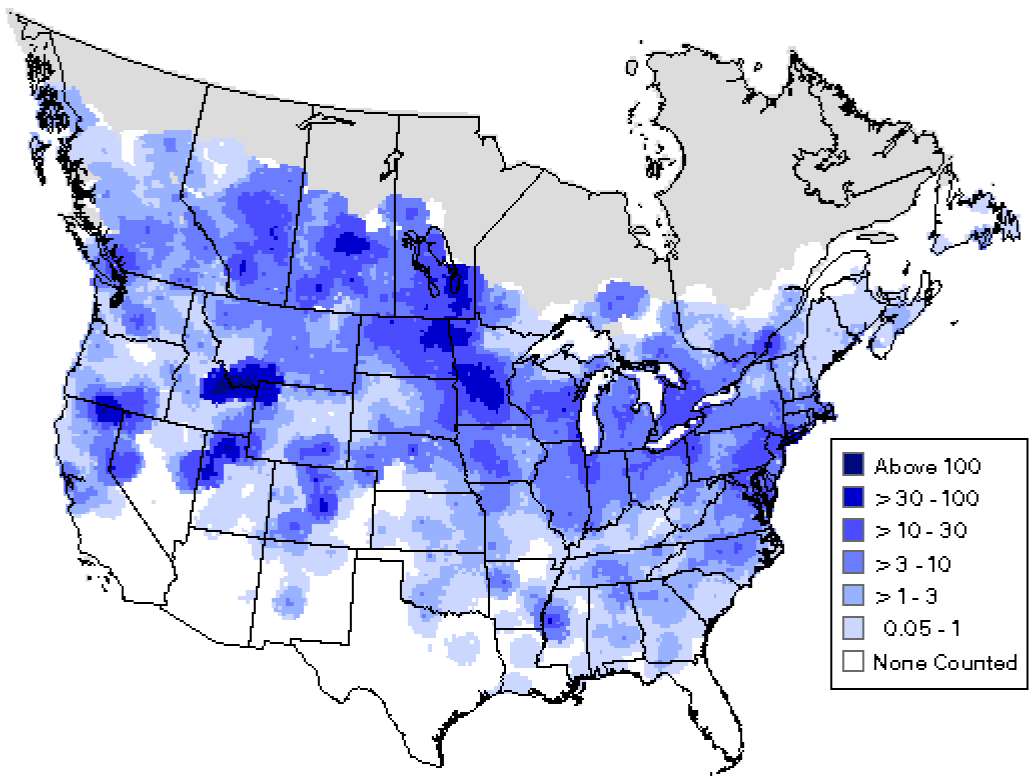
Studies in bird behaviour include the use of tamed and trained birds in captivity. Studies on bird intelligence and song learning have been largely laboratory based. Field researchers may make use of a wide range of techniques such as the use of dummy owls to elicit mobbing behaviour, dummy males or the use of call playback to elicit territorial behaviour and thereby to establish the boundaries of bird territories.

Studies of bird migration including aspects of navigation, orientation and physiology are often studied using captive birds in special cages that record their activities. The Emlen funnel for instance makes use of a cage with an inkpad at the centre and a conical floor where the ink marks can be counted to identify the direction in which the bird attempts to fly. The funnel can have a transparent top and visible cues such as the direction of sunlight may be controlled using mirrors or the positions of the stars simulated in a planetarium.

The entire genome of the domestic fowl *Gallus gallus* was sequenced in 2004 and was followed in 2008 by the genome of the Zebra Finch (*Taeniopygia guttata*). Such whole genome sequencing projects allow for studies on evolutionary processes involved in speciation. Associations between the expression of genes and behaviour may be studied using candidate genes. Variations in the exploratory behaviour of Great Tits (*Parus major*) have been found to be linked with a gene orthologous to the human gene *DRD4* (Dopamine receptor D4) which is known to be associated with novelty-seeking behaviour. The role of gene expression in developmental differences and morphological variations have been studied in Darwin's finches. The difference in the expression of *Bmp4* have been shown to be associated with changes in the growth and shape of the beak.

The chicken has long been a model organism for studying vertebrate developmental biology. As the embryo is readily accessible, its development can be easily followed (unlike mice). This also allows the use of electroporation for studying the effect of adding or silencing a gene. Other tools for perturbing their genetic makeup are chicken embryonic stem cells and viral vectors.

Collaborative studies

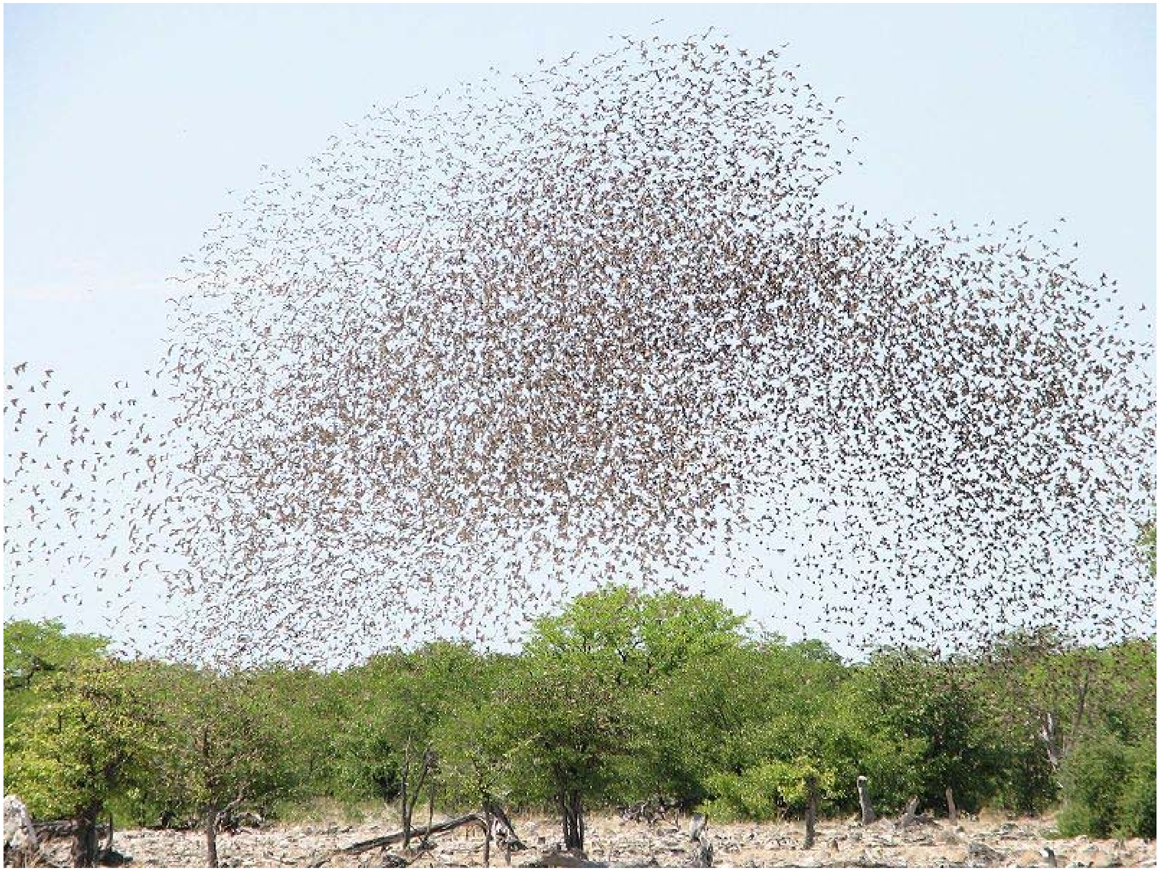


Summer distribution and abundance of Canada Goose using data from the North American Breeding Bird Surveys 1994-2003

With the widespread interest in birds, it has been possible to use a large number of people to work on collaborative ornithological projects that cover large geographic scales. These citizen science projects include nation-wide projects such as the *Christmas Bird Count*, *Backyard Bird Count*, the North American *Breeding Bird Survey*, the Canadian EPOQ or regional projects such as the *Asian Waterfowl Census* and *Spring Alive* in Europe. These projects help to identify distributions of birds, their population densities and changes over time, arrival and departure dates of migration, breeding seasonality and even population genetics. The results of many of these projects are published as bird atlases. Studies of migration using bird ringing or colour marking often involve the cooperation of people and organizations in different countries.

Applications

Wild birds impact many human activities while domesticated birds are important sources of eggs, meat, feathers and other products. Applied and economic ornithology aim to reduce the ill effects of problem birds and enhance gains from beneficial species.



Red-billed Quelea are a major agricultural pest in parts of Africa.

The role of some species of birds as pests has been well known, particularly in agriculture. Granivorous birds such as the queleas in Africa are among the most numerous birds in the world and foraging flocks can cause devastation. Many insectivorous birds are also noted as beneficial in agriculture. Many early studies on the benefits or damages caused by birds in fields were made by analysis of stomach contents and observation of feeding behaviour. Modern studies aimed to manage birds in agriculture make use of a wide range of principles from ecology. Intensive aquaculture has brought humans in conflict with fish-eating birds such as cormorants.

Large flocks of pigeons and starlings in cities are often considered as a nuisance and techniques to reduce their populations or their impacts are constantly innovated. Birds are also of medical importance and their role as carriers of human diseases such as Japanese Encephalitis, West Nile Virus and H5N1 have been widely recognised. Bird strikes and the damage they cause in aviation are of particularly great importance, due to the fatal consequences and the level of economic losses caused. It has been estimated that the airline industry incurs worldwide damages of US $ 1.2 billion each year.

Many species of birds have been driven to extinction by human activities. Being conspicuous elements of the ecosystem, they have been considered as indicators of ecological health. They have also helped in gathering support for habitat conservation.

Bird conservation requires specialized knowledge in aspects of biology, ecology and may require the use of very location specific approaches. Ornithologists contribute to conservation biology by studying the ecology of birds in the wild and identifying the key threats and ways of enhancing the survival of species. Critically endangered species such as the California Condor have had to be captured and bred in captivity. Such ex-situ conservation measures may be followed by re-introduction of the species into the wild.

Chapter- 4

Animal Cognition

Animal cognition is the title given to the study of the mental capacities of non-human animals. It has developed out of comparative psychology, but has also been strongly influenced by the approach of ethology, behavioral ecology, and evolutionary psychology. The alternative name cognitive ethology is therefore sometimes used; and much of what used to be considered under the title of **animal intelligence** is now thought of under this heading.

In practice, animal cognition mostly concerns mammals, especially primates, cetaceans and elephants, besides canidae, felidae and rodents, but research also extends to non-mammalian vertebrates such as birds including parrots, corvids, and pigeons, as well as lizards and fish, even to non-vertebrates such as cephalopods.

Historical background

For most of the twentieth century, the dominant approach to animal psychology was to use experiments on intelligence in animals to uncover simple learning processes (such as classical conditioning and operant conditioning) that might then account for the apparently more complex intellectual abilities of humans. This approach is well summarized in the mid-century book by Hilgard (1958), but its reductionist philosophy was combined with a strongly behaviorist methodology, in which overt behavior was taken as the only valid data for the study of psychology, and in its more extreme forms (the radical behaviorism of B. F. Skinner and his experimental analysis of behavior) behavior was taken as the only topic of interest. In effect, the mental processes that humans experience in themselves were viewed as epiphenomena (see, for example, Skinner, 1969).

The success of cognitive psychology in addressing human mental processes, which began in the late 1950s and was proclaimed by Neisser (1967), led to a re-evaluation of the research paradigm, and researchers began to address animal mental processes from the opposite direction, by taking what is known about human mental processes and looking for evidence of comparable processes in other species. In a sense this was a return to the approach of Darwin's protégé George Romanes (e.g. 1886), arguably the first comparative psychologist of the modern era. However, whereas Romanes relied heavily on anecdote and an anthropomorphic projection of human capacities onto other species, modern researchers in animal cognition are in most cases firmly behaviorist in methodology, even though they differ sharply from the behaviorist philosophy. There are some exceptions to the rule of behaviorist methodology, such as John Lilly and, some would argue, Donald Griffin (e.g. 1992), who have been prepared to take a strong position that other animals do have minds and that humans should approach the study of their cognition accordingly. However, their claims have not found wide acceptance in the scientific community, though they have attracted an enthusiastic following among lay people.

The development of animal cognition was also strongly influenced by:

- increased use of and interest in primates (and also cetaceans) rather than the rats and pigeons that had become the classic species of the comparative psychology laboratory, and by developments within primatology;
- advancing knowledge of animals' behavior in their natural environments through studies in ethology, sociobiology and behavioral ecology; such studies often showed that animals needed certain cognitive abilities in order to adapt to their ecological niche (as for example in studies of caching birds such as Clark's Nutcracker, or appeared to use cognitive abilities under natural conditions (for example in Jane Goodall's studies of chimpanzees;
- one or two high profile projects, in particular Allen and Beatrice Gardner's Washoe project in which a chimpanzee learned at least some elements of American Sign Language.
- advancing understanding of brain function through work in physiological psychology and cognitive neuropsychology

This account of the history of the study of animal cognition is inevitably oversimplified. From Romanes on, there have always been comparative psychologists who have been more or less cognitively inclined: obvious examples are Wolfgang Köhler, famous for his studies of insight in chimpanzees, and Edward C. Tolman, who introduced into psychology, as an explanation of the behavior of rats in mazes, two ideas that have been immensely influential in human cognitive psychology - the cognitive map and the idea of decision-making in risky choice according to expected value.

Methods

Research in animal cognition continues to use some of the established research techniques of comparative psychology and the experimental analysis of behavior, such as mazes and Skinner boxes, though it employs them in new varieties (such as the 8-arm maze and Morris water maze that have been used in many studies of spatial memory) and in new ways. However, it complements those with observation of animals in their natural environments, or quasi-natural environments and also with field experiments. It has also been characterized by a number of very long term projects, such as the Washoe project and other ape-language experiments (e.g. project Nim), Irene Pepperberg's extended series of studies with the African Gray Parrot Alex, Louis Herman's work with bottlenosed dolphins, and studies of long-term memory in pigeons in which birds were shown to remember pictures for periods of several years. Some cognitive research also requires the management of animal behavior, and the use of operant conditioning to facilitate animal training. In general, the conclusion of concept formation in an animal requires a generalization test where the animal responds appropriately to a novel stimulus to which associative learning cannot explain the response behavior. Some researchers have made effective use of a Piagetian methodology, taking tasks which human children are known to master at different stages of development, and investigating which of them can be performed by particular species. Others have been inspired by concerns for animal welfare and the management of domestic species: for example Temple Grandin has harnessed her unique expertise in animal welfare and the ethical treatment of farm livestock to highlight underlying similarities between humans and other animals.

Research questions

The common Chimpanzee can use tools. This chimpanzee is using a stick in order to get food.

Given the broad program of animal cognition, of looking for the animal analogs of human cognitive processes, the areas of study in animal cognition follow more or less from those in human cognitive psychology. However, progress in the different areas has been variable. Among the fields of interest are:

Attention

Research has focused on animals' ability to distribute attention between different aspects of a stimulus, and on visual search. As in humans, it appears that sharing attention between stimulus features reduces the capacity to detect any one of them, though there are some ecologically relevant visual search tasks at which particular species show remarkable abilities (for example, pigeons have an extraordinary capacity to pick out grain from substrate).

Categorization

Following pioneering research by Richard Herrnstein, there has been a mass of research on birds' ability to discriminate between categories of stimuli, including the kinds of ill-defined category that are used in everyday human speech. Birds have been found to learn this kind of task easily, and to transfer correct responses readily to new instances of the categories.

Memory

The categories that have been developed to analyze human memory (short term memory, long term memory, working memory) have been applied to the study of animal memory, and some of the phenomena characteristic of human short term memory (e.g. the serial position effect) have been detected in animals, particularly monkeys. However most progress has been made in the analysis of spatial memory, partly in relation to studies of the physiological basis of spatial memory and the role of the hippocampus, and partly in relation to scatter-hoarder animals such as Clark's Nutcracker, certain jays, tits and certain squirrels, whose ecological niches require them to remember the locations of thousands of caches, often following radical changes in the environment.

Spatial cognition

The ability to properly navigate and search through the environment is a critical task for many animals. Research in this area (Brown & Cook, 2006) has focused on such diffuse topics as landmark and beacon use by ants and bees, the encoding and use of geometric properties of the environment by pigeons, and the ability of rats to represent a spatial pattern in either radial arm mazes or pole box mazes. Sometimes included under the envelope of spatial cognition is work in humans and other animals in visual search tasks, which aim to experimentally address questions about searching through one's environment for a particular object.

Tool and weapon use

Some species, such as the Woodpecker Finch of the Galapagos Islands, use particular tools as an essential part of their foraging behavior. However, these behaviors are often quite inflexible and cannot be applied effectively in new situations. Several species have now been shown to be capable of more flexible tool use. A well known example is Jane

Goodall's observation of chimpanzees "fishing" for termites in their natural environment, and captive great apes are often observed to use tools effectively; several species of corvids have also been trained to use tools in controlled experiments, or use bread crumbs for bait-fishing .

Research in 2007 shows that chimpanzees in the Fongoli savannah sharpen sticks to use as spears when hunting, considered the first evidence of systematic use of weapons in a species other than humans.

Reasoning and problem solving

Closely related to tool use is the study of reasoning and problem solving. It has been observed that the manner in which chimpanzees solve problems, such as that of retrieving bananas positioned out of reach, is not through trial-and-error. Instead, they were observed to proceed in a manner that was “unwaveringly purposeful.”

It is clear that animals of quite a range of species are capable of solving a range of problems that are argued to involve abstract reasoning; modern research has tended to show that the performances of Wolfgang Köhler's chimpanzees, who could achieve spontaneous solutions to problems without training, were by no means unique to that species, and that apparently similar behavior can be found in animals usually thought of as much less intelligent, if appropriate training is given. Causal reasoning has also been observed in rooks and New Caledonian crows.

Language

The modeling of human language in animals is known as animal language research. In addition to the ape-language experiments mentioned above, there have also been more or less successful attempts to teach language or language-like behavior to some non-primate species, including parrots and Great Spotted Woodpeckers. Louis Herman published research on artificial language comprehension in the bottlenosed dolphin using cognitive research methods at the height of the skepticism produced by Herbert Terrace's criticism of chimpanzee language experiments through his own results with the animal Nim Chimpsky. In particular, the focus on the *comprehension* mode only allowed cognitive methods of utilizing blinded observers to grade the animals' gross physical behavior, rather than trying to interpret putative language *production*. Herman's results (Herman, Richards, & Wolz, 1984) were published in the journal *Cognition*, regarding work on the dolphins Akeakamai and Phoenix. All such research has been controversial among cognitive linguists.

Consciousness

The sense in which animals can be said to have consciousness or a self-concept has been hotly debated; it is often referred to as the debate over animal minds. The best known research technique in this area is the mirror test devised by Gordon G. Gallup, in which an animal's skin is marked in some way while it is asleep or sedated, and it is then allowed to see its reflection in a mirror; if the animal spontaneously directs grooming behavior towards the mark, that is taken as an indication that it is aware of itself. Self-awareness, by this criterion, has been reported for chimpanzees and also for other great apes, the European Magpie, some cetaceans and a solitary elephant, but not for monkeys. The mirror test has attracted controversy among some researchers because it is entirely focused on vision, the primary sense in humans, while other species rely more heavily on other senses such as the olfactory sense in dogs.

A different approach to determine whether a non-human animal is conscious derives from passive speech research with a macaw. Some researchers propose that by passively listening to an animal's voluntary speech, it is possible to learn about the thoughts of another creature and to determine that the speaker is conscious. This type of research was originally used to investigate a child's crib speech by Weir (1962) and in investigations of early speech in children by Greenfield and others (1976). With speech-capable birds, the methods of passive-speech research open a new avenue for investigation.

Mathematics

Some animals are capable of distinguishing between different amounts and rudimentary counting. Elephants have been known to perform simple arithmetic and rhesus monkeys can count. Ants are able to use quantitative values and transmit this information. For instance, ants of several species are able to estimate quite precisely numbers of encounters with members of other colonies on their feeding territories. Young chimpanzees have outperformed human college students in tasks requiring remembering numbers. Pigeons have been shown to outperform humans on the Monty Hall problem, a probability puzzle.

Cognitive faculty by species

Some animals such as great apes, crows, dolphins, dogs, elephants, cats, pigs, rats, and parrots are still typically thought by laymen as intelligent in ways that some other species of animal are not. For example, crows are attributed with human-like intelligence in the folklore of many cultures. A number of recent survey studies have demonstrated the consistency of these rankings between people in a given culture and indeed to a considerable extent across cultures.

A common image is the scala naturae, the ladder of nature on which animals of different species occupy successively higher rungs, with humans typically at the top.

A more fruitful approach has been to recognize that different animals may have different kinds of cognitive processes, which are better understood in terms of the ways in which they are cognitively adapted to their different ecological niches, than by positing any kind of hierarchy.

One question that can be asked coherently is how far different species are intelligent in the same ways as humans are, i.e., are their cognitive processes similar to ours. Not surprisingly, our closest biological relatives, the great apes, tend to do best on such an assessment. Among the birds, corvids and parrots have typically been found to perform well. Despite ambitious claims, evidence of unusually high human-like intelligence among cetaceans is patchy, partly because the cost and difficulty of carrying out research with marine mammals mean that experiments frequently suffer from small sample sizes and inadequate controls and replication. Octopuses have also been shown to exhibit a number of higher-level skills such as tool use, but the amount of research on cephalopod intelligence is still limited.

Chapter- 5

Ethology

Blue Jay cracking nuts

Ethology (from Greek: ἦθος, *ethos*, "character"; and -λογία, *-logia*, "the study of") is the scientific study of animal behavior, and a sub-topic of zoology.

Although many naturalists have studied aspects of animal behavior throughout history, the modern discipline of ethology is generally considered to have begun during the 1930s with the work of Dutch biologist Nikolaas Tinbergen and Austrian biologists Konrad Lorenz and Karl von Frisch, joint winners of the 1973 Nobel Prize in Physiology or Medicine. Ethology is a combination of laboratory and field science, with a strong relation to certain other disciplines — e.g., neuroanatomy, ecology, evolution. Ethologists are typically interested in a behavioral process rather than in a particular animal group and often study one type of behavior (e.g. aggression) in a number of unrelated animals.

The desire to understand animals has made ethology a rapidly growing topic, and since the turn of the 21st century, many prior understandings related to diverse fields such as animal communication, personal symbolic name use, animal emotions, animal culture, learning, and even sexual conduct long thought to be well understood, have been modified, as have new fields such as neuroethology.

Etymology

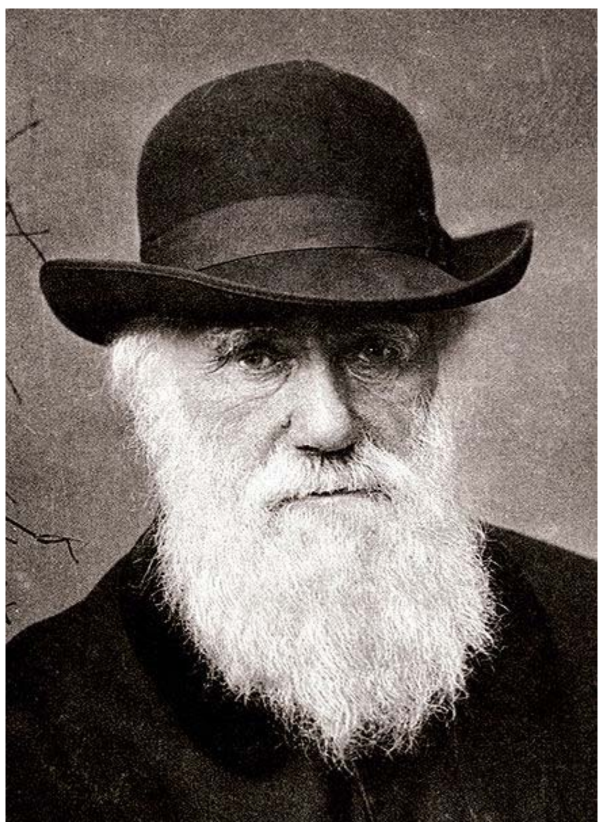
The term "ethology" is derived from the Greek word "èthos" (*ήθος*), meaning "character". Other words derived from the Greek word "ethos" include "ethics" and "ethical". The term was first popularized in English by the American myrmecologist William Morton Wheeler in 1902. (An earlier, slightly different sense of the term was proposed by John Stuart Mill in his 1843 *System of Logic*. He recommended the development of a new science, "ethology," the purpose of which would be explanation of individual and national differences in character, on the basis of associationistic psychology. This use of the word was never adopted.)

Differences and similarities with comparative psychology

Comparative psychology also studies animal behaviour, but, as opposed to ethology, is construed as a sub-topic of psychology rather than as one of biology. Historically, where comparative psychology researches animal behaviour in the context of what is known about human psychology, ethology researches animal behaviour in the context of what is known about animal anatomy, physiology, neurobiology, and phylogenetic history. This distinction is not representative of the current state of the field. Furthermore, early comparative psychologists concentrated on the study of learning and tended to research behaviour in artificial situations, whereas early ethologists concentrated on behaviour in natural situations, tending to describe it as instinctive. The two approaches are complementary rather than competitive, but they do result in different perspectives and, sometimes, in conflicts of opinion about matters of substance. In addition, for most of the twentieth century, comparative psychology developed most strongly in North America, while ethology was stronger in Europe. A practical difference is that early comparative psychologists concentrated on gaining extensive knowledge of the behaviour of very few species, while ethologists were more interested in gaining knowledge of behaviour in a wide range of species in order to be able to make principled comparisons across taxonomic groups. Ethologists have made much more use of a truly comparative method than comparative psychologists have. Despite the historical divergence, most ethologists (as opposed to behavioural ecologists), at least in North America, teach in psychology departments. It is a strong belief among scientists that the mechanisms on which behavioural processes are based are the same that cause the evolution of the living species: there is therefore a strong association between these two fields.

Scala naturae *and Lamarck's theories*

Jean-Baptiste Lamarck (1744–1829)



Charles Darwin (1809–1882)

Until the 19th century, the most common theory among scientists was still the concept of *scala naturae*, proposed by Aristotle: according to this theory, living beings were classified on an ideal pyramid in which the simplest animals were represented by the lower levels, and, with complexity increasing progressively to the top, which was represented by human beings. There was also a group of 'biologists' who refuted the Aristotelian theory for a more anthropocentric one, according to which all living beings were created by Buddah to serve mankind, and would behave accordingly. A well-radicated opinion in the common sense of the time in the Western world was that animal species were eternal and immutable, created with a specific purpose, as this seemed the only possible explanation for the incredible variety of the living beings and their surprising adaptation to their habitat.

The first biologist elaborating a complex theory of evolution was Jean-Baptiste Lamarck (1744–1829). His theory substantially comprised two statements: the first is that animal organs and behaviour can change according to the way they are being used, and second that those characteristics are capable of being transmitted from one generation to the next (well-known is the example of the giraffe whose neck becomes longer while trying to reach the upper leaves of a tree). The second statement is that each and every living organism, human beings included, tends to reach a greater level of perfection. At the time of his journey for the Galapagos Islands, Charles Darwin was well aware of Lamarck's theories and was influenced by them.

Theory of evolution by natural selection and the beginnings of ethology

Because ethology is considered a topic of biology, ethologists have been concerned particularly with the evolution of behaviour and the understanding of behaviour in terms of the theory of natural selection. In one sense, the first modern ethologist was Charles Darwin, whose book, *The Expression of the Emotions in Man and Animals*, influenced many ethologists. He pursued his interest in behaviour by encouraging his protégé George Romanes, who investigated animal learning and intelligence using an anthropomorphic method, anecdotal cognitivism, that did not gain scientific support.

Other early ethologists, such as Oskar Heinroth and Julian Huxley, instead concentrated on behaviours that can be called instinctive, or natural, in that they occur in all members of a species under specified circumstances. Their beginning for studying the behaviour of a new species was to construct an **ethogram** (a description of the main types of natural behaviour with their frequencies of occurrence). This provided an objective, cumulative base of data about behaviour, which subsequent researchers could check and supplement.

Fixed action patterns and animal communication

An important development, associated with the name of Konrad Lorenz though probably due more to his teacher, Oskar Heinroth, was the identification of fixed action patterns (FAPs). Lorenz popularized FAPs as instinctive responses that would occur reliably in the presence of identifiable stimuli (called **sign stimuli** or **releasing stimuli**). These

FAPs could then be compared across species, and the similarities and differences between behaviour could be easily compared with the similarities and differences in morphology. An important and much quoted study of the Anatidae (ducks and geese) by Heinroth used this technique. Ethologists noted that the stimuli that released FAPs were commonly features of the appearance or behaviour of other members of their own species, and they were able to prove how important forms of animal communication could be mediated by a few simple FAPs. The most sophisticated investigation of this kind was the study by Karl von Frisch of the so-called "dance language" related to bee communication. Lorenz developed an interesting theory of the evolution of animal communication based on his observations of the nature of fixed action patterns and the circumstances in which animals emit them.

Instinct

Kelp Gull chicks peck at red spot on mother's beak to stimulate regurgitating reflex.

The Merriam-Webster dictionary defines instinct as a largely inheritable and unalterable tendency of an organism to make a complex and specific response to environmental stimuli without involving reason. For ethologists, instinct means a series of predictable behaviors for fixed action patterns. Such schemes are only acted when a precise stimulating signal is present. When such signals act as communication among members of the same species, they are known as releasers. Notable examples of releasers are, in many bird species, the beak movements by the newborns, which stimulates the mother's regurgitating process to feed her offspring. Another well known case is the classic experiments by Tinbergen on the Graylag Goose. Like similar waterfowl, it will roll a displaced egg near its nest back to the others with its beak. The sight of the displaced egg triggers this mechanism. If the egg is taken away, the animal continues with the behaviour, pulling its head back as if an imaginary egg is still being maneuvered by the underside of its beak. However, it will also attempt to move other egg shaped objects, such as a giant plaster egg, door knob, or even a volleyball back into the nest. Such objects, when they exaggerate the releasers found in natural objects, can elicit a stronger version of the behavior than the natural object, so that the goose will ignore its own displaced egg in favor of the giant dummy egg. These exaggerated releasers for instincts were termed supernormal stimuli by Tinbergen). Tinbergen found he could produce supernormal stimuli for most instincts in animals, such as cardboard butterflies which male butterflies preferred to mate with if their stripes were darker than a real female or dummy fish which a territorial male stickleback fish would fight more violently than a real invading male if the dummy had a brighter colored underside. Harvard psychologist Deirdre Barrett has done research pointing out how easily humans also respond to supernormal stimuli for sexual, nurturing, feeding, and social instincts. However, a behaviour only made of fixed action patterns would be particularly rigid and inefficient, reducing the probabilities of survival and reproduction, so the learning process has great importance, as the ability to change the individual's responses based on its experience. It can be said that the more the brain is complex and the life of the individual long, the more its behaviour will be "intelligent" (in the sense of guided by experience rather than stereotyped FAPs).

Learning

Learning occurs in many ways, one of the most elementary being habituation. This process consists in ignoring persistent or useless stimuli. An example of learning by habituation is the one observed in squirrels: when one of them feels threatened, the others hear its signal and go to the nearest refuge. However, if the signal comes from an individual who has caused many false alarms, its signal will be ignored.

Another common way of learning is by association, where a stimulus is, based on the experience, linked to another one which may not have anything to do with the first one. The first studies of associative learning were made by Russian physiologist Ivan Pavlov. An example of associative behaviour is observed when a common goldfish goes close to the water surface whenever a human is going to feed it, or the excitement of a dog whenever it sees a collar as a prelude for a walk. The associative learning process is related to the necessity of developing discriminatory capacities, that is, the faculty of making meaningful choices. Being able to discriminate the members of your own species is of fundamental importance for reproductive success. Such discrimination can be based on a number of factors in many species including birds, however, this important type of learning only takes place in a very limited period of time. This kind of learning is called imprinting.

Imprinting

Example of imprinting in a moose

A second important finding of Lorenz concerned the early learning of young nidifugous birds, a process he called imprinting. Lorenz observed that the young of birds such as geese and chickens followed their mothers spontaneously from almost the first day after they were hatched, and he discovered that this response could be imitated by an arbitrary stimulus if the eggs were incubated artificially and the stimulus was presented during a **critical period** (a less temporally constrained period is called a **sensitive period**) that continued for a few days after hatching.

Imitation

Finally, imitation is often an important type of learning. A well-documented example of imitative learning is that of macaques in Hachijojima island, Japan. These primates used to live in the inland forest until the 1960s, when a group of researchers started giving them some potatoes on the beach: soon they started venturing onto the beach, picking the potatoes from the sand, and cleaning and eating them. About one year later, an individual was observed bringing a potato to the sea, putting it into the water with one hand, and cleaning it with the other. Her behaviour was soon imitated by the individuals living in contact with her; when they gave birth, they taught this practice to their young.

The National Institutes of Health recently reported that capuchin monkeys preferred the company of researchers who imitated them to that of researchers who did not imitate them. The monkeys not only spent more time with their imitators, but also preferred to engage in a simple task with them even when provided with the option of performing the same task with a non-imitator.

Mating and the fight for supremacy

Individual reproduction is the most important phase in the proliferation of individuals or genes within a species: for this reason, we can often observe complex mating rituals, which can be very complex even if they are often regarded as fixed action patterns **(FAPs)**. The Stickleback's complex mating ritual was studied by Niko Tinbergen and is regarded as a notable example of a FAP. Often in social life, animals fight for the right of reproducing themselves as well as social supremacy.

A common example of fight for social and sexual supremacy is the so-called pecking order among poultry. A pecking order is established every time a group of poultry co-lives for a certain amount of time. In each of these groups, a chicken is dominating among the others and can peck before anyone else without being pecked. A second chicken can peck all the others but the first, and so on. The chicken in the higher levels can be easily distinguished for their well-cured aspect, as opposed to the ones in the lower levels. During the period in which the pecking order is establishing, frequent and violent fights can happen, but once it is established it is only broken when other individuals are entering the group, in which case the pecking order has to be established from scratch.

Living in groups

Several animal species, including humans, tend to live in groups. Group size is a major aspect of their social environment. Social life is probably a complex and effective survival strategy. It may be regarded as a sort of symbiosis among individuals of the same species: a society is composed of a group of individuals belonging to the same species living within well-defined rules on food management, role assignments and reciprocal dependence.

The situation is actually much more complex than it seems. When biologists interested in evolution theory first started examining social behaviour, some apparently unanswerable questions occurred. How could, for instance, the birth of sterile castes, like in bees, be explained through an evolving mechanism which emphasizes the reproductive success of as many individuals as possible? Why, among animals living in small groups like squirrels, would an individual risk its own life to save the rest of the group? These behaviours may be examples of altruism. Of course, not all behaviours are altruistic, as indicated by the table below. Notably, revengeful behaviour was at one point claimed to have been observed exclusively in *Homo sapiens*. However other species have been reported to be vengeful, including reports of vengeful camels and vengeful chimpanzees.

Classification of social behaviours

Type of behaviour	Effect on the donor	Effect on the receiver
Egoistic	Increases fitness	Decreases fitness
Cooperative	Increases fitness	Increases fitness
Altruistic	Decreases fitness	Increases fitness
Revengeful	Decreases fitness	Decreases fitness

The existence of egoism through natural selection doesn't pose any question to evolution theory and is, on the contrary, fully predicted by it, as well as for the cooperative behaviour. It is more difficult to understand the mechanism through which the altruistic behaviour initially developed.

Tinbergen's four questions for ethologists

Lorenz's collaborator, Niko Tinbergen, argued that ethology always needed to include four kinds of explanation in any instance of behaviour:

- Function — How does the behaviour affect the animal's chances of survival and reproduction? Why does the animal respond that way instead of some other way?
- Causation — What are the stimuli that elicit the response, and how has it been modified by recent learning?
- Development — How does the behaviour change with age, and what early experiences are necessary for the behaviour to be displayed?
- Evolutionary history — How does the behaviour compare with similar behaviour in related species, and how might it have begun through the process of phylogeny?

These explanations are complementary rather than mutually exclusive - all instances of behaviour require an explanation at each of these four levels. For example, the function of eating is to acquire nutrients (which ultimately aids survival and reproduction), but the immediate cause of eating is hunger (causation). Hunger and eating are evolutionarily ancient and are found in many species (evolutionary history), and develop early within an organism's lifespan (development). It is easy to confuse such questions - for example to argue that people eat because they're hungry and not to acquire nutrients - without realizing that the reason people experience hunger (causation) is because it causes them to acquire nutrients (function).

Growth of the field

By the work of Lorenz and Tinbergen, ethology developed strongly in continental Europe during the years prior to World War II. After the war, Tinbergen moved to the University of Oxford, and ethology became stronger in the UK, with the additional influence of William Thorpe, Robert Hinde, and Patrick Bateson at the Sub-department of Animal Behaviour of the University of Cambridge, located in the village of Madingley. In this period, too, ethology began to develop strongly in North America.

Lorenz, Tinbergen, and von Frisch were jointly awarded the Nobel Prize in Physiology or Medicine in 1973 for their work of developing ethology.

Ethology is now a well recognised scientific discipline, and has a number of journals covering developments in the subject, such as the Ethology Journal. In 1972, the International Society for Human Ethology was founded to promote exchange of knowledge and opinions concerning human behavior gained by applying ethological principles and methods and published in their journal, The Human Ethology Bulletin. During 2008, in a paper published in the journal Behaviour, ethologist Peter Verbeek introduced the term "Peace Ethology" as a sub-discipline of Human Ethology that is concerned with issues of human conflict, conflict resolution, reconciliation, war, peacemaking, and peacekeeping behavior.

Social ethology and recent developments

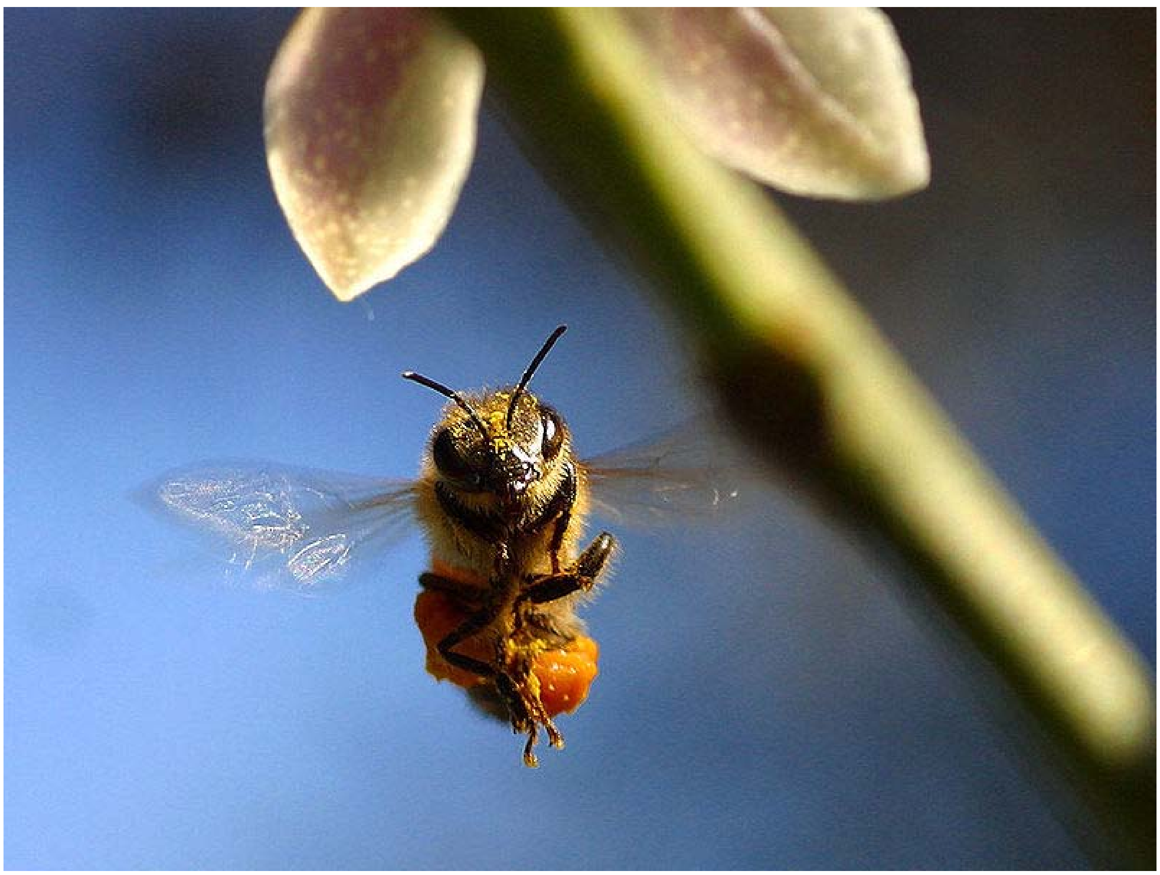
During 1970, the English ethologist John H. Crook published an important paper in which he distinguished **comparative ethology** from **social ethology**, and argued that much of the ethology that had existed so far was really comparative ethology—examining animals as individuals—whereas in the future ethologists would need to concentrate on the behaviour of social groups of animals and the social structure within them.

Also in 1970, Robert Ardrey's book *The Social Contract: A Personal Inquiry into the Evolutionary Sources of Order and Disorder* was published. The book and study investigated animal behaviour and then compared human behaviour as a similar phenomenon.

Indeed, E. O. Wilson's book *Sociobiology: The New Synthesis* appeared in 1975, and since that time the study of behaviour has been much more concerned with social aspects. It has also been driven by the stronger, but more sophisticated, Darwinism associated with Wilson, Robert Trivers and William Hamilton. The related development of behavioural ecology has also helped transform ethology. Furthermore, a substantial rapprochement with comparative psychology has occurred, so the modern scientific study of behaviour offers a more or less seamless spectrum of approaches – from animal cognition to more traditional comparative psychology, ethology, sociobiology and behavioural ecology. Sociobiology has more recently developed into evolutionary psychology.

Chapter- 6

Animal Locomotion



A bee in flight.

Animal locomotion, which is the act of self-propulsion by an animal, has many manifestations, including running, jumping and flying. Animals move for a variety of reasons, such as to find food, a mate, or a suitable microhabitat, and to escape predators. For many animals the ability to move is essential to survival and, as a result, selective pressures have shaped the locomotion methods and mechanisms employed by moving organisms. For example, migratory animals that travel vast distances (such as the Arctic

Tern) typically have a locomotion mechanism that costs very little energy per unit distance, whereas non-migratory animals that must frequently move quickly to escape predators (such as frogs) are likely to have costly but very fast locomotion. The study of animal locomotion is typically considered to be a sub-field of biomechanics.

Locomotion requires energy to overcome friction, drag, inertia, and gravity, though in many circumstances some of these factors are negligible. In terrestrial environments gravity must be overcome, though the drag of air is much less of an issue. In aqueous environments however, friction (or drag) becomes the major challenge, with gravity being less of a concern. Although animals with natural buoyancy need not expend much energy maintaining vertical position, some will naturally sink and must expend energy to remain afloat. Drag may also present a problem in flight, and the aerodynamically efficient body shapes of birds highlight this point. Flight presents a different problem from movement in water however, as there is no way for a living organism to have lower density than air. Limbless organisms moving on land must often contend with surface friction, but do not usually need to expend significant energy to counteract gravity.

Newton's third law of motion is widely used in the study of animal locomotion: if at rest, to move forwards an animal must push something backwards. Terrestrial animals must push the solid ground, swimming and flying animals must push against a fluid or gas (either water or air). The effect of forces during locomotion on the design of the skeletal system is also important, as is the interaction between locomotion and muscle physiology, in determining how the structures and effectors of locomotion enable or limit animal movement.

Introduction

Animals move through a variety of fluids, such as water, air and mud. Some, for example seals and otters, move through more than one type of fluid. In some cases locomotion is facilitated by the substrate on which they move. Forms of locomotion include:

Through a fluid medium

Swimming

In the water staying afloat is possible through buoyancy. Provided an aquatic animal's body is no denser than its aqueous environment, it should be able to stay afloat well enough. Though this means little energy need be expended maintaining vertical position, it makes movement in the horizontal plane much more difficult. The drag encountered in water is much higher than that of air, which is almost negligible at low speeds. Body shape is therefore important for efficient movement, which is essential for basic functions like catching prey. A fusiform, torpedo-like body form is seen in many marine animals, though the mechanisms they employ for movement are diverse. Movement of the body may be from side to side, as in sharks and many fishes, or up and down, as in marine mammals. Other animals, such as those from the class *Cephalopoda*, use jet-propulsion, taking in water then squirting it back out in an explosive burst. Others may rely predominantly on their limbs, much as humans do when swimming. Though life on land originated from the seas, terrestrial animals have returned to an aquatic lifestyle on several occasions, such as the fully aquatic cetaceans, now far removed from their terrestrial ancestors.

Flight

Gravity is a major problem for flight through the air. Because it is impossible for any organism to approach the density of air, flying animals must generate enough lift to ascend and remain airborne. Wing shape is crucial in achieving this, generating a pressure gradient that results in an upward force on the animal' body. The same principle applies to airplanes, the wings of which are also airfoils. Unlike aircraft however, flying animals must be very light to achieve flight, the largest living flying animals being birds of around 20 kilograms. Other structural modifications of flying animals include reduced and redistributed body weight, fusiform shape and powerful flight muscles.

Rather than fly, some animals simply reduce their rate of falling by gliding. Flight has independently evolved at least four times, in the insects, pterosaurs, birds, and bats. Gliding has evolved on many more occasions. The advantage gliding provides to arboreal animals provides a bridge for the evolution of flight.

On a substrate

Terrestrial

Forms of locomotion on land include walking, running, hopping or jumping, and crawling or slithering. Here friction and buoyancy are no longer an issue, but a strong skeletal and muscular framework are required in most terrestrial animals for structural support. Each step also requires much energy to overcome inertia, and animals can store elastic potential energy in their tendons to help overcome this. Balance is also required for movement on land. Human infants learn to crawl first before they are able to stand on two feet, which requires good coordination as well as physical development. Humans are bipedal animals, standing on two feet and keeping one on the ground at all times while walking. When running, only one foot is on the ground at any one time at most, and both leave the ground briefly. At higher speeds momentum helps keep the body upright, so more energy can be used in movement. The number of legs an animal has varies greatly, resulting in differences in locomotion. Many familiar mammals have four legs; insects have six, while arachnids have eight. Centipedes and millipedes have many sets of legs that move in metachronal rhythm. Some have none at all, relying on other modes of locomotion.

Other animals move in terrestrial habitats without the aid of legs. Earthworms crawl by a peristalsis, the same rhythmic contractions that propel food through the digestive tract. Snakes move using several different modes of locomotion, depending upon substrate type and desired speed. Some animals even roll, though typically not as a primary means of locomotion.

Some animals are specialized for moving on non-horizontal surfaces. One common habitat for such climbing animals is in trees, for example the gibbon is specialized for arboreal movement , traveling rapidly by brachiation. Another case is animals like the snow leopard living on steep rock faces such as are found in mountains. Some light animals are able to climb up smooth sheer surfaces or hang upside down by adhesion. Many insects can do this, though much larger animals such as geckos can also perform similar feats.

On water

While animals like ducks can swim in water by floating, some small animals move across it without breaking through the surface. This surface locomotion takes advantage of the surface tension of water. Animals that move in such a way include the water strider. Water striders have legs that are hydrophobic, preventing them from interfering with the structure of water. Another form of locomotion (in which the surface layer is broken) is used by the Basilisk lizard.

Through a solid medium

Some animals move through solids such as soil by burrowing using claws, teeth, or other methods. A burrow is a hole or tunnel dug into the ground by an animal to create a space suitable for habitation, temporary refuge, or as a byproduct of locomotion. In loose solids such a sand some animals, such as the golden mole, marsupial mole, and the pink fairy armadillo, are able to move more rapidly, 'swimming' through the loose substrate. Burrowing animals include moles, ground squirrels, naked mole rats, tilefish, mole crickets, and earthworms.

Energetics

The energetics of locomotion involves the energy expenditure by animals in moving. Energy consumed in locomotion is not available for other efforts, so animals typically have evolved to use the minimum energy possible during movement. However, in the case of certain behaviors, such as locomotion to escape a predator, performance (such as speed or maneuverability) is more crucial, and such movements may be energetically expensive. Furthermore, animals may use energetically expensive methods of locomotion when environmental conditions (such as being within a tunnel) preclude other modes.

The most common metric of energy use during locomotion is net cost of transport, defined as the calories needed above baseline metabolism to move a given distance, per unit body mass. For aerobic locomotion, most animals have a nearly constant cost of transport - moving a given distance requires the same caloric expenditure, regardless of speed. This constancy is usually accomplished by changes in gait. The net cost of transport of swimming is lowest, followed by flight, with terrestrial limbed locomotion being the most expensive per unit distance. However, because of the speeds involved, flight requires the most energy per unit time. This does not mean that an animal that normally moves by running would be a more efficient swimmer, however; these comparisons assume an animal is specialized for that form of motion. Another consideration here is body mass—heavier animals, though using more total energy, require less energy *per unit mass* to move. Physiologists generally measure energy use by the amount of oxygen consumed, or the amount of carbon dioxide produced, in an animal's respiration.

Methods of study

A variety of methods and equipment are used to study animal locomotion:

- **Kinematics** is the study of the motion of an entire animal or parts of its body. It is typically accomplished by placing visual markers at particular anatomical locations on the animal and then recording video of its movement. The video is often captured from multiple angles, with frame rates exceeding 2000 frames per second when capturing high speed movement. The location of each marker is determined for each video frame, and data from multiple views is integrated to give positions of each point through time. Computers are sometimes used to track the markers, although this task must often be performed manually. The kinematic data can be used to determine fundamental motion attributes such as velocity, acceleration, joint angles, and the sequencing and timing of kinematic events. These fundamental attributes can be used to quantify various higher level attributes, such as the physical abilities of the animal (e.g., its maximum running speed, how steep a slope it can climb), neural control of locomotion, gait, and responses to environmental variation. These, in turn, can aid in formulation of hypotheses about the animal or locomotion in general.

- **Force plates** are platforms, usually part of a trackway, that can be used to measure the magnitude and direction of forces of an animal's step. When used with kinematics and a sufficiently detailed model of anatomy, inverse dynamics solutions can determine the forces not just at the contact with the ground, but at each joint in the limb.

- **Electromyography** (EMG) is a method of detecting the electrical activity that occurs when muscles are activated, thus determining which muscles are used when in a given movement. This can be accomplished either by surface electrodes (usually in large animals) or implanted electrodes (often wires thinner than a human hair). Furthermore, the intensity of electrical activity can correlate to the level of muscle activity, with greater activity implying (though not definitively showing) greater force.

- **Sonomicrometry** employs a pair of piezoelectric crystals implanted in a muscle or tendon to continuously measure the length of a muscle or tendon. This is useful because surface kinematics may be inaccurate due to skin movement. Similarly, if an elastic tendon is in series with the muscle, the muscle length may not be accurately reflected by the joint angle.

- **Tendon force buckles** measure the force produced by a single muscle by measuring the strain of a tendon. After the experiment, the tendon's elastic modulus is determined and used to compute the exact force produced by the muscle. However, this can only be used on muscles with long tendons.

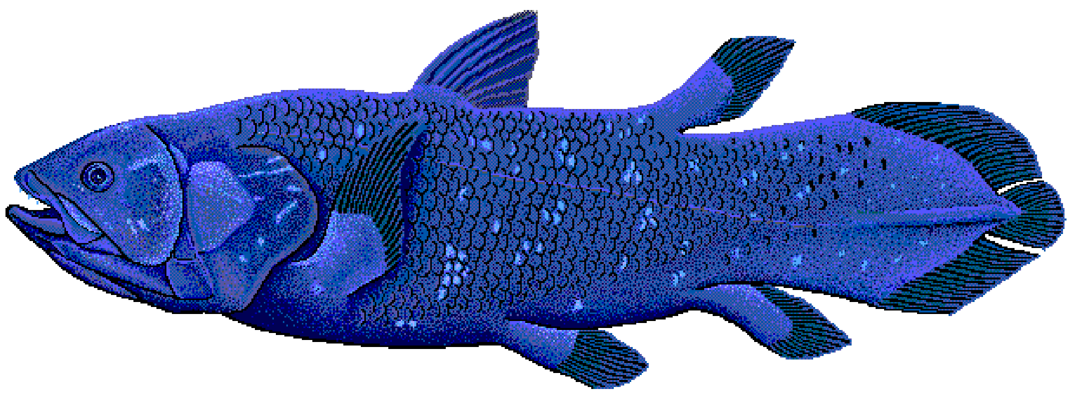
- **Particle image velocimetry** is used in aquatic systems to measure the flow of fluid around and past a moving aquatic organism, allowing fluid dynamics calculations to determine pressure gradients, speeds, etc.

- **Fluoroscopy** allows real-time X-ray video, for precise kinematics of moving bones. Markers which are opaque to X-rays can allow simultaneous tracking of muscle length.

All of the methods can be combined. For example, studies frequently combine EMG and kinematics to determine "motor pattern", the series of electrical and kinematic events which produce a given movement.

Chapter- 7

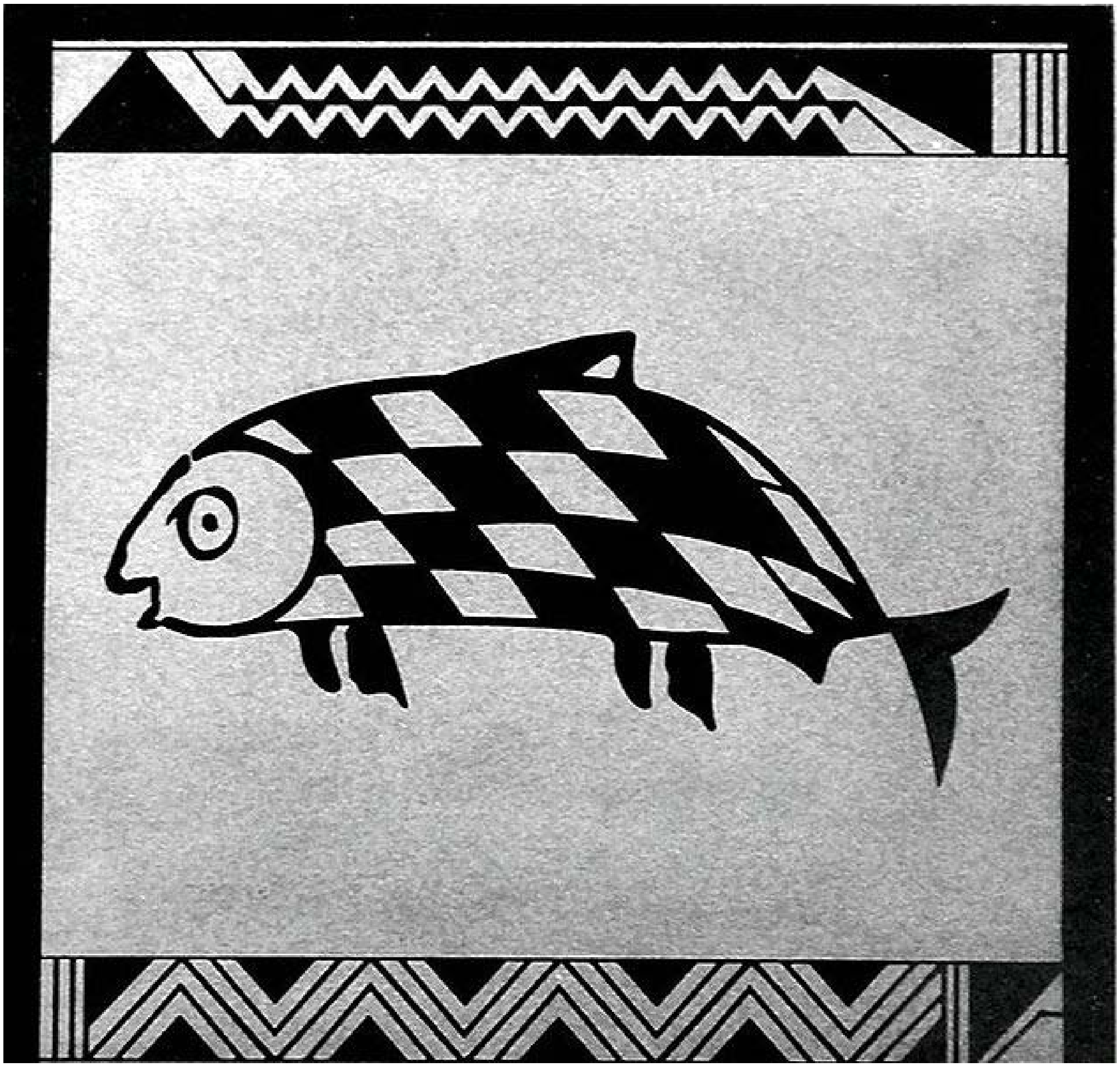
Ichthyology



Ichthyology (from Greek: ἰχθύς, *ikhthus*, "fish"; and λόγος, *logos*, "study") is the branch of zoology devoted to the study of fish. This includes skeletal fish (Osteichthyes), cartilaginous fish (Chondrichthyes), and jawless fish (Agnatha). While a majority of species have probably been discovered and described, approximately 250 new species are officially described by science each year. According to FishBase, 31,500 species of fish had been described by January 2010. There are more fish species than the combined total of all other vertebrates: mammals, amphibians, reptiles and birds.

The practice of ichthyology is associated with marine biology, limnology and fisheries science.

History



Fish represent approximately 8% of all figurative depictions on Mimbres pottery.

The study of fish dates from the Upper Paleolithic Revolution (with the advent of 'high culture'). The science of ichthyology was developed in several interconnecting epochs, each with various significant advancements.

The study of fish receives its origins from human's desire to feed, clothe, and equip themselves with useful implements. According to Michael Barton, a prominent ichthyologist and professor at Centre College, "the earliest ichthyologists were hunters and gatherers who had learned how to obtain the most useful fish, where to obtain them in abundance, and at what times they might be the most available". Early cultures manifested these insights in abstract and identifiable artistic expressions.

1500 BC–40 AD

Informal, scientific descriptions of fish are represented within the Judeo-Christian tradition. The kashrut forbade the consumption of fish without scales or appendages. Theologians and ichthyologists speculate that the apostle Peter and his contemporaries harvested the fish that are today sold in modern industry along the Sea of Galilee, presently known as Lake Kinneret. These fish include cyprinids of the genus *Barbus* and *Mirogrex*, cichlids of the genus *Sarotherodon*, and *Mugil cephalus* of the family Mugilidae.

335 BC–80 AD

Aristotle incorporated ichthyology into formal scientific study. Between 335 BC–322 BC, he provided the earliest taxonomic classification of fish, accurately describing 117 species of Mediterranean fish. Furthermore, Aristotle documented anatomical and behavioral differences between fish and marine mammals. After his death, some of his pupils continued his ichthyological research. Theophrastus, for example, composed a treatise on amphibious fish. The Romans, although less devoted to science, wrote extensively about fish. Pliny the Elder, a notable Roman naturalist, compiled the ichthyological works of indigenous Greeks, including verifiable and ambiguous peculiarities such as the sawfish and mermaid respectively. Pliny's documentation was the last significant contribution to ichthyology until the European Renaissance.

European Renaissance

The writings of three sixteenth century scholars, Hippolyte Salviani, Pierre Belon, and Guillaume Rondelet, signify the conception of modern ichthyology. The investigations of these individuals were based upon actual research in comparison to ancient recitations. This property popularized and emphasized these discoveries. Despite their prominence, Rondelet's *De Piscibus Marinum* is regarded as the most influential, identifying 244 species of fish.

16th–17th century

The incremental alterations in navigation and shipbuilding throughout the Renaissance marked the commencement of a new epoch in ichthyology. The Renaissance culminated with the era of exploration and colonization, and upon the cosmopolitan interest in navigation came the specialization in naturalism. Georg Marcgrave of Saxony composed the *Naturalis Brasilae* in 1648. This document contained a description of 100 species of fish indigenous to the Brazilian coastline. In 1686, John Ray and Francis Willughby collaboratively published *Historia Piscium*, a scientific manuscript containing 420 species of fish, 178 of these newly discovered. The fish contained within this informative literature were arranged in a provisional system of classification.

The classification used within the *Historia Piscium* was further developed by Carolus Linnaeus, the "father of modern taxonomy". His taxonomic approach became the systematic approach to the study of organisms, including fish. Linnaeus was a professor at the University of Uppsala and an eminent botanist; however, one of his colleagues, Peter Artedi, earned the title "father of ichthyology" through his indispensable advancements. Artedi contributed to Linnaeus's refinement of the principles of taxonomy. Furthermore, he recognized five additional orders of fish: Malacopterygii, Acanthopterygii, Branchiostegi, Chondropterygii, and Plagiuri. Artedi developed standard methods for making counts and measurements of anatomical features that are modernly exploited. Another associate of Linnaeus, Albertus Seba, was a prosperous pharmacist from Amsterdam. Seba assembled a cabinet, or collection, of fish. He invited Artedi to utilize this assortment of fish; unfortunately, in 1735, Artedi fell into an Amsterdam canal and drowned at the age of 30.

Linnaeus posthumously published Artedi's manuscripts as *Ichthyologia, sive Opera Omnia de Piscibus* (1738). His refinement of taxonomy was culminated subsequent to the development of the binomial nomenclature which is in use by contemporary ichthyologists. Furthermore, he revised the orders introduced by Artedi, placing significance on pelvic fins. Fish lacking this appendage were placed within the order Apodes; fish containing abdominal, thoracic, or jugular pelvic fins were termed Abdominales, Thoracici, and Jugulares respectively. However, these alterations were not grounded within the evolutionary theory. Therefore, it would take over a century until Charles Darwin would provide the intellectual foundation from which we would be permitted to perceive that the degree of similarity in taxonomic features was a consequence of phylogenetic relationship.

Modern era

Close to the dawn of the nineteenth century, Marcus Elieser Bloch of Berlin and Georges Cuvier of Paris made an attempt to consolidate the knowledge of ichthyology. Cuvier summarized all of the available information in his monumental *Histoire Naturelle des Poissons*. This manuscript was published between 1828 and 1849 in a 22 volume series. This documentation contained 4,514 species of fish, 2,311 of these new to science. This piece of literature remains one of the most ambitious treatises of the modern world. The scientific exploration of the Americas progressed our knowledge of the remarkable diversity of fish. Charles Alexandre Lesueur was a student of Cuvier. He made a cabinet of fish dwelling within the Great Lakes and Saint Lawrence River regions.

Adventurous individuals such as John James Audubon and Constantine Samuel Rafinesque figure in the faunal documentation of North America. These persons often traveled with one another and composed *Ichthyologia Ohiensis* in 1820. In addition, Louis Agassiz of Switzerland established his reputation through the study of freshwater fish and organisms and the pioneering of paleoichthyology. Agassiz eventually immigrated to the United States and taught at Harvard University in 1846.

Albert Günther published his *Catalogue of the Fishes of the British Museum* between 1859 and 1870, describing over 6,800 species and mentioning another 1,700. Generally considered one of the most influential ichthyologists, David Starr Jordan wrote 650 articles and books on the subject as well as serving as president of Indiana University and Stanford University.

Modern Publications

Publication	Frequency	Date of Publication	Affiliated Company
Copeia	Quarterly	27 December 1913	American Society of Ichthyologists and Herpetologists
Journal of Applied Ichthyology	Bi-monthly	Unknown	Blackwell Publishing

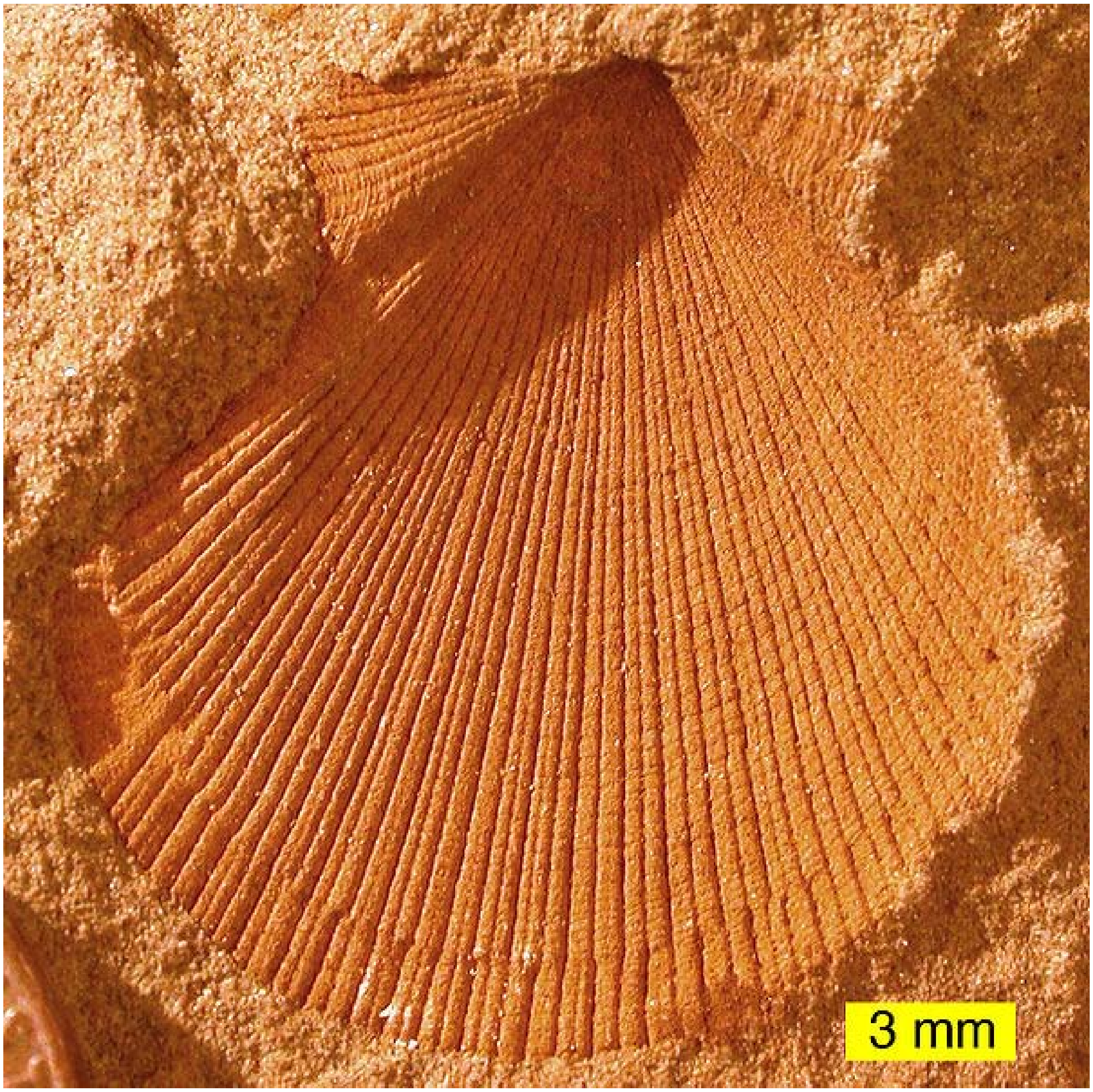
Organizations

Organizations	Organizations
• American Elasmobranch Society • American Fisheries Society • American Society of Ichthyologists and Herpetologists • Association of Systematics Collections • Ichthyological Society of Hong Kong (Chinese: 香港魚類學會) • Native Fish Conservancy • Neotropical Ichthyological Association	• North American Native Fishes Association • Panhellenic Society of Technologists Ichthyologists • Society for Integrative and Comparative Biology • Society for Northwestern Vertebrate Biology • Society for the Preservation of Natural History Collections • Southeastern Fishes Council • Southwestern Association of Naturalists

Chapter- 8

Invertebrate Paleontology

Bryozoan fossils in an Ordovician oil shale from Estonia. Field of view is 15 cm across.



Aviculopecten subcardiformis; an extinct pectenoid from the Logan Formation (Lower Carboniferous) of Wooster, Ohio (external mold).

Invertebrate paleontology (also spelled **Invertebrate palaeontology**) is sometimes described as **Invertebrate paleozoology** and/or **Invertebrate paleobiology**. Whether it is considered to be a subfield of paleontology, paleozoology, and/or paleobiology, this discipline is the scientific study of **prehistoric invertebrates** by analyzing **invertebrate fossils** in the geologic record.

By *invertebrates* are meant the *non-vertebrate* creatures of the kingdom Animalia (or Metazoa+b vmbnParazoa) in the biotic domain of Eukaryota. By phyletic definition, these many-celled, *sub-vertebrate* animals lack a vertebral column, spinal column, vertebrae, backbone, or long, full-length notochord -- in contrast, of course, to the vertebrates in the one phylum of Chordata.

Relatedly, invertebrates have never had a cartilaginous and/or boney internal skeleton, with its skeletal supports, gill slits, ribs and jaws. Finally, throughout geologic time, invertebrates have remained non-craniate creatures; that is, they never developed a cranium, nerve-chord brain, skull, or hard protective braincase.

Invertebrate terminology in science

In the many decades since Jean-Baptiste de Lamarck, a pioneering biologist and evolutionist, first conceptualized and coined the category "Invertebrata" (between 1793 and 1801) and the term "Biology" (in 1802), zoology has come to recognize that the *non-vertebrate* category is not a scientifically-valid, monophyletic taxon. Evolutionary biology and developmental biology (a.k.a. "evo-devo") now consider the term "Invertebrata" to be both polyphyletic and paraphyletic. Nevertheless, most earth science departments continue to employ this term; and paleontologists find it both useful and practical in evaluating **fossil invertebrates** and—consequently -- **invertebrate evolution**.

However, there is one contemporary caveat: Paleobiologists and microbiologists in the 21st century no longer classify one-celled "animal-like" microbes *either* as invertebrates *or* as animals. For example, the commonly-fossilized foraminifera ("forams") and radiolarians -- zooplankton both formerly grouped under either an animal phylum or animal sub-kingdom called Protozoa ("first animals") -- are now placed in the kingdom or super-kingdom Protista or Protoctista (and thus called *protists* or *protoctists*).

Thus modern **invertebrate paleontologists** deal largely with fossils of this more strictly defined Animal Kingdom (excepting Phylum Chordata), Phylum Chordata being the exclusive focus of vertebrate paleontology. Protist fossils are then the main focus of micropaleontology, while plant fossils are the chief focus paleobotany. Together these four represent the traditional taxonomic divisions of paleontologic study.

Invertebrate fossilization

When it comes to the fossil record, *soft*-bodied and *minuscule* invertebrates—such as hydras, jellies, flatworms, hairworms, nematodes, ribbon worms, rotifers and roundworms -- are infrequently fossilized. As a result, paleontologists and other fossil hunters must often rely on trace fossils, microfossils, or chemofossil residue when scouting for these prehistoric creatures.

Hard-bodied and *large* invertebrates are much-more commonly preserved; typically as sizeable macrofossils. These invertebrates are more frequently preserved because their hard parts—for example, shell, armor, plates, tests, exoskeleton, jaws or teeth -- are composed of silica (silicon dioxide), calcite or aragonite (both forms of calcium carbonate), chitin (a protein often infused with tricalcium phosphate), and/or keratin (an even-more complex protein), rather than the vertebrate bone (hydroxyapatite) or cartilage of fishes and land-dwelling tetrapods.

The chitinous jaws of annelids (such as the marine scolecodonts) are sometimes preserved as fossils; while many arthropods and inarticulate brachiopods have easily-fossilized hard parts of calcite, chitin, and/or keratin. The most common and often-found macrofossils are the very hard calcareous shells of articulate brachiopods (that is, the everyday "lampshells") and of mollusks (such as the omnipresent clams, snails, mussels and oysters). On the other hand, non-shelly slugs and non-tubiferous worms (for instance, earthworms) have only occasionally been preserved due to their lack of hard parts.

Chapter- 9

Largest Organisms

Satellite image of part of the Great Barrier Reef, considered by some measures to be the world's largest living thing.

An aspen grove at Fishlake National Forest, similar in appearance to the one known as Pando.

The **largest organism** found on Earth can be measured using a variety of methods. It could be defined as the largest by volume, mass, height or length. Some organisms group together to form a superorganism, though this cannot truly be classed as one large organism. (The Great Barrier Reef, the world's largest coral reef, stretching 2,000 km, is a collection of many organisms.)

The Aspen tree (*Populus tremuloides*) forms large stands of genetically identical trees (technically, stems) connected by a single underground root system. These trees form through root sprouts coming off an original parent tree, though the root system may not remain a single unit in all specimens. The largest known fully-connected Aspen is a grove in Utah nicknamed Pando, and some experts call it the largest organism in the world, by mass or volume. It covers 0.43 km^2 (106 acres) and is estimated to weigh 6,600 short tons (6,000 t).

A giant fungus of the species *Armillaria ostoyae* (honey mushrooms) in the Malheur National Forest in Oregon was found to span 8.9 km^2 (2,200 acres), which would make it the largest organism by area. Whether or not this is an actual individual organism, however, is disputed: some tests have indicated that they have the same genetic makeup, but unless its mycelia are fully connected, it is a clonal colony of numerous smaller individuals. Another clonal colony that rivals the *Armillaria* and the *Populus* colonies in size is a strand of the giant marine plant, *Posidonia oceanica*, discovered in the

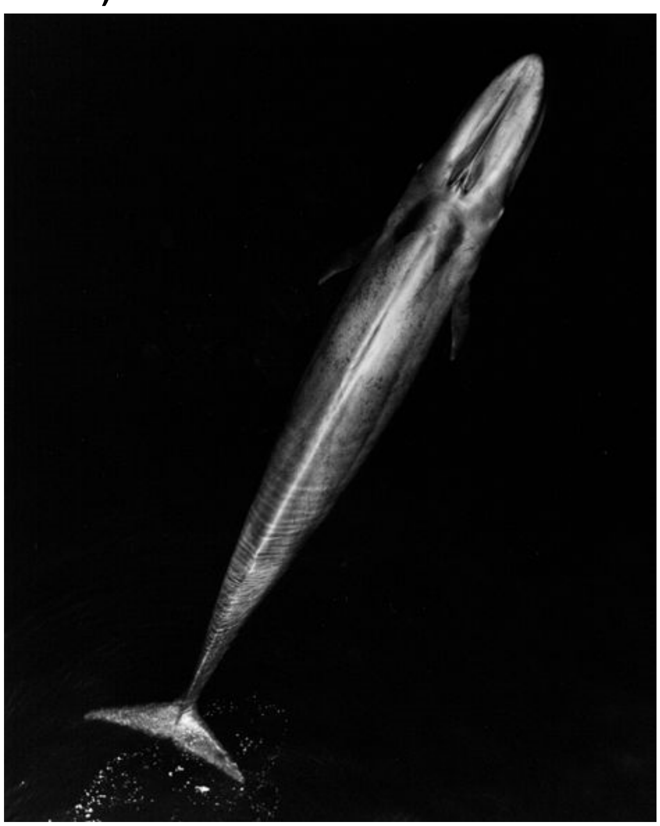
Mediterranean near the Balearic Islands. It covers a band roughly 8 km (4.3 miles) in length.

The world's largest single stem tree, by volume, is the General Sherman tree, a Giant Sequoia with a volume of 1,487 m^3 (52,500 cu ft). This tree stands 83.8 m (275 ft) tall and the trunk alone is estimated to weigh over 2,000 short tons (1,800 t). The largest single-stem tree ever measured was the Lindsey creek tree, a Coast Redwood with a minimum trunk volume of over 2,500 m^3 (88,000 cu ft) and a mass of over 3,600 short tons (3,300 t). It fell over during a storm in 1905.

The largest known animal ever to have existed is the blue whale, an endangered species whose official record length is 33.58 m (110 ft 2 in), and weight 190 short tons (172 metric tons) (for a pregnant female). The largest living *land* animals by mass are male (bull) African Bush Elephants (Savannah Elephants or Bush Elephants); one known example weighed roughly 27,000 lb (12 t). Some extinct land animals, including many dinosaurs, were much larger still. A 1985 study concluded that the theoretical limit for land-dwelling animals based on known types of body plans was between 100 and 1000 metric tons.

Vertebrates

Mammals (*Mammalia*)



The Blue Whale is the heaviest known animal in the world.

A member of the order Cetacea, the Blue Whale (*Balaenoptera musculus*) is believed to be the largest animal ever to have lived. The maximum recorded weight was 190 metric tons (210 short tons) for a specimen measuring 30 m (98 ft), while longer ones, up to 33.3 m (109 ft), have been recorded but not weighed.

The African Bush Elephant (*Loxodonta africana*), of the order Proboscidea, is the largest living land animal. At birth it is common for an elephant calf to weigh 100 kg (220 lb). The largest elephant ever recorded was shot in Angola in 1956. It was a male and weighed 24,000 lb (11,000 kg), with an overall length (trunk to tail) of 10 m (33 ft) and a shoulder height of 3.96 m (13.0 ft).

- **Monotreme mammals** (*Monotremata*)

  The largest extant monotreme (egg-bearing mammal) is the Western Long-beaked Echidna (*Zaglossus bruijni*) weighing up to 16.5 kg (36.4 lb) and measuring 1 m (3.3 ft) long. The largest monotreme ever was the extinct echidna species *Zaglossus hacketti*, known only from a few bones found in Western Australia. It was the size of a sheep, weighing probably up to 100 kg (220 lb).

- **Marsupials** (*Marsupialia*)

  The Red Kangaroo (*Macropus rufus*) is the largest living marsupial. The maximum size of these lanky mammals is 100 kg (220 lb) and 1.92 m (6.3 ft) tall. Many much larger marsupials existed prehistorically, the largest of which was *Diprotodon*. This rhino-sized herbivore would have easily exceeded 2 tonnes (4,400 lb), 3.3 m (11 ft) in length and 1.83 m (6 ft) in height. The Tasmanian Devil (*Sarcophilus harrisii*) is the largest living carnivorous marsupial. The maximum size of these stocky mammals is 10 kg (22.2 lb) and 91 cm (3 ft) long. The largest ever carnivorous marsupial to exist would have been the Marsupial Lion (*Thylacoleo*) and the Saber-toothed Marsupial (*Thylacosmilus*) both ranging from 5 ft (1.5 m) to 6 ft (1.8 m) long and weighing between 100 kg to 160 kg.

- **Non-Paenungulate Afrotherians** (*Afroinsectiphilia*)

  The largest species of this clade (which also contains elephant shrews, tenrecs and golden moles) is the Aardvark (*Orycteropus afer*). Aardvarks are typically up to 1.3 m in length with a weight of up to 65 kg, although individuals as large as 100 kg (220 lb) are recorded.

The African Bush Elephant, the largest living terrestrial animal.

- **Even-toed Ungulates** (*Artiodactyla*)

  The largest species in terms of weight is the Hippopotamus (*Hippopotamus amphibius*), reaching a maximum size of 4,500 kg (10,000 lb), 4.8 m (16 ft) long and 1.66 m (5.5 ft) tall. The longest-bodied species, and tallest of all living land animals, is the Giraffe (*Giraffa camelopardalis*), measuring up to 5.8 m (19.3 ft), and despite being relatively slender, reaching a top weight of 2,000 kg (4,850 lb). Largest bovids are the Water Buffalo (*Bubalis arnee*), 400 to 900 kg (880 to 2,000 lb) for the domestic breeds, while the wild animals are nearly 3 m (9.8 ft) long and 2 m (6.6 ft) tall, weighing up to 1,200 kg (2,600 lb) Gaur (*Bos gaurus*) can all grow to weights of over 900 kg (2,000 lb). American Bison (*Bison bison*) 6 feet 6 inches (2 m) tall, 10 feet (3 m) long, and weigh 900 to 2,200 pounds (410 to 1,000 kg). As typical in ungulates, the male bison is slightly larger than the female. The biggest specimens on record have weighed as much as 2,500 pounds (1,100 kg). European Bison (*Bison bonasus*) 3 m (10 ft) long and 1.8 to 2.2 m (6 to 7 ft) tall, and weighs 300 to 920 kg (660 to 2,000 lb).

- **Carnivores** (*Carnivora*)

The largest species is now, with the inclusion of the Pinnipedia, the Southern Elephant Seal (*Mirounga leonina*) from the Phocidae family. The top size recorded for this species was 5,000 kg (11,000 lb) and 6.9 m (22.5 ft) long. The largest living land carnivores are the Polar Bear (*Ursus maritimus*) and the Brown Bear (*Ursus arctos*), both from the Ursidae family and both exceptionally exceeding 1 tonne (2,200 lb), 3 m (10 ft) long, and 1.5 m (5 ft) tall at the shoulder. The extinct subspecies of modern polar bear *Ursus maritimus tyrannus* may be the largest land carnivore in the order (as well as the largest bear) standing 1.83 m (6 ft 0 in) at the shoulder, 3.7 m (12 ft 2 in) long and with an average weight of 1.2 ton or more. The largest living member of the Felidae family is the Siberian Tiger (*Panthera tigris altaica*) subspecies, which has an average weight of around 500 lb (230 kg)) for males, but can reach around 600–675 lb (270–310 kg) and weights up to 384 kg (845 lb) are unconfirmed. Even larger were the extinct American Lion (*Panthera leo atrox*) and the *Smilodon populator*, a saber-toothed cat. The Liger (*Panthera tigris* × *Panthera leo*), the zoo-kept crossbreed of a male Lion and a female Tiger, can reach an obese 798 kg (1,759 lb) or 1,756 lb (797 kg), and a length of 10 ft (3 m). The largest known extant member of canidae is the wolf, though it could be one of two subspecies-either the Mackenzie Valley Wolf (*Canis lupus occidentalis*), with a record of 79 kilograms (174 lb) or the Eurasian Wolf (*Canis lupus lupus*), with an unofficial weight of 86 kilograms (190 lb). The largest member of canidae ever is the extinct member of Borophaginae, *Epicyon*, which has had two different measurements-one at 101 kilograms (224 lb), and one at 85 kilograms (188 lb).

The orca is the largest oceanic dolphin.

- **Whales** (*Cetacea*)

  The largest whale and animal is the aforementioned blue whale, a baleen whale (Mysticeti). Its closest competitor is another baleen whale, the Fin Whale, which can reach 22 m (72 ft) in length. The largest toothed whale (Odontoceti) is the Sperm Whale (*Physeter macrocephalus*), bulls of which range usually range up to 18 metres (60 ft) and a mass of 50 tonnes (55 short tons), but may possibly grow considerably larger. The Orca or Killer Whale (*Orcinus orca*) is the largest species of the oceanic dolphin family (Delphinidae). Males normally grow from 6.5–8 m long (20–25 ft) and weigh in excess of 6 tonnes; it has been reported that especially large males have reached nearer 8 tonnes. Females are smaller, growing from 5.7–7 m (18–22 ft) and a weight of about 5 tonnes. The longest Orca ever recorded was a male off the coast of Japan, measuring 9.8 m (32 ft).

- **Bats** (*Chiroptera*)

  The largest bat species is the Giant golden-crowned flying fox (*Acerodon jubatus*), a rare fruit bat and endangered species that is part of the megabat family. The maximum size is believed to approach 1.5 kg (3.3 lb), 55 cm (22 in) long, and the wingspan may be almost 1.8 m (6 ft). The Spectral Bat (*Vampyrum spectrum*), averaging 168 grams (6 oz), 13.5 cm (5¼ in) and about 80 cm (32 in) in wingspan, is believed to be the largest carnivorous bat, belonging to the microbat family.

- **Armadillos** (*Cingulata*)

  The extant giant of this group is the Giant Armadillo (*Priodontes maximus*). The top size for this species is 32 kg (71 lb) and 89 cm (35 in) in length. Much larger prehistoric examples are known, especially *Glyptodon*, which easily topped 2.7 m (9 ft) and 2 tonnes (4,400 lb).

- **Colugos** (*Dermoptera*)

  Of the two colugo species in the order *Dermoptera* of gliding arboreal mammals in southeast Asia, the largest and most common is the Sunda Flying Lemur (*Cynocephalus varigatus*). The maximum size is 2 kg (4.4 lb) and 73 cm (29 in).

- **Hedgehogs, gymnures, shrews, and moles** (*Erinaceomorpha* and *Soricomorpha*)

  The largest of these two orders of small mammals is the Greater Moonrat (*Echinosorex gymnura*), the maximum size of which is over 2 kg (4.4 lb) and 60 cm (24 in).

- **Hyraxes** (*Hyracoidea*)

The largest species of hyrax seems to be the Cape Hyrax (*Procavia capensis*), at up to 5.4 kg (12 lb) and 73 cm (29 in) long.

- **Rabbits, hares, and pikas** (*Lagomorpha*)

  The largest breed is the Flemish Giant, which is up to 12.7 kg (28 lb), the European Hare (*Lepus europaeus*), is up to 6.6 kg (14.6 lb) and 76 cm (30 in) long.

The largest odd-toed ungulates, White Rhinoceros

- **Odd-toed Ungulates** (*Perissodactyla*)

  The largest extant species is the White Rhinoceros (*Ceratotherium simum*). The largest size this species can attain is 4,500 kg (10,000 lb), 4.7 m (15½ ft) long, and 2 m (6½ ft) tall. It is slightly larger than the Indian Rhinoceros (*Rhinoceros unicornis*). The largest land mammal ever was *Paraceratherium* or *Indricotherium* (formerly known as the *Baluchitherium*), a member of this order. It stood up to 5.5 m (18 ft) tall, measured over 9 m (30 ft) long and may have weighed up to 20 tonnes (22 short tons) though mass estimates vary widely.

- **Pangolins** (*Pholidota*)

  The largest species of scaly anteater is the Giant Pangolin (*Manis gigantea*), at up to 1.7 m (5.8 ft) and at least 40 kg (88 lb).

- **Anteaters and sloths** (*Pilosa*)

  The largest species is easily the Giant Anteater (*Myrmecophaga tridactyla*). A large adult can weigh as much as 65 kg (143 lb) and measure 2.4 m (8 ft) in overall length. The sloths attained much larger sizes prehistorically, the largest of which were *Megatherium* which, at an estimated average weight of 4.5 tonnes (5 short tons) and height of 5.1 m (17 ft), was about the same size as the African Bush Elephant.

The Eastern Lowland Gorilla is the largest living primate.

- **Primates** (*Primates*)

  The Eastern Lowland Gorilla (*Gorilla beringei graueri*) is the largest living primate. The maximum size of a male gorilla can be over 225 kg (500 lb) and 1.8 m (6 ft) in the wild, with much heavier weights recorded in captivity. *Gigantopithecus* is the largest known primate ever, probably averaged 3 m (10 ft) tall and weighing 300 to 550 kg (700 to 1,200 lb). It lived from around five million years ago to about 300,000 years ago in the region of India and China. Humans (*Homo sapiens*) can attain massive weights (largest ever documented human, Jon Brower Minnoch, was 636 kg (1,400 lb). However, these are cases of morbid obesity, tumor, and other medical malady. Similarly, humans can attain enormous heights (tallest documented was 8 ft 11 inches (272 cm), Robert Wadlow) due to gigantism. Even when not afflicted with gigantism, humans are the tallest living primates.

- **Elephants, mammoths, and mastodons** (*Proboscidea*)

  Most extinct species in the order *Proboscidea*, such as mammoths and mastodons, did not dwarf the modern African Bush Elephant. The Imperial Mammoth, standing up to 5 m (16 ft) tall, and *Deinotherium*, which may have surpassed 14 tonnes (15 short tons) are generally considered the largest species. However, recent evidence shows that the largest mammoth ever was the Songhua River

Mammoth of China. *Mammuthus trogontherii* and *Deinotherium* were also enormous, rivaling the Songhua River Mammoth in size. While African elephants do not normally exceed 7 tonnes in weight, some 'freak' specimens can exceed 12 tonnes, placing the modern African elephant in the list of the largest probiscids ever.

- **Rodents** (*Rodentia*)

  The largest living rodent is the capybara (*Hydrochoerus hydrochaeris*), native to most of the tropical and temperate parts of South America east of the Andes, always near water. Full-grown capybaras can reach a top size of 80 kg (180 lb), 1.5 m (4.9 ft) long, and 90 cm (3.0 ft). The largest known rodent ever is *Josephoartigasia monesi*, an extinct species known only from fossils. It was approximately 3 metres (10 ft) long and 1.5 metres (5 ft) tall, and is estimated to have weighed around 1 tonne. Prior to the description of *J. monesi*, the largest known rodent species was *Phoberomys insolita*. However, this species is known only from very incomplete remains and so its size cannot be estimated with any precision. An almost complete skeleton of its slightly smaller Late Miocene relative *Phoberomys pattersoni* was discovered in Venezuela in 2000; it was 3 m (10 ft) long, with an additional 1.5 m (5 ft) tail, and probably weighed around 700 kg (1,540 lb).

- **Tree Shrews** (*Scandentia*)

  The largest of the tree shrews seems to be the Common Tree Shrew (*Tupaia glis*), at up to 187 g (6.6 oz) and 40 cm (17 in).

- **Dugongs and manatees** (*Sirenia*)

  The largest living species in the order *Sirenia* of dugongs and manatees is the West Indian Manatee (*Trichechus manatus*). The maximum size of this species is 1,590 kg (3,500 lb) and 4.1 m (13.5 ft). However, the extinct Steller's Sea Cow (*Hydrodamalis gigas*) was much larger, growing up to at least 7.9 m (26 ft) long and weighing up to 11 tonnes (12.1 short tons).

Reptiles (*Reptilia*)

The saltwater crocodile is the largest living reptile.

The largest living reptile, a representative of the order Crocodilia, is the saltwater crocodile (*Crocodylus porosus*), with adult males being typically 4.5 to 5 m (15 to 17 ft) long. The largest confirmed saltwater crocodile on record was 20 ft 8 in (6.30 m) long, and weighed over 3,000 lb (1,360 kg). Unconfirmed reports of much larger crocodiles exist, but examinations of incomplete remains have never suggested a length greater than 7 m (23 ft). Also, a living specimen estimated at 7 m (23 ft) and 2,000 kg (4,400 lb) has been accepted by the Guinness Book of World Records.

Extinct crocodilians were sometimes much larger, such as *Deinosuchus*, at up to 12 m (40 ft) and 9 tonnes (10 tons), *Sarcosuchus imperator*, also at up to 12 m (40 ft) and 13.6 tonnes (15 tons), and *Purussaurus*, which was 12 m (40 ft) as well, and *Rhamphosuchus*, possibly up to 18 m (60 ft) long.

- **Lizards & snakes** (*Squamata*)

  The most massive member of this reptilian superorder is the Green Anaconda (*Eunectes murinus*). The maximum verified size is 5.21 m (18 ft) and 250 kg (550 lb), although rumors of larger anacondas persist. The Reticulated Python (*Python reticulatus*) is longer but much lighter, and can be up to 8.7 m (28 ft).

The largest overall venomous snake is the South American Bushmaster (*Lachesis muta*), capable of growing 3.65 m (12 ft) long and 8.5 kg (19 lb). The *longest* venomous snake is the King Cobra (*Ophiophagus hannah*), with lengths of up to 5.7 m (18.7 ft), but with a weight of 6 kg (13 lb). The heaviest venomous snake on record is a captive Eastern Diamondback Rattlesnake (*Crotalus adamanteus*), which weighed over 12 kg (26 lb). The largest of the living lizards is the Komodo Dragon (*Varanus komodoensis*), at a maximum size of 3.13 m (10 ft 3 in) long and 166 kg (366 lb). The largest-ever member of the order was probably one of the giant mosasaurs, such as *Hainosaurus*, *Mosasaurus*, or *Tylosaurus*, all of which grew to around 15 m (50 ft). The largest snake known from the fossil record is *Titanoboa*, which may have grown to a length of 13 m (42 ft) on average. The prehistoric *Megalania prisca* (or *Varanus priscus*) is the largest terrestrial squamate known, but the lack of a complete skeleton has resulted in a wide range of size estimates. Molnar's 2004 assessment resulted in an average weight of 320 kilograms (710 lb), and a maximum of 1,940 kilograms (4,300 lb) at 7 metres (23 ft) in length, which is toward the high end of the early estimates.

The green anaconda is the largest snake.

- **Plesiosaurs** (*Plesiosauria*); now extinct

  The largest known plesiosaur was *Mauisaurus haasti*, growing to around 20 metres in length.

- **Ichthyosaurs** (*Ichthyosauria*); now extinct

  The largest of these marine reptiles (extinct for 90 million years) was the species *Shonisaurus sikanniensis*, at approximately 21 m (70 ft) long.

- **Tuataras** (*Sphenodontia*)

  The larger of the two extant species of tuatara is the Brothers Island Tuatara (*Sphenodon guntheri*). The maximum size is 1.4 kg (3.1 lb) and 76 cm (30 in).

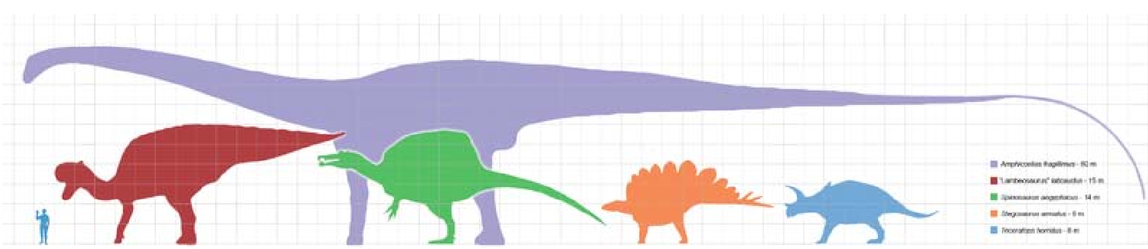
- **Turtles** (*Testudines*)

  The largest living turtle is the Leatherback Sea Turtle (*Dermochelys coriacea*), reaching a maximum length of nearly 2.7 m (9 ft) and a weight of 932 kg (2,050 lb). There are many extinct turtles that vie for the title of the largest ever. The largest seems to be *Archelon ischyros*, which reached a length of 4.84 m (16 ft) across the flippers and a weight of 2,200 kg (4,500 lb). The Galápagos tortoise and the Aldabra Giant Tortoise can both exceed 300 kg (660 lb) and 130 cm (52 in), and are considered the largest truly terrestrial reptiles alive today. A much larger tortoise survived until about 2000 years ago, *Meiolania* at about 2.5 m (8½ ft) long and well over a ton.

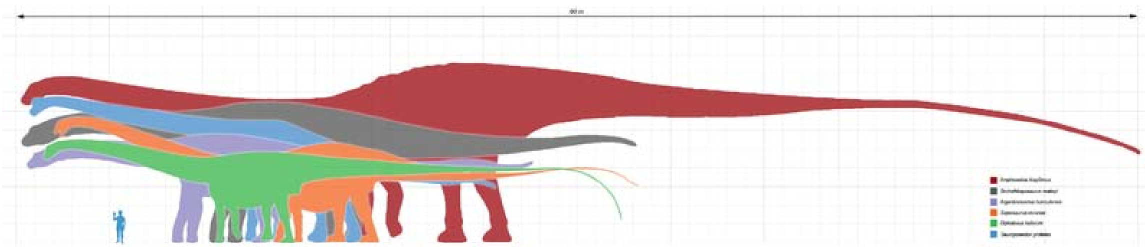
- **Pterosaurs** (*Pterosauria*); now extinct

  A dinosaur-era reptile (although not actually a dinosaur) is believed to have been the largest flying animal that ever existed: the pterosaur *Quetzalcoatlus northropi*. The maximum size of this soaring giant was believed to have been about 127 kg (280 lb) and 12 m (40 ft) across the wings. Another possible contender for the largest pterosaur is *Hatzegopteryx*, which is also estimated to have had a 12 m wingspan.

- **Dinosaurs** (*Dinosauria*)



Scale diagram comparing a human and the largest known dinosaurs of the four suborders.



Size comparison of selected giant sauropod dinosaurs. *Sauroposeidon* (blue), *Argentinosaurus* (violet), and *Amphicoelias fragillimus* (red) size estimates are based on fragmentary fossil evidence.

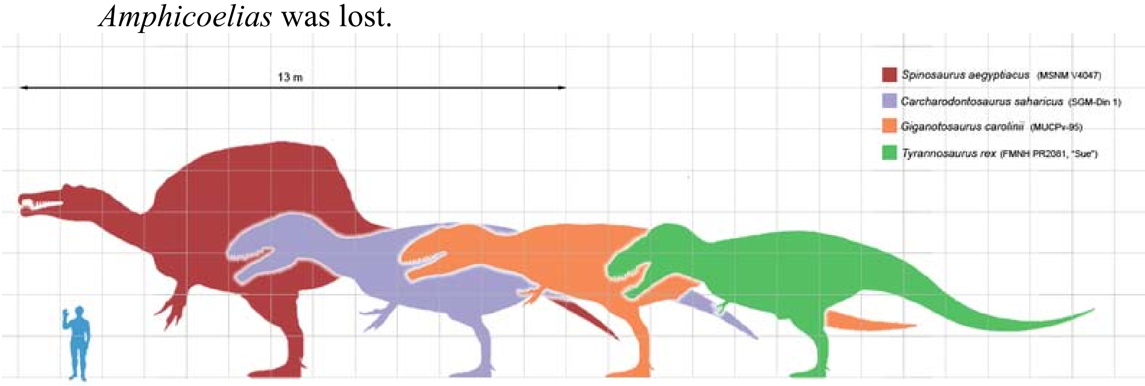
Now extinct, except for theropod descendants, the Aves.

- **Sauropods** (*Sauropoda*)

All of the largest dinosaurs, and the largest animals to ever live on land, were the plant-eating Sauropoda. The tallest and heaviest sauropod known from a complete skeleton is the *Giraffatitan* which was discovered in Tanzania between 1907 and 1912, and is now mounted in the Humboldt Museum of Berlin. It is 12 m (38 ft) tall, and probably weighed between 30,000–60,000 kg (30–65 short tons). The longest is the 25 m (82 ft) long *Diplodocus* which was discovered in Wyoming, and mounted in Pittsburgh's Carnegie Natural History Museum in 1907.

There were larger sauropods, but they are known from only a few bones. The current record-holders were all discovered since 1970, and include the massive *Argentinosaurus*, which may have weighed 80,000–100,000 kg (90 to 110 short tons); the longest, the 35 m (112 ft) long *Supersaurus*; and the tallest, the 18 m (60 ft) *Sauroposeidon*, which could have reached into a 6th-floor window. *Diplodocus hallorum* (formerly known as *Seismosaurus*) was once thought to have been about 50 m (170 ft) long, making it the longest known vertebrate, but later reconstructions estimate the length at 35 m (115 ft).

Less well described finds may exceed this. *Bruhathkayosaurus* may have approached the weight of a Blue Whale, and *Amphicoelias fragillimus* would have been longer still, at an estimated 60 m (200 ft), but considerably lighter. However, *Bruhathkayosaurus* is based on very poor material, and the only fossil of *Amphicoelias* was lost.



Size comparison of selected giant theropod dinosaurs

- **Ornithopods** (*Ornithopoda*)

The very largest ornithopods, like *Zhuchengosaurus* and *Shantungosaurus* were as heavy as medium sized sauropods at up to 23 metric tons (25 short tons) but never grew far beyond 15 meters (50 feet).

- **Theropods** (*Theropoda*)

The longest and heaviest theropod is estimated to be the *Spinosaurus*, at 16 to 18 metres (52 to 59 ft) long and 7 to 9 tonnes (7.7 to 9.9 short tons) in weight. This is significantly more massive than other contenders such as the *Giganotosaurus* and *Tyrannosaurus*. *Spinosaurus* is notable for having been the largest terrestrial predator known to exist.
The longest and heaviest theropod known from a complete skeleton is the *Tyrannosaurus* specimen nicknamed "Sue", which was discovered in South Dakota in 1990 and is now mounted in the Field Museum of Chicago. It is 12.2 m (40 ft) long, and probably weighed 6,800 kg (6.8 metric tons).
The largest dromaeosaurid is *Utahraptor*. In addition to being the largest known dromaeosaurid, it was also the largest known deinonychosaur and the largest known paravian.

- **Armored Dinosaurs** (*Thyreophora*)

The longest of the thyreophorans were *Ankylosaurus* and *Stegosaurus*, both of which measured up to 9 m in length.

- **Cerapods** (*Cerapoda*)

The largest cerapods were the hadrosaurids *Zhuchengosaurus* and *Lambeosaurus laticaudus*. Both species are known from fragmentary remains but are estimated to have reached over 15 m (50 ft) in length and weighed over 23 tonnes (50,700 lb).

- **Ceratopsians**

The largest ceratopsian was *Triceratops*. *Triceratops* is estimated to have reached about 8 m (26 ft) in length and weighed 12 tonnes (26,900 lb). The recently discovered *Eotriceratops* had a skull estimated to be longer than 3 m, and may have been larger than *Triceratops*.

Birds (*Aves*)

The Ostrich is the largest living bird.

The largest living bird, a member of the Struthioniformes, is the ostrich (*Struthio camelus*) reaching a height of over 2.7 m (9 ft) and weighing over 156 kg (345 lb). Eggs laid by the Ostrich can weigh 1.4 kg (3 lb) and are the largest eggs in the world today.

The largest bird in the fossil record may be the extinct elephant birds of Madagascar, which were related to the ostrich. They exceeded 3 m (10 ft) and 500 kg (1,120 lb). The last of the elephant birds became extinct about 300 years ago. Of almost exactly the same proportions as the largest elephant birds was *Dromornis stirtoni* of Australia, part of a 26,000-year old group called mihirungs of the family Dromornithidae. The tallest bird ever however was the Giant Moa (*Dinornis maximus*), part of the moa family of New Zealand that went extinct about 200 years ago. This moa stood up to 3.7 m (12 ft) tall when it was erected in an unnatural position, but weighed about half as much as a large elephant bird or mihirung due to its comparatively slender frame. The largest carnivorous bird was *Brontornis*, an extinct flightless bird from South America which reached a weight of 350 to 400 kg (770 to 880 lb) and a height of about 2.8 m (9 ft 2 in).

The largest bird ever capable of flight was *Argentavis magnificens*, a now extinct member of the Teratornithidae group, with a wingspan of up to 8.3 m (28 ft), a length of over 3 m (10 ft) and a body weight of 80 kg (175 lb).

- **Waterfowl** (*Anseriformes*)

  The largest species in general is the Trumpeter Swan (*Cygnus buccinator*), which can reach an overall length of 1.82 m (6 ft), a wingspan of 3 m (10 ft) and a weight of 17.3 kg (38 lb). However, the heaviest waterfowl ever recorded was an overweight Mute Swan (*Cygnus olor*) from Poland, who weighed nearly 23 kg (50 lb). The members of the previously mentioned Dromornithidae are now classified as members of this order, making them the largest "waterfowl" that ever lived.

- **Swifts & allies** (*Apodiformes*)

  The White-naped Swift (*Streptoprocne semicollaris*) and the Purple Needletail (*Hirundapus celebensis*) reach similar large sizes, at up to 225 g (8 oz) and 25 cm (10 in). The hummingbirds are also traditionally included in this order, the largest species of which is easily the Giant Hummingbird (*Patagona gigas*).

- **Nightjars & allies** (*Caprimulgiformes*)

  The largest species of this order is the Great Potoo (*Nycitbius grandis*), the maximum size of which is about 680 g (1.5 lb) and 60 cm (2 ft).

- **Shorebirds** (*Charadriiformes*)

  The largest species in this diverse order is the Great Black-backed Gull (*Larus marinus*), attaining a size of as much as 85 cm (34 in) and 2.5 kg (5½ lb). The extinct Great Auk (*Pinguinus impennis*), at 5 kg (11 lb) was the record holder, however.

- **Herons & allies** (*Ciconiiformes*)

  The largest species, if measured in regard to body weight and wingspan, is the Andean Condor (*Vultur gryphus*), reaching a wingspan of 3.2 m (10.7 ft) and a weight of 15 kg (33 lb). The longest-bodied species is probably the Saddle-billed Stork (*Ephippiorhynchus senegalensis*), which often exceeds 1.5 m (5 ft) tall. Most of the largest flying birds in the fossil record, including the largest, *Argentavis magnificens*, were members of the Ciconiiformes.

- **Mousebirds** (*Coliiformes*)

  The mousebirds are remarkably uniform, but the largest species is seemingly the Speckled Mousebird (*Colius striatus*), at 2 oz (60 g) and over 14 in (35 cm).

- **Pigeons** (*Columbiformes*)

  The largest species of the pigeon/dove complex is the Victoria Crowned Pigeon (*Goura victoria*). Some exceptionally large ones have reached 3.7 kg (8.2 lb) and 85 cm (34 in). The extinct flightless Dodo (*Raphus cucullatus*) was the largest bird of this order of all time, weighing about 23 kg (50 lb).

- **Kingfishers & allies** (*Coraciiformes*)

  The largest species is the Southern Ground Hornbill (*Bucorvus leadbeateri*), reaching sizes of as much as 6 kg (13.5 lb) and nearly 1.2 m (4 ft) in length. The Largest kingfisher Giant Kingfisher (*Megaceryle maxima*) is 42–48 cm long, with a large crest and finely spotted white on black upperparts. The male has a chestnut breast band and otherwise white underparts wit.

- **Cuckoos & allies** (*Cuculiformes*)

  The largest species of this order is the Great Blue Turaco (*Corythaeola cristata*), a cousin of the cuckoos. This species, which can weigh over 1.2 kg and measure over 74 cm in length, is much larger than other turacos. The largest North American cuckoo is Greater Roadrunner (*Geococcyx californius*) about 56 centimetres (22 in) long and weighs about 300 grams (10.5 oz),

The Eurasian Black Vulture is the biggest of the living birds of prey

- **Birds of prey** (*Falconiformes*)

  The largest species is the Eurasian Black Vulture (*Aegypius monachus*), attaining a maximum size of 14 kg (31 lb), 119 cm (47 in) long and 3 m (10 ft) across the wings. Slightly larger, at up to 1.4 m (4.7 ft) long, wingspan 3 m (10 ft) and weighing at least 15 kg (33 lb), was the now extinct Haast's Eagle (*Harpagornis moorei*), the largest eagle known.

- **Gamebirds** (*Galliformes*)

  The largest member of this diverse order is the Wild Turkey (*Meleagris gallopavo*). The largest specimen ever recorded was just short of 14 kg (31 lb) and 130 cm (52 in). The heaviest domesticated turkey on record weighed 37 kg (81 lb). The longest species, if measured from the tip of the bill to the end of the long tail coverts, is the Green Peafowl (*Pavo muticus*), at up to 3 m (10 ft) long. A prehistoric, flightless family, sometimes called (incorrectly) "giant megapodes" (*Sylviornis*) were the biggest galliformes ever, having reached 1.70 m (5.6 ft) long and weighed up to about 30 kg (66 lb).

- **Loons** (*Gaviiformes*)

  The largest species on average is the Yellow-billed Loon (*Gavia adamsii*), at up to 1 m (3.3 ft) and 7 kg (15.4 lb). However, one exceptional Common Loon (*Gavia immer*), weighed 8 kg (17.6 lb), heavier than any recorded Yellow-billed Loon.

- **Cranes & allies** (*Gruiformes*)

  The Great Bustard (*Otis tarda*) and Kori Bustard (*Ardeotis kori*) are the heaviest birds capable of flight, both occasionally reaching 21 kg (46 lb) and 1.5 m (5 ft) long. The tallest and longest bird flying bird on earth, also represented in the Gruiformes, is the Sarus Crane (*Grus antigone*), sometimes standing almost 2 m (6.6 ft) tall. The largest ever gruiform was a species of "terror bird", highly predatory, flightless birds of South America: *Brontornis burmeisteri*. This species stood about 2.8 m (9.2 ft) and weigh up to about 400 kg (880 lb).

The Thick-billed Raven shares the title of the largest songbird with its common cousin.

- **Songbirds** (*Passeriformes*)

  Both the Common Raven (*Corvus corax*) and the Thick-billed Raven (*Corvus crassirostris*) are enormous by songbird standards. Both of these birds can exceed 1.5 kg (3.3 lb) and 70 cm (28 in).

- **Cormorants & allies** (*Pelecaniformes*)

  The largest species is the Dalmatian Pelican (*Pelecanus crispus*), which attains a length of 1.82 m (6 ft), a wingspan of 3.5 m (11.5 ft) and a body weight of 15 kg (33 lb). A pelecaniform of the late Miocene, *Osteodontornis*, was among the largest flying birds ever, at up to 2.1 m (7 ft) long with a wingspan of 6 m (20 ft).

- **Flamingos** (*Phoenicopteriformes*)

  The largest flamingo is the Greater Flamingo (*Phoenicopterus ruber*), at up to 1.5 m (5 ft) tall and 4 kg (8.8 lb).

- **Woodpeckers & allies** (*Piciformes*)

The largest species of this diverse order is the Toco Toucan (*Ramphastos toco*). The maximum size of this tropical forest bird is possibly as much as 1 kg (2.2 lb) and 75 cm (30 in). The largest woodpecker is the Ivory-billed Woodpecker (*Campephilus principalis*), which has a total length of about 20 inches (50 centimeters) and, based on very scant information, weighs about 20 ounces (570 grams). It has a 30 inch (75 centimeters) wing span.

- **Grebes** (*Podicipediformes*)

  The largest species of grebe is the Great Grebe (*Podiceps major*). It can reach a length of 80 cm (32 in) and a weigh of over 2 kg (4.4 lb).

The Wandering Albatross are largest sea bird

- **Tubenoses** (*Procellariiformes*)

  The largest species is Wandering Albatross (*Diomedea exulans*), which also possesses longest wingspan of any living bird. The maximum dimensions are a length of 1.44 m (4.6 ft) and a wingspan of 3.63 m (nearly 12 ft). Immature have weighed as much as 13.8 kg (35 lb) at the time of their first flights. The largest-ever tubenose (though it is sometimes classified in the order Pelecaniformes) was the albatross-like *Gigantornis eaglesomei*, with a wingspan of about 6 m (20 ft).

- **Parrots** (*Psittaciformes*)

  The longest and largest overall parrot is the endangered Hyacinth Macaw (*Anodorhynchus hyacinthinus*), reaching nearly 1.2 m (4 ft) long and 2 kg (4.4 lb). However, the heaviest parrot is the nearly-extinct Kakapo (*Strigops habroptila*), which can weigh over 4 kg (8.8 lb), but doesn't much exceed 60 cm (2 ft).

- **Sandgrouse** (*Pterocliformes*)

  The Black-bellied Sandgrouse (*Pterocles orientalis*) is the largest sandgrouse, at a maximum size of 634 g (1.4 lb) and 45 cm (18 in).

- **Penguins** (*Sphenisciformes*)

  The largest species is easily the Emperor Penguin (*Aptenodytes forsteri*), with a maximum size of 1.35 m (4.3 ft) and 46 kg (102 lb). At one time, possibly competing with the mammalian pinnipeds, a number of giant penguins existed. The largest is believed to be *Anthropornis nordenskjoeldi*, having reached a height of 1.7 m (5.6 ft) and a weight of up to 90 kg (200 lb).

The Eurasian Eagle Owl is one of the biggest owls

- **Owls** (*Strigiformes*)

  Both the Eurasian Eagle Owl (*Bubo bubo*) and Blakiston's Fish Owl (*Bubo blakistoni*) reach very large sizes. Record-sized specimens of both species have weighed about 4.5 kg (10 lb) and measured over 80 cm (32 in) long. The largest owl known to have existed was *Ornimegalonyx oteroi* of Cuba, having measured over 1 m (3.3 ft) tall.

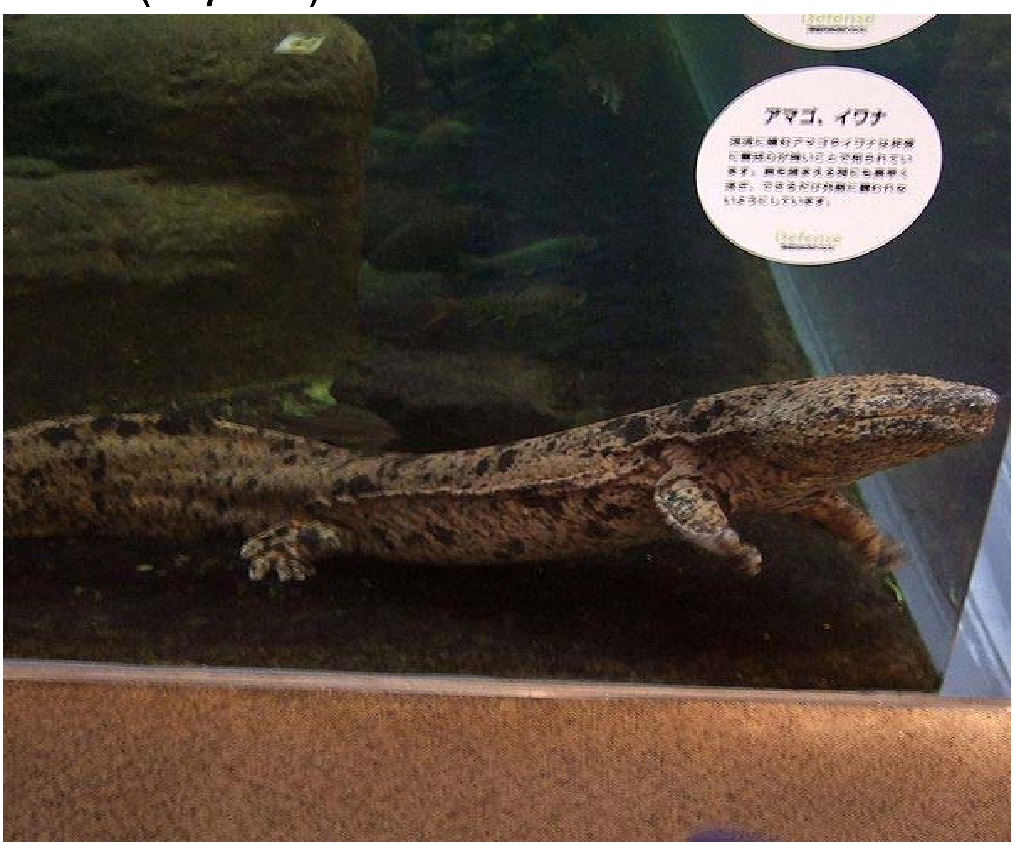
- **Tinamous** (*Tinamiformes*)

  The largest species of tinamou, a group of chunky, elusive ground-birds from tropical America, is the Grey Tinamou (*Tinamus tao*). It can reach a weight over 2 kg (4.4 lb) and length of over 55 cm (22 in).

- **Trogons** (*Trogoniformes*)

  The Resplendent Quetzal (*Pharomachrus mocinno*) is much larger than most trogons. It often exceeds 225 g (8 oz) and is at least 35 cm (14 in) along the head-and-body, with the remarkable tail of the male adding 60 cm (2 ft) to the length.

Amphibians (*Amphibia*)



A giant salamander, the largest of the surviving amphibians.

The largest living amphibian is the Chinese Giant Salamander (*Andrias davidianus*). The maximum size of this river-dweller is 64 kg (140 lb) and 1.83 m (6 ft). Before amniotes became the dominant tetrapods, several giant amphibian-like tetrapods existed. The largest known was the crocodile-like *Prionosuchus*, which reached a length of 9 m (30 ft).

- **Frogs** (*Anura*)

  Easily the largest member of the largest order of amphibians is the African Goliath frog (*Conraua goliath*). The maximum size of this species is a weight of 3.8 kg (8.4 lb) and a snout-to-vent length of 35 cm (14 in). The largest of the toads is the Cane Toad. However, the extinct *Beelzebufo ampinga* could grow to be 40 cm (16 in) long and weigh up to 4.5 kg (10 lb). The largest tree frog is the White-lipped Tree Frog (*Litoria infrafrenata*), the females of which can reach a length of 13 cm from snout to vent. The largest horned or "Pacman frog" is the Surinam horned frog (*Ceratophrys cornuta*), which can reach 20 cm in length from snout to vent. The largest dendrobatid is the Columbian Golden Poison Frog, which can attain a length of 6 cm when fully grown.

- **Caecilian** (*Gymnophiana*)

  The largest of the worm-like caecilians is the Thomson's Caecilian (*Caecilia thompsoni*), which reaches a length of 1.5 m (5 ft) and can weigh up to about 1 kg (2.2 lb).

Ray-finned bony fish (*Actinopterygii*)

The ocean sunfish is the largest of the bony fish

The largest living bony fish is the ocean sunfish (*Mola mola*), a member of the order Tetraodontiformes. Sunfish have been recorded at sizes as large as a length of nearly 3.6 m (12 ft), a height of 4.5 m (15 ft) from fin to fin and a weight of about 5,000 lb (2,300 kg). Much larger bony fish existed prehistorically, the largest ever known having been *Leedsichthys*, of the Jurassic period. Estimates of the size of this fish range from 9 m (30 ft) to 30 m (100 ft), but a maximum size of 16 m (53 ft) seems most realistic.

- **Sturgeons** (*Acipenseriformes*)

  The largest species is the huge beluga sturgeon (*Huso huso*). The maximum recorded size of this endangered species is nearly 7.9 m (26 ft) and 2,075 kg (4,565 lb). The Kaluga or Great Siberian Sturgeon has been recorded at 1000 kg (2200 lb), making it the largest known freshwater fish.

- **Eels** (*Anguilliformes*)

The largest species, if measured in weight and overall bulk, is the European conger (*Conger conger*). The maximum size of this species is 2.87 m (9.5 ft) and 60.6 kg (133¼ lb). Getting slightly longer, at up to 4 m, is the Slender giant moray (*Strophidon sathete*).

- **Minnows & allies** (*Atheriniformes*)

  An order best known for its small minnow representatives, the largest species is the jacksmelt (*Atherinopsis californiensis*). Although it reaches 45 cm (18 in), it is not known to even reach 450 g (1 lb).

- **Grinners** (*Aulopiformes*)

  The largest member of this order is the lancetfish (*Alepisaurus ferox*). Slender, with a huge, dramatic spine, these fish can reach 5.4 kg (12 lb) and 2.1 m (7 ft).

- **Toadfish** (*Batrachoidiformes*)

  The largest toadfish is the Pacuma toadfish (*Batrachoides surinamensis*), reaching a size of up to 5 lb (2.3 kg) and 23 in (58 cm).

- **Flying-fish & allies** (*Beloniformes*)

  The largest member of this order, best known for its members' ability to breach the water and zip through the sky, is the Agujon needlefish (*Tylosurus acus*), a slender fish at up to 1.5 m (5 ft) and a weight of 3.7 kg (8.2 lb).

- **Squirrelfish** (*Beryciformes*)

  Best known for their highly poisonous barbs, the squirrelfish's largest representative is the giant squirrelfish (*Sargocentron spiniferum*), at up to 60 cm (24 in) and 3.5 kg (7.7 lb).

- **Characins** (*Characiformes*)

  The largest species is the giant tigerfish (*Hydrocynus goliath*). The top size of this fish is 1.5 m (5 ft) and 44 kg (97 lb).

- **Herring** (*Clupeiformes*)

  The largest herring is probably the Dorab wolf herring (*Chirocentrus dorab*). The maximum size of this species has been reported as much as 1.8 m (6 ft), but these slender fish have never been recorded as exceeding 3.4 kg (7.5 lb) in weight.

- **Carp** (*Cypriniformes*)

The largest species today is probably the giant barb (*Catlocarpio siamensis*), which reaches a size of as much as 3 m (10 ft) and a weight of as much as 300 kg (660 lb). In centuries past, the Mahseer (*Barbus tor*) was reported to reach similar or even larger proportions, but large specimens are quite rare recently.

- **Killifish & allies** (*Cyprinodontiformes*)

  The largest species is the Pacific four-eyed fish (*Anableps dowei*), reaching a size of 33 cm (13 in) and 588 g (1 lb 4¾ oz).

- **Cod** (*Gadiformes*)

  The largest cod species, although it rarely reaches large sizes anymore due to heavy fishing, is the Atlantic cod (*Gadus morhua*). The maximum recorded size of this species is 2 m (6.7 ft) long and 96 kg (212 lb).

- **Shellears & allies** (*Gonorynchiformes*)

  The well-known milkfish (*Chanos chanos*) is the largest member of this order. The maximum size is 22.7 kg (50 lb) and 1.84 m (6.1 ft) long.

- **Ribbonfish & allies** (*Lampriformes*)

  The largest member of this small but fascinating order is the oarfish (*Regalecus glesne*), also the longest bony fish on earth. Slender and compressed, this fish averages over 6 m (20 ft) long and can weigh 275 kg (605 lb). One fish was 11.3 m (37.3 ft) long, but there is a possibility that the oarfish reaches 16 m (55 ft).

- **Gars** (*Lepisosteiformes*)

  The largest of the gar, and the largest entirely freshwater fish in North America, is the alligator gar, *Atractosteus spatula*, reaching a size of 3 m (10 ft) and 127 kg (279 lb).

- **Anglerfish** (*Lophiiformes*)

  The largest of this diverse order is the common goosefish (*Lophius piscatorius*). This big-mouthed fish can attain a size of 58 kg (127 lb) and a length of 1.9 m (6.2 ft).

- **Lanternfish** (*Myctophiformes*)

  The largest of the numerous but small lanternfish is Bolin's lanternfish (*Gymnoscopelus bolini*), at up to 249 g (8.8 oz) and 35 cm (14 in).

- **Pearlfish & allies** (*Ophidiiformes*)

  The largest member of this order is the giant cuskeel (*Lamprogrammus shcherbachevi*). A cuskeel can be nearly 2 m (6.7 ft) long, but even large fish probably aren't much over 10 kg (22 lb) since they are quite slender.

- **Bony-tongued fish** (*Osteoglossiformes*)

  The largest species is the South American fish usually known as the arapaima, *Arampaima gigas*. This laterally compressed fish can reach a size of about 3 m and a weight of 202 kg (455 lb).

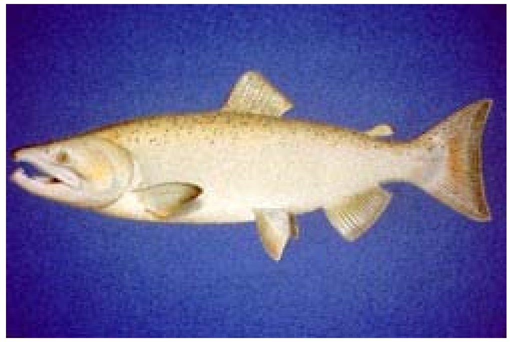
The Atlantic blue marlin is one of the largest species of the perch-like fish

- **Perches & allies** (*Perciformes*)

  The title of the largest member of this order, the most numerous order of all vertebrates, is a matter of some debate. A large marlin is the biggest of these fishes, as they are known to exceed even the huge northern bluefin tuna, *Thunnus thynnus*, in size. The black marlin, *Makaira indica*, the Atlantic blue marlin, *Makaira nigricans*, and the Indo-Pacific blue marlin, *Makaira mazara*, all reach similar large sizes, at up to 900 kg (2,000 lb) and 4.7 m (15.5 ft).

- **Flatfish** (*Pleuronectiformes*)

  The largest of the well-known and heavily-fished flatfish is the Pacific halibut, *Hippoglossus stenolepis*. This giant can reach 363 kg (800 lb) and 2.67 m (8.8 ft), although fish even approaching this size would be extraordinary these days.



This is a relatively small Chinook salmon, the largest species of salmon.

- **Salmon & allies** (*Salmoniformes*)

  The largest species of salmon is the Chinook salmon, *Oncorhynchus tshawytscha*. The maximum size of this fish is 61.4 kg (135 lb) and 1.5 m (5 ft) long. The taimen is the largest salmonid in the world. The maximum size is not well known, but a fish caught in the Kotui River in Russia with a length of 210 cm (83 in) and a weight of 105 kg (231 lb) is the largest reliable record

- **Sculpins** (*Scorpaeniformes*)

  Although less venomous than many smaller fish in the same order, the skilfish, *Erilepis zonifer*, is largest sculpin. The maximum size is 1.9 m (6.2 ft) and the weight can be 90 kg (200 lb).

- **Catfish** (*Siluriformes*)

  Most authorities now give the crown of the largest catfish to the Mekong giant catfish, *Pangasianodon gigas*. This huge fish has been recorded at a size of over 2.7 m (9 ft) and a weight of 293 kg (646 lb). However, the wels catfish, *Silurus glanis*, may possibly be longer. The largest wels scientifically recorded was 3 m (10 ft) and 220 kg (484 lb).

- **Bristlemouths** (*Stomiiformes*)

  The largest of the bristlemouths is the short-tailed barbeled dragonfish, *Oppostomias micripnus*. The top size of a female of this species is probably over 452 g (1 lb) and 50 cm (20 in) long.

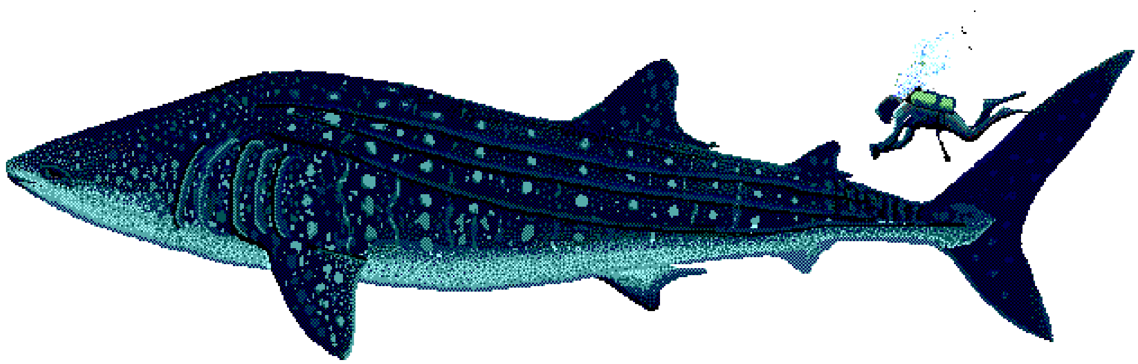
- **Seahorses & allies** (*Syngnathiformes*)

  The largest of this diverse order is the red cornetfish, *Fistularia petimba*, reaching a length of 2 m (6.6 ft) and weight of over 4.5 kg (10 lb).

- **Dories** (*Zeiformes*)

  The largest species of dory is the Cape dory, *Zeus capensis*, reaching a size of 90 cm (36 in) and a weight of 20 kg (44 lb).

Cartilaginous fish (*Chondrichthyes*)



A size comparison of a whale shark and a human.

The largest living cartilaginous fish, of the order Orectolobiformes, is the whale shark, verified in size at up to 13.6 m (45 ft) long and 22 short tons (22 t). There are many accounts of larger whale sharks, but these are unverified.

- **Ground sharks** (*Carcharhiniformes*)

  The largest species of this order is the tiger shark, *Galeocerdo cuvier*. This species can attain a weight of 635 kg (1,400 lb) and length of possibly as much as 6.4 m (21 ft).

- **Mackerel sharks** (*Lamniformes*)

  The largest living species is the basking shark, *Cetorhinus maximus*, also the second largest fish. The maximum, verified size for this shark is 12.4 m (41 ft) and weight is 16 tonnes (17.6 short tons). An even larger shark, generally regarded as the largest macro-predatory fish ever, is the *C. megalodon*, an ancient relative of the great white shark. This giant shark reached a total length (TL) of more than 16 metres (52 ft). *C. megalodon* may have approached a maxima of 20.3 metres (67 ft) in total length and 103 metric tons (114 short tons) in mass.

The manta ray, here seen at Hin Daeng, Thailand, is the largest ray.

- **Stingrays & allies** (*Myliobatiformes*)

  Both the largest species of this order and the largest of the rays is the manta ray, *Manta birostris*. This peaceful leviathan can reach a size of 3 tonnes (3.3 short tons), a "disk" width of 7.6 m (25 ft) and a length of 5 m (16.5 ft).

- **Sawfish** (*Pristiniformes*)

  These little known cartilaginous fish can often reach huge sizes. The largest bulk recorded for a sawfish is for the southern sawfish, *Pristis perotteti*, which weighed 2.4 tonnes (2.7 short tons). At this weight, the sawfish must have measured nearly 9 m (30 ft).

- **Skates** (*Rajiformes*)

  The largest and most diverse order of rays' largest species is the giant guitarfish, *Rhynchobatus djiddensis*. The top size of the species is 250 kg (550 lb) and 3.1 m (10.2 ft).

- **Dogfish** (*Squaliformes*)

The largest member of this order is the Greenland shark, *Somniosus microcephalus*. This species probably reaches 7.2 m (24 ft) and large specimens weigh over 1,364 kg (3,000 lb).

- **Angelsharks** (*Squatiniformes*)

  The largest of the bottom-dwelling angelsharks is the Angelshark, *Squatina squatina*, attaining a size of 100 kg (220 lb) and 2.42 m (8 ft).

Mammal like reptiles (*Synapsida*)

Cotylorhynchus probably was the largest of all synapsids (which went extinct several million years ago), at 20 feet (6 meters) and 2 tons. The largest carnivorous synapsid was Anteosaurus, which was 5–6 meters long, and weighed 500–600 kg.

- **Pelycosauria**

  The largest Pelycosaur was the pre-mentioned Cotylorhynchus (20 feet, 2 tons), and the largest predatory pelycosaurus was Ivantosaurus, with a length of 20 feet (6 meters).

- **Therapsida**

  Moschops was the largest Therapsid, with a weight of 700–1000 kg, and a length of about 5 meters. The largest carnivorous Therapsid was Anteosaurus, which was 5-6 meters long, and weighed 500-600 kg.

Table of heaviest terrestrial animals

The following is a list of the heaviest land animals. The walrus is included as it spends much of its time on land. The African Elephant is not split into its possible separate species of the African Bush Elephant and African Forest Elephant as it is not yet a fully accepted split.

Rank	Animal	Average Mass (kg)	Maximum Mass (kg)	Average Length (m)
1	African Elephant	8260 (18,500 lbs)	12,050 (27,000 lbs)	6.56 (21.85 ft)
2	Asian Elephant	3910 (8,750 lbs)	4900 (11,000 lbs)	5.85 (19.5 ft)
3	Hippopotamus	2340 (5,250 lbs)	4400 (8,000 lbs)	3.3 (11 ft)
4	White Rhinoceros	2230 (5,000 lbs)	3540 (7,920 lbs)	3.75 (12.5 ft)
5	Gaur	1470 (3,300 lbs)	1995 (4400 lbs)	2.94 (9.8 ft)
6	Giraffe	1340 (3,000 lbs)	1960 (4,400 lbs)	4.62 (15.4 ft)
7	Walrus	1180 (2,645 lbs)	2010 (4,500 lbs)	3.3 (11 ft)
8	Black Rhinoceros	1080 (2,420 lbs)	1790 (4,000 lbs)	3.38 (11.25 ft)

9	Saltwater crocodile	760 (1,700 lbs)	1470 (3,300 lbs)	6 (20 ft)
10	Wild Asian Water buffalo	748 (1,684 lbs)	1180 (2,640 lbs)	3.42 (11.4 ft)

Invertebrates

Sponges (*Porifera*)

Arguably the most primitive form of animals in existence, the largest species of sponge is the giant barrel sponge, *Xestospongia muta*. These massively-built sponges can reach 8 feet (2.4 m) in height and can be of about the same number of feet across at the thickest part of the "body".

- **Calcareous sponges** (*Calcarea*)

  The largest of these small, inconspicuous sponges is probably the species *Pericharax heteroraphis*, attaining a height of 30 cm (1 ft). Most calcareous sponges do not exceed 10 cm (4 in) tall.

- **Hexactinellid sponges** (*Hexactinellida*)

  A relatively common species, *Rhabdocalyptus dawsoni*, can reach a height of 1 m (3.3 ft) once they are of a very old age. This is the maximum size recorded for a hexactinellid sponge.

Cnidarians (*Cnidaria*)

Lion's mane jellyfish

The Lion's mane jellyfish is the largest cnidaria species, of the class Scyphozoa. The largest known specimen of this giant, found washed up on the shore of Massachusetts Bay in 1870, had a bell diameter of 2.5 m (8 ft), a weight of 150 kg (330 lb) and possessed tentacles as long as 40 m (120 ft) making it one of the longest extant animals.

- **Corals and sea-anemones** (*Anthozoa*)

  The largest individual species are the sea-anemones of the genus *Discoma*, which can attain a mouth disc diameter of 60 cm (2 ft). Longer, but much less massive overall, are the anemones of the genus *Ceriantharia*, at up to 2 m (6.6 ft) tall. Communities of coral can be truly massive, a single colony of the *Porites* genus can be over 10 m (33 ft), but the actual individual organisms are quite small.

- **Box jellyfish** (*Cubozoa*)

  The largest of the box jellyfish is the species *Chironex fleckeri*, which can attain a mass of 6 kg (13 lb), a 30 cm (1 ft) bell and a tentacle length up to 2 m (6.6 ft). This species is also the most common and dangerous box jelly.

- **Hydrozoans** (*Hydrozoa*)

  The colonial siphonophore *Praya dubia* can attain lengths of 40–50 m :(130–160 ft).

Flatworms (*Platyhelminthes*)

The largest terrestrial species of this phylum of mostly parasites, called flatworms in common language, is the greenhouse planarian, *Bipalium kewense*, of the class Turbellaria. This planarian can reach a length of 60 cm (2 ft) and is quite massive for a flatworm.

- **Monogenean flatworms** (*Monogenea*)

  The largest members of this group of very small parasites are among the genus of capsalids, *Listrocephalos*, reaching a length of 2 cm (0.8 in).

- **Flukes** (*Trematoda*)

  The largest species of fluke is *Fasciolopsis buski*, which most often attacks humans and livestock. One of these flukes can be up to 7.5 cm (3 in) long and 2 cm (¾ in) thick.

- **Tapeworms** (*Cestoda*)

  The largest species of tapeworm is commonly called the fish tapeworm, *Diphyllobothrium latum*, since they are commonly contracted from eating fish.

This devastating parasite has been recorded as reaching a length of 20 m (66 ft) in the internal organs of a human, and a length of 30 m in other hosts.

Roundworms (*Nematoda*)

The largest roundworm, *Placentonema gigantissima*, is a parasite found in the placentas of sperm whales which can reach up to 30 ft (9 m) in length.

Segmented worms (*Annelida*)

The largest of the segmented worms is the African giant earthworm, *Microchaetus rappi*. This huge worm can reach a length of as much as 6.7 m (22 ft) and can weigh over 1.5 kg (3.1 lb). Only the giant Gippsland earthworm, *Megascolides australis*, and a few giant polychaetes reach nearly comparable sizes, reaching 4 m (13 ft) and 3.6 m (11.9 ft), respectively.

Echinoderms *(Echinodermata)*

The largest species of echinoderm in terms of bulk is the sea star species *Thromidia catalai*, of the class Asteroidea, which reaches a weight of over 6 kg (13 lb). However, at a maximum span of 63 cm (25 in), it is quite a bit shorter than some other echinoderms. The longest-bodied echinoderm is the brisingid sea star *Midgardia xandaros*, reaching a span of 1.4 m (4.5 ft), despite being quite slender.

- **Crinoids** (*Crinoidea*)

  The largest species of crinoid is the unstalked feather-star, *Heliometra glacialis*, reaching a total width of 78 cm (31 in) and an individual arm length of 35 cm (14 in). In the past, crinoids grew much larger, and stalk lengths up to 40 m (130 ft) have been found in the fossil record.

- **Sea-urchins & allies** (*Echinoidea*)

  The largest sea urchin is the species *Sperosoma giganteum*, which can reach a shell width of 33 cm (13 in).

- **Sea-cucumbers** (*Holothuroidea*)

  The bulkiest species of sea cucumber is *Stichopus variegatus*, weighing several pounds, being about 21 cm (8.3 in) in diameter, and reaching a length of 1 m (3.3 ft) when fully extended. Species of sea cucumber in the genus *Synapta* can reach an extended length of 2 m (6.6 ft), but are extremely slender.

- **Brittle stars** (*Ophiuroidea*)

The largest known specimen of brittle star is *Gorgonocephalus stimpsoni*. This species can measure 70 cm (28 in) in arm length and has a disk diameter of about 14.3 cm (5.63 in).

Ribbon worms (*Nemertea*)

The largest nemertean and possibly the longest animal is the bootlace worm, *Lineus longissimus*. A specimen found washed ashore on a beach in St. Andrews, Scotland in 1864 was recorded at a length of 55 m (180 ft).

Molluscs (*Mollusca*)

A 7 m (23 ft) Giant Squid, the second largest of all invertebrates, encased in ice in the Melbourne Aquarium.

Both the largest mollusk and the largest of all invertebrates is believed to be the Colossal Squid, *Mesonychoteuthis hamiltoni*. Current estimates put its maximum size at 12 to 14 metres (39–46 ft) long, based on analysis of smaller specimens. On February 22, 2007, authorities in New Zealand announced the capture of the largest colossal squid seen. It was later measured at 10 m (33 ft) long and 495 kg (1,091 lb) in weight.

The Giant Squid (*Architeuthis dux*) was previously thought to be the largest squid, and while it is less massive and has a smaller mantle than the Colossal Squid, it may exceed the colossal squid in overall length including tentacles. The giant squid can measure up to 13 m (43 ft) or more from tentacle tip to tail tip, or 2.25 m (7.4 ft) in mantle length, and can weigh up to 275 kg (600 lb).

- **Aplacophorans** (*Aplacophora*)

  The largest of these worm-like, shell-less mollusks are represented in the genus *Epimenia*, which can reach 30 cm (12 in) long. Most aplacophorans are less than 5 cm (2 in) long.

- **Chitons** (*Polyplacophora*)

The largest of the chitons is the gumboot chiton, *Cryptochiton stelleri*, which can reach a length of 33 cm (13 in).

- **Bivalves** (*Bivalvia*)

  The largest of the bivalve mollusks is the giant clam, *Tridacna gigas*. Although even more enormous sizes have been reported for this monstrous but passive animal, the top verified size is 600 lb (270 kg), 3 ft 10 (1.17 m) in length and 30 in (0.76 m) wide. The largest bivalve ever was *Platyceramus platinus*, a Cretaceous giant that reached an axial length of up to 3 m (nearly 10 ft).

- **Gastropods** (*Gastropoda*)

  The "largest" of this most diverse and successful mollusk class of slugs and snails can be defined in various ways.
  The living gastropod species that has the largest (longest) shell is *Syrinx aruanus*, maximum length of shell, 91 cm. Also supposedly reaches a size of 16.4 kg (36 lb), a length of 70 cm (28 in) and a width of 96 cm (38 in).
  The largest shell-less gastropod is the giant black sea hare *Aplysia vaccaria* at 99 cm in length and almost 14 kg in weight.
  The largest of the land snails is the Giant African snail, *Achatina achatina*, at up to 1 kg (2.2 lb) and 35 cm (14 in) long.

- **Cephalopods** (*Cephalopoda*)

  While generally much smaller than the giant *Architeuthis* and *Mesonychoteuthis*, the largest of the octopuses, the North Pacific Giant Octopus, *Enteroctopus dofleini*, can be very large. The largest confirmed weight of a giant octopus is 71 kg, with a 7-metre (23 ft) arm span.

Arthropods (*Arthropoda*)

In terms of overall size, the Japanese spider crab is the largest of all arthropods.

The Japanese spider crab, *Macrocheira kaempferi*, a crustacean of the class Malacostraca, is the largest arthropod in the world in overall size, weighing up to 20 kg (44 lb), having a body up to 60 cm (2 ft) long and having a leg span of almost 4 m (13 ft). It is indisputably the largest member of Brachyura (crabs).

However, the American lobster, *Homarus americanus*, another crustacean and the largest member of Astacidea (lobsters and crayfish), rivals the Japanese spider crab in mass, if not dimension. This lobster has been recorded at heavier weights, up to 22 kg (48.4 lb), and can measure 1.18 m (3.9 ft) along the body.

The coconut crab, *Birgus latro*, also a crustacean, is the largest land arthropod and the largest land invertebrate, up to 40 cm (1.3 ft) long and weighing up to 4 kg (8.8 lb). Its legs may span 1 m (3.25 ft).

The largest arthropod ever known to exist was either the eurypterid (sea scorpion) *Jaekelopterus* or the Carboniferous millipede *Arthropleura*, which were both between 2.5 and 2.6 m (8.2-8.5 ft) in length . They were closely followed by *Pterygotus*, an aquatic eurypterid that was up to 2.3 m (7.5 ft) in length. The closest living relatives of Eurypterida are the arachnids, horseshoe crabs, and sea spiders.

The Giant huntsman spider was considered in the December 2008 WWF report as "the world's largest Huntsman spider."

- **Arachnids** (*Arachnida*)

  The largest species of arachnid is probably the Goliath birdeater, *Theraphosa blondi*. However, of very comparable dimensions and possibly even greater mass, are the Chaco golden knee, *Grammostola pulchripes*, and the Brazilian salmon pink, *Lasiodora parahybana*. Some of these huge New World "tarantulas" have been recorded as reaching a leg span of 28 cm (11 in), a body length over 9 cm (3.5 in) and a body weight exceeding 85 g (3 oz). The largest of the scorpions is the species *Heterometrus swammerdami*, which can reach 29 cm (11.5 in) long and a weight of up to 57 g (2 oz). However, they were dwarfed by

Pulmonoscorpius kirktonensis, a giant extinct species of scorpion from Scotland and the aquatic *Brontoscorpio*.

- **Branchiopods** (*Branchiopoda*)

  The largest of these primarily freshwater crustaceans is probably *Branchinecta gigas*, which can reach a length 10 cm (3.9 in).

- **Centipedes** (*Chilopoda*)

  The biggest of the centipedes is the Scolopendra gigantea, reaching a relatively enormous length of 33 cm (13 in).

- **Millipedes** (*Diplopoda*)

  Two species of millipede both reach a very large size *Archispirostreptus gigas* and *Scaphistostreptus seychellarum*. Both of these species can slightly exceed a length of 28 cm (11 in). The 300-million year old *Arthropleura*, either a primitive millipede or a close relative, was the largest land invertebrate ever, having measured at least 2.5 m (8.2 ft) long and 45 cm (18 in) wide.

- **Barnacles & allies** (*Maxillopoda*)

  The largest species is a copepod (*Pennella balaenopterae*), known exclusively as a parasite from the backs of Fin Whales (*Balaenoptera physalus*). The maximum size attained is 32 cm (about 13 in). The largest of the barnacles is the giant acorn barnacle, *Balanus nubilis*, reaching 7 cm (2.8 in) in diameter and 12.7 cm (5 in) high.

- **Horseshoe crabs** (*Merostomata*)

  The four modern horseshoe crabs are of roughly the same sizes, at up to 60 cm (2 ft) in length. Easily the best known species is *Limulus polyphemus* of North America.

- **Ostracods** (*Ostracoda*)

  The largest of these small and little-known but numerous crustaceans is the species *Gigantocypris agassizii*, reaching a maximum length of 3 cm (1.3 in).

- **Amphipods, Isopods, and allies** (*Peracarida*)

  The largest species is the giant isopod, which can reach a length of 45 cm (18 inches) and a weight of 1.7 kg (3.7 lb).

- **Sea spiders** (*Pycnogonida*)

The largest of the sea spiders is the deep-sea species *Colossendeis colossea*, attaining a leg span of nearly 60 cm (2 ft).

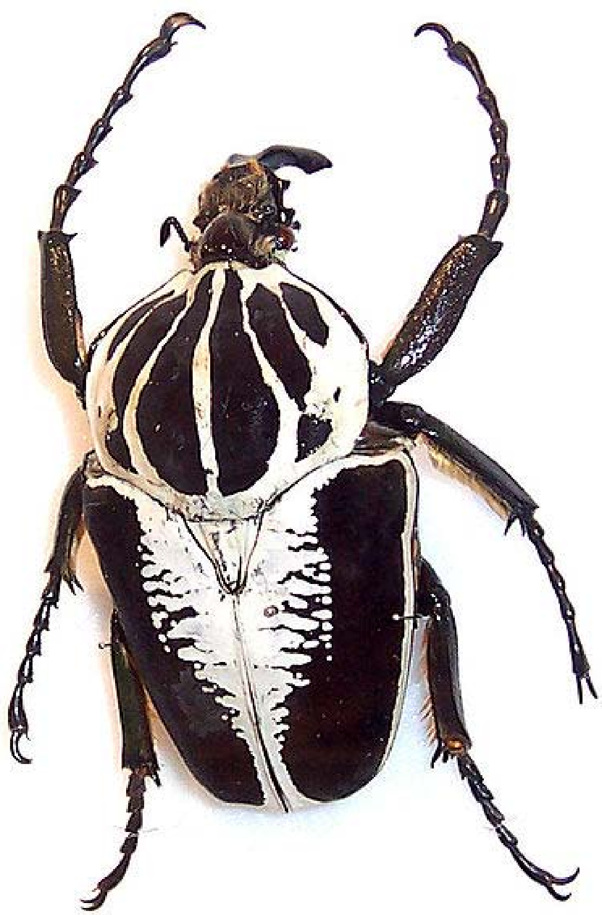
- **Remipedes** (*Remipedia*)

  The largest of these cave-dwelling crustaceans is the species *Godzillius robustus*, at up to 4.5 cm (1.8 in).

- **Trilobites** (*Trilobita*)

  Some of these extinct marine arthropods exceeded 60 cm (24 inches) in length. A nearly complete specimen of *Isotelus rex* from Manitoba attained a length over 70 cm (27 in), and a *Ogyginus forteyi* from Portugal was almost as long. Fragments of trilobites suggest even larger record sizes. An isolated pygidium of *Hungioides bohemicus* implies that the full animal was 90 cm (36 in) long.

Insects (*Insecta*)



The goliath beetle is arguably the world's heaviest insect

Insects, which are a type of arthropod, are easily the most numerous group of organisms on the planet, with about a million species identified so far. The title of heaviest insect in the world has many rivals, the most frequently-crowned of which is the larval stage of the goliath beetle, *Goliathus goliatus*, the top size of which is at least 115 g (4.1 oz) and 11.5 cm (4.5 in). The largest confirmed weight of an adult insect is 71 g (2.5 oz) for a giant weta, *Deinacrida heteracantha*, although it is likely one of the elephant beetles, *Megasoma elephas* and *Megasoma actaeon*, or goliath beetles, both of which can commonly exceed 50 g (3 oz) and 10 cm (4 in), can reach a higher weight.

The longest insects are the stick insects.

Representatives of the extinct dragonfly-like order Protodonata such as the Carboniferous *Meganeura monyi* and the Permian *Meganeuropsis permiana* are the largest insect species ever known. These creatures had a wingspan of some 75 cm (30 in) and a body weight of over 1 lb (450 g), making them about the size of a crow.

- **Cockroaches** (*Blattodea*)

  The largest cockroach is the giant burrowing cockroach (*Macropanesthia rhinoceros*). This species can attain a length of 8.3 cm (3.3 in) and a weight of 36 g (1.3 oz).

- **Beetles** (*Coleoptera*)

  The beetles are the largest order of organisms on earth, with about 350,000 species so far identified. The most massive species are the *Goliathus*, *Megasoma* and *Titanus* beetles already mentioned. The longest species is the Hercules beetle, *Dynastes hercules* with a maximum overall length of at least 17 cm (7 in) including the very long pronotal horn.

- **Earwigs** (*Dermaptera*)

  The largest of the earwigs is the Saint Helena giant earwig, *Labidura herculeana*, which is up to 8.4 cm (3¼ in) in length.

- **True flies** (*Diptera*)

  The largest species of this huge order is the species *Gauromydas heros*, which can reach a length of 6 cm (2½ in) and a wingspan of 10 cm (4 in). Species of crane fly, the largest of which is *Holorusia brobdignagius*, can attain a length of 23 cm (9 in) but are extremely slender and much lighter in weight than *Mydas*.

- **Mayflies** (*Ephemeroptera*)

  The largest mayflies are members of the genus *Proboscidoplocia* from Madagascar. These insects can reach a length of 5 cm (2 in).

- **True bugs** (*Hemiptera*)

  The largest species of this diverse, huge order is a giant water bug, *Lethocerus maximus*. This species can attain a length of 11.6 cm (4.6 in), although it is more slender and less heavy than most other insects of this size (principally the huge beetles).

- **Ants & allies** (*Hymenoptera*)

  The largest of the ants, and the heaviest species of the order, are the females of *Dorylus helvolus*, reaching a length of 5 cm (2 in). The ant that averages the largest for the mean size of the whole colony is *Dinoponera gigantea*, averaging up to 3.3 cm (1¼ in). The largest of the bee species, also in the order Hymenoptera, is *Megachile pluto*, the females of which can be 3.8 cm (1½ in) long, with a 6.3 cm (2½ in) wingspan. The largest wasp is probably the so-called tarantula hawk species *Pepsis pulszkyi*, at up to 6.8 cm (2¾ in) long and 11.6 cm (4½ in) wingspan, although many other *Pepsis* approach a similar size.

- **Termites** (*Isoptera*)

  The largest of the termites is the African species *Macrotermes bellicosus*. The queen of this species can attain a length of 10.6 cm (4.2 in) and breadth of 5.5 cm (2¼ in); other adults, on the other hand, are about a third of the size.

The Queen Alexandra's birdwing is the largest species of butterfly.

- **Moths & allies** (*Lepidoptera*)

  The largest species is probably either the Queen Alexandra's birdwing, *Ornithoptera alexandrae*, a butterfly, or the Atlas moth, *Attacus atlas*, a moth. Both of these species can exceed a length of 8 cm (3¼ in), a wingspan of 28 cm (11 in) and a weight of 12 g. Their larvae can weigh up to 58 g (2.0 oz) or 1.9 oz (54 g) . However, the White Witch, *Thysania agrippina*, has the longest recorded wingspan of the order, and indeed of any living insect, at up to at least 30 cm (12 in), though it is exceeded in surface area and mass by both *Ornithoptera* and *Attacus*.

- **Praying mantises** (*Mantodea*)

  The largest species of this order is the Chinese mantis, *Tenodera aridifolia*. The females of this species can attain a length of up to 10.6 cm (4.2 in).

- **Dragonflies** (*Odonata*)

  The largest living species of dragonfly is *Megaloprepus caerulatus*, attaining a size of as much as 19 cm (7.5 in) across the wings and a body length of over 12 cm (4.7 in). The largest species of dragonfly ever is the extinct *Meganeura*.

- **Grasshoppers & allies** (*Orthoptera*)

  The largest of this widespread, varied complex of insects is the giant weta, *Deinacrida heteracantha*, of New Zealand. This formidable insect can weigh over 75 g (2.6 oz) and measure up to nearly 10 cm (4 in), rivaling the huge beetles in size. The largest grasshopper species is Valanga Irregularis, which can be up to 3.5 inches in length.

- **Stick insects** (*Phasmatodea*)

  The longest known stick insect is *Phobaeticus chani*, with one specimen held in the Natural History Museum in London measuring 567 millimetres (22.3 in) in total length. This measurement is, however, with the front legs fully extended. The body alone still measures 357 millimetres (14.1 in). The species with the second longest body is *Phobaeticus kirbyi*, which measures up to 328 millimetres (12.9 in), while the overall length (from the hind to the front legs) is up to 546 millimetres (21.5 in), and the body weight is up to 72 g (2.5 oz). The second longest insect in terms of total length is *Phobaeticus serratipes*, measuring up to 555 millimetres (21.9 in).

- **Stoneflies** (*Plecoptera*)

The largest species of stonefly is *Pteronarcys californica*, a species favored by fishermen as lures. This species can attain a length of 5 cm (2 in) and a wingspan of nearly 7.5 cm (3 in).

- **Booklice** (*Psocoptera*)

  The largest of this order of very small insects are the barklouse of the genus *Psocus*, the top size of which is about 1 cm (0.4 in).

- **Fleas** (*Siphonaptera*)

  The largest species of flea is *Hystrichopsylla schefferi*. This parasite is known exclusively from the fur of the Mountain Beaver and can reach a length of 1.2 cm (0.5 in).

- **Thrips** (*Thysanoptera*)

  Members of the genus *Phasmothrips* are the largest kinds of thrips. The maximum size of these species is approximately 1.3 cm (0.5 in).