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What do zoologists use animals for?

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Zoology, the study of animals (Figure 1), is by itself a subject worthy of study. In recent years zoology departments in many universities in the United States have been redefined, divided up, merged, or simply eliminated. This follows more than fifty years of increased government regulation driven by selective funding and administration of scientific research, as well as a tight job market in the academic profession that has been characterized as either an opportunity for *social justice*, or as a seductive *pyramid game*. Both views have good support from the available data. But zoology as a subject has never been owned by the academic professions, although the economic support that publicly-funded institutions obtain for related studies is far greater than that generally available in the private sector. Today, equipment can be very expensive.

Humans use animals in many ways, as food, material (e.g., fur, ivory, bone, collections or fertilizer), beasts of burden, companions, pest controllers, entertainers and instructors. There is no sign that humans will ever be willing (or able, in any case) to relinquish their dominion over the animal kingdom, and in fact most attempts to secure collections of animals (materials) have had nothing to do with the preservation of wilderness or entire communities of living things, which is really the only way to protect animal species. Outside of its wilderness home, however small or shrinking, the animal is really just a specimen. I have seen museum collectors with large bottles filled with hundreds of lizards, collected in numbers from one site for exchange to obtain specimens from other institutions. So, the specimen trade is still with us.

Of course, the *zoologist* is also a human, and an animal. And as an animal that readily manipulates its environment in new and unforeseen ways, the human necessarily competes with all other animals, including humans. The human is by no means exempt from population genetics, biogeography, mutation, selection and evolution. The humans of tomorrow will be quite different from those of today.

I have known zoologists or ecologists that do *all* of their work with mathematics. We had a whole school of *population genetics* in the United States that was based almost entirely on the testing of numerical models with large numbers of tenebrionid beetles grown on meal in laboratory jars. In this environment, even a slight change in the humidity of a culture medium might change the relative populations of two competing species, something that could then be measured and published as a *new discovery*. These studies did not require the use of wild animals. But a tendency to recognize animals as *systems*, of limited intrinsic interest by themselves, for the study of specific *natural phenomena that transcend the subject of study* (e.g. *multimodal communication*) lingers on. I have read a number of recent papers that do not mention the identity of the animals that have been studied for many pages, and then only briefly, almost as a footnote.

Figure 1. Some representative animals. Today the term *animal* refers specifically to a metazoan, but traditionally this has also included a range of motile, single-celled protists like *Euglena* and *Paramecium*. None of the animals shown here should be thought of as primitive, as they all represent groups that been evolving for hundreds of millions of years. **1,** Bigfin reef squid, *Sepioteuthis lessoniana*. **2**, Jumping spider, *Plexippus paykulli*. **3,** Brooding anemone, *Epiactis prolifera*. **4,** Feather star, *Himerometra robustipinna*. **5,** Grey heron (*Ardea cinerea*) with prey. Both are members of the large clade of bony fish (Osteichthyes) that includes most living vertebrates. **6,** Oriental garden lizard, *Calotes versicolor*.

Zoologists must do research, and they must publish. In many if not most cases, a zoologist begins his or her career as a graduate or postdoctoral student by using methods and subjects determined largely by the interests or funding of a sponsor. This is responsible for the division of academic zoology into many different *schools* of research, each a specialty unto itself, and these invariably evolve over time. But each of these schools is constrained by several factors. First, some kinds of animals are more useful for certain kinds of study. That is, choice of *your animal* makes certain kinds of study much easier, and other kinds of study much more difficult. Second, changing technology can be linked directly to the kind of studies that are popular at any point in time. Thus microscopic anatomy or histology became popular with the advent of light microscopes, just as more detailed anatomy (*ultrastructure*) became more popular with the advent of scanning electron microscopy. More recently DNA sequencing technologies have led to a rapid growth in studies of evolution and phylogeny, largely supplanting earlier studies in comparative morphology. The ability to attach visible markers to molecules used to communicate and regulate cell differentiation has led to the resurgence of developmental biology. Combined with DNA sequencing, this has produced an entirely new field of evolutionary development (EVO/DEVO). Advanced technologies for the study of molecular structure have also led to the emergence of both chemical ecology and molecular evolution. So there is a lot going on these days, even if the career opportunities are limited.

It is fair to say that most *professional* zoologists use animals to conduct research that allows them to stay employed in a career that gives them an income, providing economic support for all of the other things that they want to do. Here we will look more specifically at the use of animals by academic zoologists, looking at the mapping of animal groups to the various kinds of research that these animals tend to support. We should note that it is quite common for a zoologist to take a liking to a particular group of animals at an early age, and then to pursue a career that includes the study of these animals to address subjects that they are useful for. This may actually be much more common that the selection of animals after a research subject is chosen. For example, a person who studies wolf territories probably had an interest in *wolves* long before any later interest in *the energy investment of terrestrial animals in the maintenance of hunting territories* became apparent.

In this brief discussion (Table 1) I will not cover most research in the areas of *systematics* (taxonomy or classification), *phylogeny* and *biogeography*, as these seem generally applicable to all animals. In these areas, the study of little-known animals may actually take precedence over the study of well-known or popular animals, as they may contribute more to the resolution of larger questions in phylogeny.

In general, any studies of mammalian, vertebrate, or even non-vertebrate deuterostome physiology might be related to human medicine, as various grades in this continuum could shed light on aspects of human physiology. Beyond direct applications of vertebrate physiology to medical science and the practice of medicine, the parasites that affect humans and related vertebrates also get attention (as *parasitology*). Other areas that get a lot of attention relate to pest control (e*ntomology* and a*carology*), game or fisheries management (including *wildlife management*, *biological oceanography*, and *biological limnology*) and animal husbandry (*veterinary* or *animal science*), directly related to food production but also to a large and growing *animal companion industry* in western countries.

What is of particular interest is how many animal groups really fall outside of the practical applications arena (although not for lack of trying!). Again excluding systematics and related studies with general application, some of these groups, like the turtles (Chelonia) are very popular with the public, but have found few uses for research. At one time herpetological journals published many studies based on the collection of large numbers of turtles so that they could be dissected, and their gut contents could be examined and tallied. As turtles are not known as remarkable subjects for the study of behavior, that was at least one thing that zoologists could do to them.

Another study that was once popular with turtles and other cold-blooded or poikilothermic amphibians and reptiles has also found disfavor with those who advocate animal rights or welfare. In this study the unfortunate animals were subjected to extreme conditions of heat, cold, or perhaps even oxygen deprivation to see what their survival limits were. This may seem cruel today, but we still bulldoze and burn whole ecosystems with little regard for the myriad of animals that live in these places. And even advocates of animal rights for predatory companion animals take little regard for the vast number of wild creatures that are either killed, or lose their habitat to provide processed food for these companions. For every wolf in the wild, there are at least ten thousand companion dogs in the United States. While cruelty to dogs is outlawed, coyotes are ruthlessly exterminated.

Table 1. Focus of study subjects, by animal group. This informal list does not include systematics, phylogeny and biogeography, and is based largely on limited sampling of recent papers and the subjective impressions of the author. Not all animal groups are shown here, and this is certainly incomplete. Publications often suggest *practical applications*, or justifications for the respective work, even when these have not been demonstrated. For example, it is popular to claim that a study provides essential information required to protect animals in an era of *climate change*. An estimated 95 percent of animal studies in medicine involve just two species, the mouse and the rat. However not all studies have obvious applications.

animal group	typical study subjects	practical application
mouse (*Mus musculus*) and rat (*Rattus norwegicus*)	most medical studies of human disease, drugs	medicine
guinea pig (*Cavia porcellus*)	medical studies, now of little importance	medicine
primates, pigs (*Sus*)	behavior, experimental surgery, physiology	medicine
domestic mammals	animal science (many subjects, mostly medical)	food production, veterinary care of pets
mammalian macrofauna	animal science, wildlife biology	zoos, ecotourism, wildlife conservation
birds	behavior, toxicology, physiology	medicine, game management, ecotourism
snakes (Squamata: Serpentes)	venom	antivenom
frogs (Anura) and lizards (Squamata)	distribution, ecology	conservation
fish in general	reproduction, growth, ecology	game and commercial fisheries, pet trade (less)
Zebrafish (*Danio rerio*)	physiology, development	medicine
starfish (Asteroidea)	impact on ecosystem	oyster and mussel fisheries, coral reef health
sea urchins	developmental biology	
large crustaceans (Malacostraca)	reproduction, growth, ecology	commercial fisheries
small or pelagic crustaceans	reproduction, growth, ecology	commercial fisheries
insects in general (most groups)	effect of biological and chemical agents	protection of crop plants
bees and wasps (Hymenoptera)	social behavior, navigation	commercial pollination (limited)
butterflies (Lepidoptera) and beetles (Coleoptera)	detailed variations	commercial trade in specimens
fruit flies (*Drosphila melanogaster*)	genetics, developmental genetics	human genome function
mosquitoes and biting flies	reproduction, growth, ecology	control of parasites
mites (Acariformes)	reproduction, growth, ecology	protection of crop plants
mites (Parasitiformes)	reproduction, growth, ecology	control of parasites
spiders	behavior	
squid and cuttlefish (cephalopods)	reproduction, growth, ecology	commercial fisheries
clams and mussels (pelecypods)	reproduction, growth, ecology	commercial fisheries
freshwater snails (gastropods)	histopathology, physiology, life cycle	control of parasites
parasitic flatworms (cestodes, trematodes)	histopathology, physiology, life cycle	control of parasites
corals, shallow sea animals in general	growth, distribution	coral reef health, ecotourism

Here I will consider the study of spiders, since this is something that I have enjoyed for many years. Spiders (Araneae) are relatively well-known for their complex behaviors, particularly those related to their mating behavior (something like *artificial insemination* with the male pedipalp), and their predatory behavior that can include some remarkable uses for silk. Their venom and chemosensory abilities have also received some attention in recent years. There have also been some less-than-successful attempts to relate spiders to biocontrol. Spiders certainly have a great impact on insect populations, but they also prey on other spiders and their role as generalists apparently works against their effectiveness in controlling specific insect pests.

Tom Eisner (*For Love of Insects*, Belknap Press, 2003) wrote this about the relationship of spider science to entomology:

> *I have wondered often why there are so few spider experts, given that spiders are so incredibly interesting. The answer, I think, lies in the fact that spiders have eight legs rather than six, and therefore don't qualify for study by entomologists. Arachnologists are scarce because they must come into being on their own. There are no arachnological equivalents of entomology departments to churn them out in numbers.*

I think that there are several other factors that also limit the study of spiders. Spiders may be generally beneficial with respect to regulation of insect populations, but as noted above their utility in biocontrol programs is questionable. In addition, we have varying degrees of *arachnophobia* to contend with, even among zoologists. Colorful birds and butterflies in aviaries and butterfly rainforests are popular and even draw admission fees, but spiders are something else, often feared and disliked.

In recent years most spider groups have received limited attention, mostly from a small number of dedicated systematists (many working on their own time) who like spiders, and people who rear the large theraphosids ("tarantulas") as pets. But the jumping spiders, members of the family Salticidae (Figures 1.2, 2) have recently gained a much larger following. This has had much to do with the discovery new species, like the Australian peacock spiders (genus *Maratus*) sought by adventurers willing to venture into the bush to find them. The study of spiders has also found support from skilled photographers in places like Singapore and South Africa. Affordable digital macrophotography, which allows close examination and documentation of these small creatures without need for a microscope, has greatly expanded public interest and participation (as *citizen scientists*) in the study of small animals.

Figure 2. Courtship display by an adult male *Phidippus adonis* from Morelos, Mexico. Jumping spiders have large eyes, and faces that we can relate to.

Returning to the wider subject of zoological studies, two more considerations deserve mention here. One is the *national character* of the subject. By the end of the nineteeth century it was clear that Britain was *the* world leader in matters of animal collection, comparative anatomy, classification, and all kinds of studies related to the natural history and distribution of animals. This country and its global empire was able to withstand the devastation of two World Wars in the twentieth century. At the beginning of the twentieth century Germany was clearly the leader in animal studies related to microscopy, physiology and functional anatomy. Prominent zoologists in other nations also played a role, but they were on the periphery of what was largely a bilingual, Anglo-Saxon science. For perspective, we need to realize that the great majority of all people in both Europe and North America worked in agriculture or fisheries, and the rearing of animals was a key component of their livelihood, as it was for many generations of their ancestors. Many still hunted for food. Today this is not the case, and these places are now dominated by urban culture in an urban landscape.

After the second World War, things began to change, but slowly at first. For some years the Russians and the eastern European countries that they dominated were constrained by a phenomenon that we now refer to as *Lysenkoism*. Lysenko (Figure 3.1) was a political biologist who did not accept natural selection, a concept that now lies at the core of biological science. Even worse, he rejected the role of genes in inheritance. Thousands of biologists who rejected his dogma were sent to labor camps or even executed. Even after the second World War, Lysenkoism was viewed as the only correct view in the Soviet Union. Zoology in other European countries like Poland and East Germany also retreated under this dogma, as recently as 1964.

Figure 3. Contemporaries. **1,** Trofim Denisovich Lysenko (1898-1976) of the Russian Empire and Soviet Union, in 1938. **2,** Karl Ritter von Frisch (1886-1982) of Austria-Hungary and West Germany, ca. 1920.

In recent years we have seen a resurgence of Lysenkoism, this time in western universities, with a denial of the role of genetics in the evolution of human behavior. The recent motivation is part of a popular, and intensely political, *tabula rasa* or *blank slate* doctrine that maintains that virtually all human behavior is caused by societal, rather than genetic influences. The effect of this dogma on science has been chilling, and few working zoologists have had the courage (or willingness to sacrifice their livelihood) required to stand up to an onslaught originating with a growing army of administrators, societal reformers, or government agencies. Thus the study of Lysenkoism and its devastating course is of particular relevance to our present situation.

During the post World War Two era, new technologies and a growth of university populations in North America and Western Europe led to the rapid advancement of zoology, as well as many new journals. New fields of study, including *ethology* and *community ecology*, emerged. Along with Nikolaas Tinbergen (1907-1988) and Konrad Lorenz (1903-1989), Karl von Frisch (Figure 3.2) pioneered in their advocacy of a new way to study animal behavior that we now call ethology. What has emerged as a result is a growing awareness that animals, and even small animals like the honey bee (*Apis mellifera*) have far more sophisticated behavior than previously thought possible, a level of sophistication subject to selection, and thus based on real value for the survival and reproduction of these animals. When I started out as a graduate student in 1973, *ethology* was widely recognized as a *modern revolution* in zoology. Another was *quantitative ecology*, or the mathematical modeling of community interactions.

That would change. As mentioned previously, the current revolution in zoology came as a result of gene-sequencing technology developed to support the international Human Genome Project (HGP, 1990-2003). This led to a radical revision of our understanding of the evolution of animals, with the emergence of new fields including *molecular phylogeny* and *evolutionary developmental biology*. In just a few decades, we have developed a much more sophisticated understanding of the many innovations that selection works with to drive the evolution and diversification of species.

There is a second consideration that deserves mention here, and that from the perspective of *pure* (not applied) science or natural history. This is the realm of subjects that we might study in order to understand them, but not necessarily to advance some other cause. In this realm, zoology is one of the humanities, a *liberal art*. One of these subjects can be termed *functional anatomy*, to include the study of physiology and biomechanics. At one time Germany was a leader in this field, as demonstrated by the influential work of the vertebrate anatomist Heinrich Wilhelm Gottfried von Waldeyer-Hartz (Figure 4.1), or the translation of German studies on invertebrate anatomy into English by Libbie Hyman (Figure 4.2), who also published on comparative vertebrate anatomy. Now technology available at universities for the study of functional anatomy is far better than it was in the eighteeth and nineteeth centuries, and these studies should be much more popular, and sophisticated, than they are.

With the rapid onset of machine intelligence (so-called "artificial" intelligence), all of science is going to change. One obvious change will come with our increasing reliance on intelligent machines in theoretical biology. Machine intelligence by itself is already giving us new insights into the nature of intelligence (information processing), and this will most certainly lead to a reappraisal of the nature and mechanisms associated with animal intelligence in general. For example several recent advances in machine intelligence have been based on basic motivational systems that drive learning by self-taught machines, and this has given us a new appreciation for the importance of motivational systems in animal behavior. Can intelligent machines also give us insight into the *hard problem* of biology, the nature of *sentience* (or subjective experience)? Probably, although we may find evidence that sentience is not an emergent phenomenon that arises after the evolution of a complex nervous system, but rather a fundamental feature of the universe.

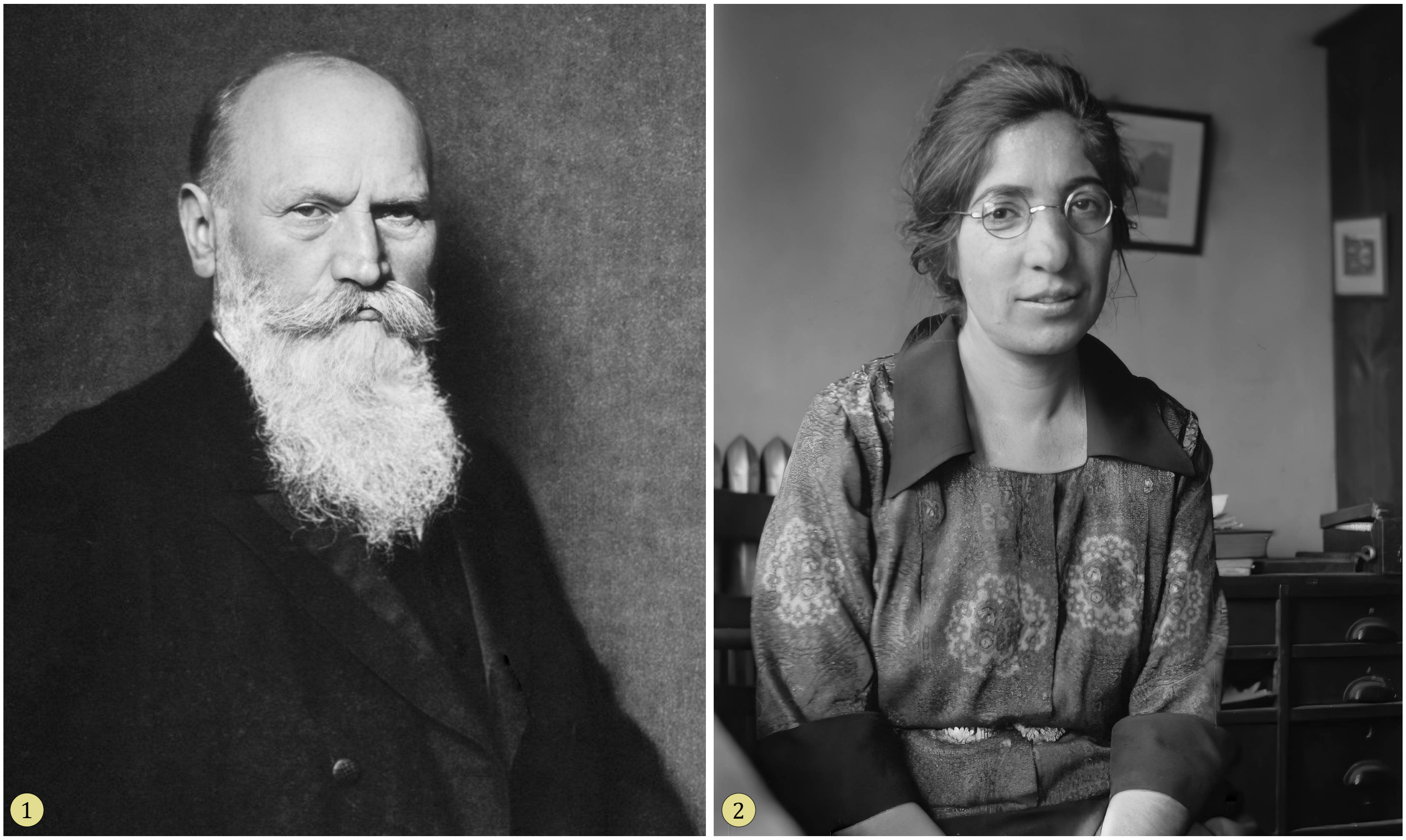

Figure 4. Two pioneers in the study of functional anatomy. **1,** Heinrich Wilhelm Gottfried von Waldeyer-Hartz (1836-1921) of Hehlen an der Weser and Berlin. He introduced the terms *chromosome* and *neuron* to science. **2,** Libbie Henrietta Hyman (1888-1969) of Iowa and New York. Her six-volume *The Invertebrates* is still a classic.

This brings us back to our first question, with a view towards the future: What will zoologists use animals for? The answer will depend largely on what our larger societies use *zoologists* for. Is the academic zoologist an "endangered species"? And, to what extent will our reliance on humans as scientists be replaced by our use of intelligent machines, vastly superior in all of their capabilities? Science is not the only arena now facing these difficult questions. I think that, for human participation in science to continue, we will have to learn how to collaborate with vastly superior machine intelligences, and we will will need to reexamine our "human" values to see how they can be maintained by our rapidly changing institutions. Beyond our own species, all animals have a great deal at stake here.