ANSWERING THE BIGGEST QUESTIONS IN

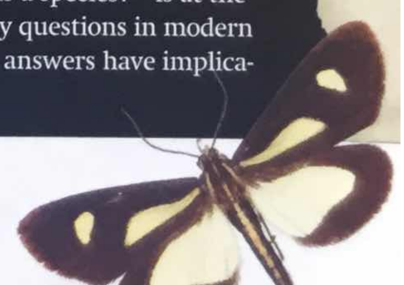
SCIENCE

What Is a Species?

People have long sought to answer some seemingly simple questions about the wealth of plants and animals surrounding us:

- **How do we tell the species apart?**
- **How many species are there?**
- **How can our understanding of species aid conservation efforts?**

One hundred and fifty years ago, Charles Darwin published *The Origin of Species*, his treatise on natural selection as a means of the evolution of new, distinct organisms [see "Origins of a Revolution in Hardcover," page 40]. But what do we mean by "species"? One oft-repeated definition is that members of the same species can mate and have fertile offspring. Sounds simple, but a scientific definition is much more complicated. There are actually many different ways that biologists decide how to define a species, with each technique potentially yielding different results. And yet this niggling question—what is a species?—is at the crux of many questions in modern biology. The answers have implica-

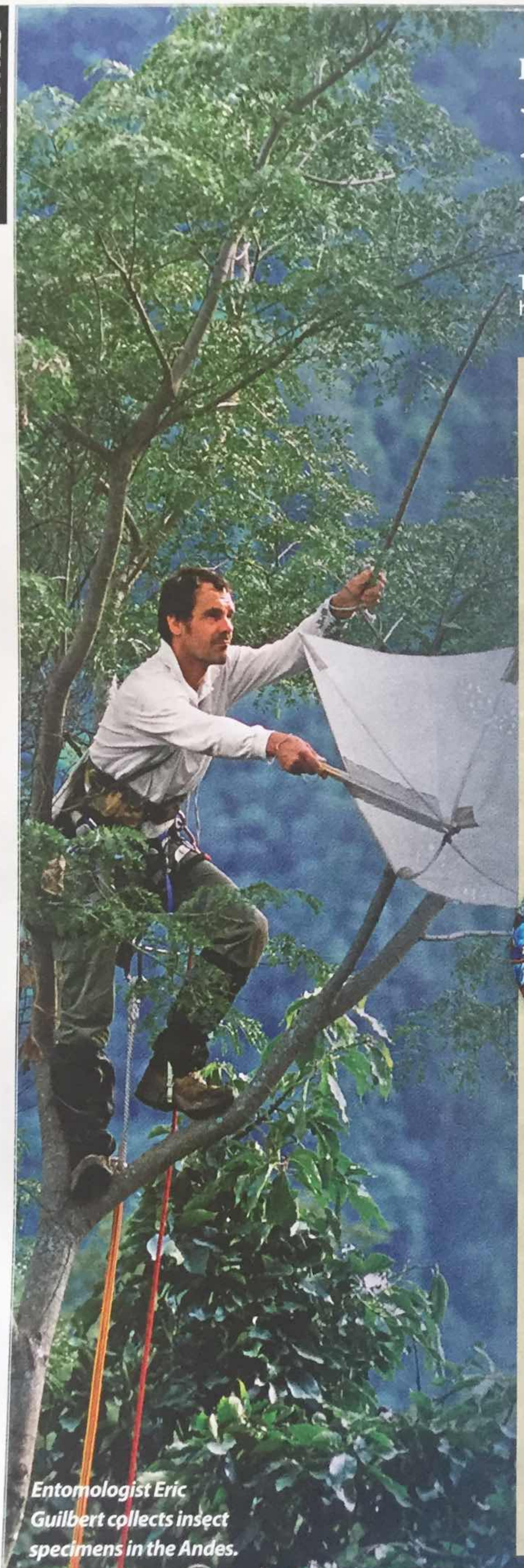


Despite their similar appearances, each of these moths is a different species in the same genus.

Putting the Puzzle Together

Examining Species through the Ages

The ancient Greeks believed that there were around 500 species. Generations of scientists have since added to the number, and today there is talk of as many as 100 million species.



Entomologist Eric Guilbert collects insect specimens in the Andes.

CIRCA 350 B.C. Aristotle, the Greek naturalist and philosopher, carries out the first known attempt to systematize animal species in his *History of Animals*.

A.D. 77 Pliny the Elder, a Roman naturalist and scholar, publishes his *Natural History*, the largest and most comprehensive census of plants and animals of its time, although many of the animals he classified were actually mythological.

1623 The Swiss botanist and physician Gaspard Bauhin develops binomial nomenclature, a taxonomy system in which every organism gets a two-part Latin name.

1735 Carl Linnaeus (left), a Swedish botanist, publishes the first edition of his *Systema Naturae*, introducing a comprehensive taxonomy system that uses binomial nomenclature.

1749–1788 France's Count de Buffon categorizes each plant and animal according to its relationship to man in his 44-volume natural-history lexicon, paving the way for evolutionists like Charles Darwin.

1758 The 10th edition of Linnaeus's *Systema Naturae* is published, listing 4,400 animal species and 7,700 plants. It has since served as the foundation for all modern taxonomic work.

1768–1771 Joseph Banks collects 30,000 plant specimens during James Cook's first expedition to the Pacific Ocean. Among the collection are the shells pictured here, as well as 1,400 new species.

1859 Charles Darwin publishes *The Origin of Species*, in which he suggests that organisms should be classified according to their shared ancestry.

1950 Zoologist Willi Hennig publishes *Basic Principles of a Theory of Phylogenetic Systematics* in German. This seminal work on cladistics goes unnoticed for nearly 20 years.

LATE 1950s The Austrian-American biologist Robert Sokal and the English microbiologist Peter Sneath are the first to apply statistics to the classification of species. Numerical taxonomy is born.

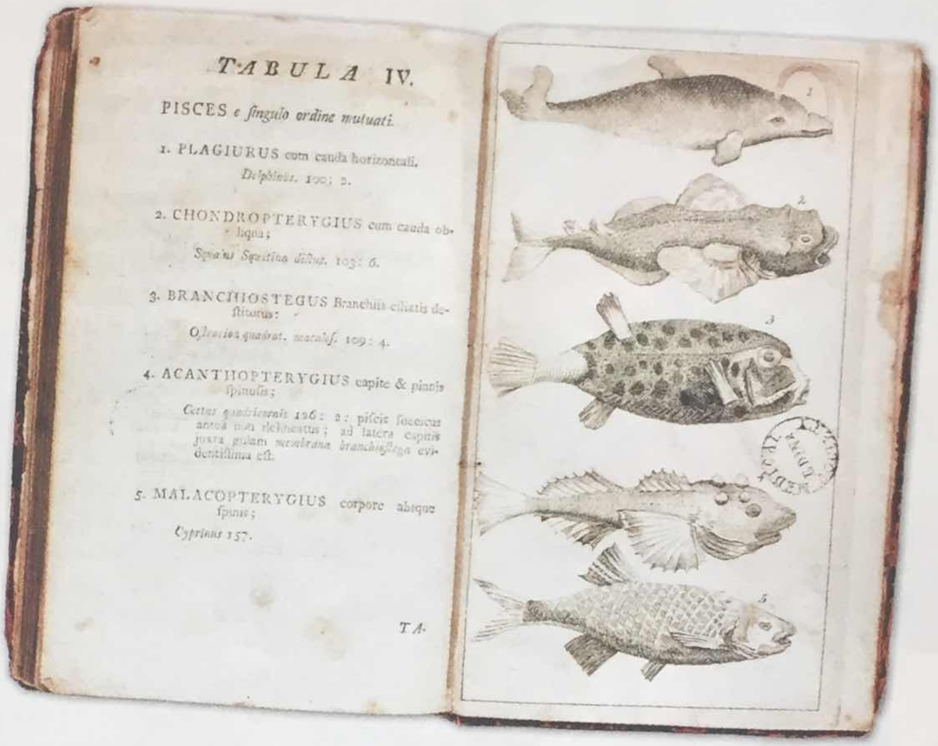
MAIN IMAGE: PHILIPPE PSAILA; FROM TOP: GETTY/ALL OVER; THE ART ARCHIVE: SPL/FOCI; NATURAL HISTORY MUSEUM, LONDON;

tions for biologists, ecologists and conservationists, who seek to understand how a huge variety of species might fit into and help drive an ecosystem.

The Earliest Species

The concept of species has been around for as long as humans have been assessing their surroundings. The earliest known grouping systems, used by ancient cultures like the Babylonians, were practical lists. Animals were divided into such categories as domesticated or wild, edible and inedible; plants were distinguished between edible and poisonous.

Aristotle (384–322 B.C.), the Greek philosopher and natural scientist, was the first to introduce a comprehensive and systematic method for organizing life. He arranged animals in relation to one another, with an emphasis on defining each fundamental kind—what we know as a species. Aristotle based his lists on his observations and his knowledge of the internal anatomy and the behaviors of various animals. He divided them into two groups: animals with blood, which more or less consisted of vertebrates; and animals without blood, which made up the rest. This latter group included cephalopods (squid, octopus and cuttlefish), insects, shellfish, crustaceans and "plant-animals," or organisms he thought looked like plants, such as jellyfish.



Carl Linnaeus's* Systema Naturae *distinguished dolphins from fish and said that a shared environment—water—explained their physical similarities.

Aristotle categorized more than 500 different animal species.

For centuries, these works were the absolute authority in natural science. Aristotle's overview was not significantly expanded until Pliny the Elder (A.D. 23–79), a Roman naturalist, published an enormous lexicon in A.D. 77. In it, he presented in detail all that was known on plant and animals at the time, including such fanciful species as dragons and mermaids, which we now know to be mythological. He devoted the majority of his text to describing uses for various plants and animals—which species were edible, for example, or which had healing properties. This practical approach was later adopted

1966 Willi Hennig's *Phylogenetic Systematics* is published in English and gains popularity within a few years.

1967 Walter Fitch, a chemist, and Emanuel Margoliash, a molecular biologist, build the first molecular evolutionary tree based on the protein cytochrome C.

1977 The American microbiologist Carl Woese identifies a new domain (a taxonomic rank higher than kingdom), archaea, or "ancient" bacteria, using RNA analysis. Previously, scientists believed there were only two domains: eukaryotes (cells with a nucleus) and prokaryotes (cells without a nucleus).

1980s Entomologist Terry Erwin calculates that the number of animal species is as many as 30 million—the first time an estimate is based on field research.

1993 The tree of life is disrupted again by molecular taxonomy: Using RNA analysis, Mitchell Sogin discovers that fungi are more closely related to animals than to plants.

2009 The German biologist Bernd Schierwater, using genetic analysis, suggests that a hypothetical amoeba-like creature called the placula is the ancestor of all animal life, rather than the sponge [see "Hunting the First Animal," page 52].

FROM TOP: CORBIS/POLFOTO; ADRIAN J. TESTA, SMITHSONIAN; iSTOCK

Once believed to be a small species of pelican, the great frigatebird is called **Fregata minor** *in Latin, meaning the "little frigate."*

by others and persisted for 1,700 years, until the Enlightenment.

Order Out of Chaos

The Enlightenment of the 18th century saw a powerful surge in scientific activity in Europe. Expeditions to every corner of the world returned home with thousands of plant and animal specimens. The English naturalist Joseph Banks, on a voyage with the explorer James Cook, brought back 30,000 plant specimens from his first trip to the Pacific Ocean, Australia and New Zealand; 1,400 of them turned out to be species previously unknown to science. That trip alone expanded the number of known plant species by nearly 25 percent.

With so many new plants and animals streaming into museums and universities, it became increasingly important to have a systematic way of naming and classifying them. The same species sometimes received a different name from every scientist who described it, and when researchers communicated across geographic and linguistic barriers, the confusion multiplied.

In an attempt to impose some order on the chaos, the Swedish botanist Carl Linnaeus (1707–1778) invented a system of classification for plants and animals, living and extinct, that is still in use today. Linnaeus borrowed certain elements from an earlier system invented by the Swiss botanist Gaspard Bauhin (1560–1624). Most notably, he married Bauhin's now-familiar system of two-part Latin names with his own intuitive parameters for defining species, which included morphology, or physical traits, and life cycles. Knowing which traits to emphasize and which to ignore was part of Linnaeus's genius. He grouped like specimens, examined and described their characteristics, and then attempted to fit each new species into a hierarchy of related organisms. For example, all flowers that looked like orchids were put into the same group, as were all birds that looked like hawks.

Linnaeus divided organisms into two kingdoms—animal and plants. These divisions are further broken down into phylum, class, order, family, genus and species; the last describes the most basic unit of the system. For example, humans are part of the animal kingdom, Animalia, under the phylum Chordata, which includes vertebrates. Next comes the class Mammalia, or mammals, the order of primates and the family hominids. Each organism is given a Latin or Greek name based on its genus and species. In the case of humans, *Homo* (our genus) *sapiens* (our species). This system has been updated in the past 40 years to include a new taxonomic rank, called a domain, which is higher than kingdom. The rest of the taxonomic ranks have remained the same.

As more scientists adopted this system of nomenclature, the description of new species gradually developed a rigorous framework governing which traits to consider and which to ignore. The first edition of Linnaeus's *Systema Naturae* was published in 1735. Its 10th edition, released in 1758, contained 4,400 animal species and 7,700 plants. The system has expanded to include 350,000 plants and more than a million animals.

The more pieces we have in the puzzle of life, the better we're able to look back in time and see how life developed on the planet.

The Modern View of a Species

As scientific techniques become more refined, our understanding of "species" becomes increasingly muddy. In Linnaeus's time, only the morphology—shape and structure—of the organism was considered. After Darwin some scientists began to try to classify organisms according to how they evolved from one another, rather than just how they looked. That led to a revision of many of Linnaeus's groups, as well as to new and more-complex ideas about what a species is. In fact, there is still no universally accepted definition of what constitutes a species. Instead there are more than 20 different working definitions, called "species concepts." For instance, the German-American biologist Ernst Mayr formalized the so-called biological species concept, by which two organisms' ability to produce fertile offspring classifies them as one species. But even this classic hypothesis has its critics and is notoriously difficult to

M. WATSON/ARDEA/ALL OVER

test in the laboratory. Some, like those used by traditional taxonomists, take only morphology into account. Others compare the structural similarities of different cellular components, like ribosomes, the machinery responsible for protein synthesis. Still others compare DNA sequences and look for similarities. Scientists often rely on a combination of these methods to decide if an organism is a new species.

One of the most controversial species concepts—and ironically, the one most rooted in pure science rather than intuition—does away with subjective appearance-based groupings altogether. This so-called cladistic approach relies only on evolutionary information, such as DNA analyses and fossil records.

This leads to some surprising outcomes. One unfortunate side effect of this rigid definition is that the grouping we call "fish" ceases to exist,

Mermaids, Sea Serpents and Kraken, Oh My!

Early taxonomists filled the medieval bestiary with fanciful creatures

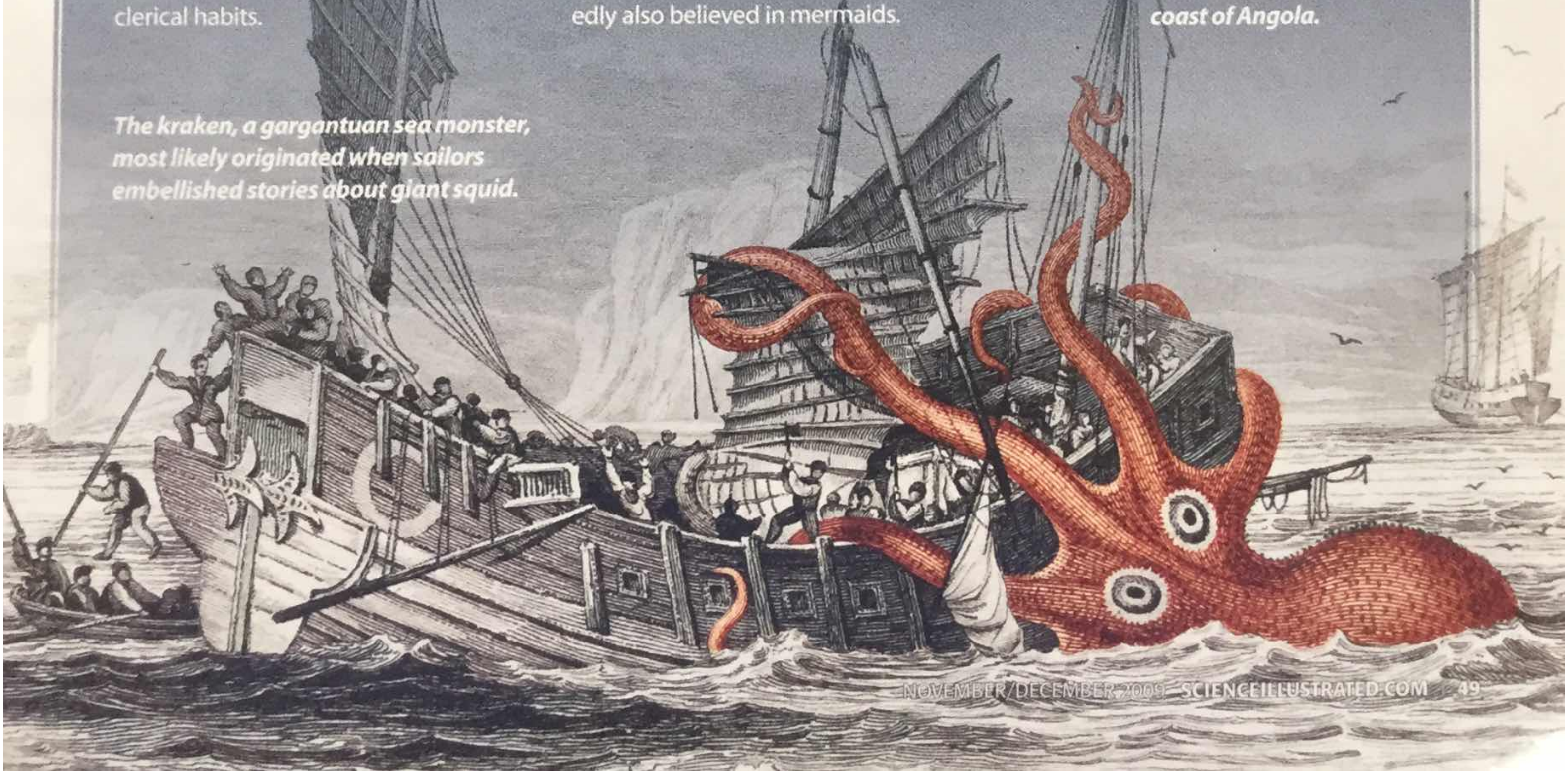
The difference between science and fantasy was, for many centuries, less obvious than it is today. Researchers who depended on reports from voyagers ended up naming mythical species such as unicorns and griffins. The Middle Ages saw detailed reports on the ecology, distribution and anatomy of unicorns and the feeding habits of the roc, an elephant-eating giant bird with a wingspan of 90 feet.

Many people also believed that each terrestrial species had a marine counterpart. Scholars not only described several types of mermaids—a hybrid of human and fish—but also so-called sea monks and sea bishops, marine creatures supposedly clad in clerical habits.

The Enlightenment did not stem the tide of mythical species. In 1755, Bishop Erik Ludvigsen Pontoppidan wrote a book on Norway's natural history and included a long list of sea serpents and monsters that lived off the Norwegian coast. He also produced a detailed description of the many-tentacled kraken, the largest monster in the world. The kraken was probably a vastly exaggerated description of a giant squid.

Carl Linnaeus, the father of modern taxonomy, was an eager participant in filling the fanciful bestiary. *Homo ferus*, the "wild man," and *Homo caudatus*, or "tailed man," were among the unusual human varieties to which he devoted scientific descriptions, and he reportedly also believed in mermaids.

In 1714, sailors claimed to have seen mermaids off the coast of Angola.



The kraken, a gargantuan sea monster, most likely originated when sailors embellished stories about giant squid.

because DNA analysis suggests that many fish are actually more closely related to land mammals than to their fellow water-dwellers. Many taxonomists (and laypersons) balk at discarding our deeply entrenched, albeit subjective, experience when attempting to classify organisms. What's worse, the Endangered Species Act, the legislation used to protect threatened plants and animals, is based on the morphological definition of a species. A widespread movement toward using only the cladistic model would mean a rewriting of the law—a costly and time-consuming process.

High-Stakes Numbers Game

Cataloging every species on the planet is a never-ending quest. The more we look for species, the more we find. In the second half of the 20th century, scientists' best estimate for the number of different species was around a million—at least three quarters of which were insects. But during the mid-1970s, the American entomologist Terry Erwin carried out unusual experiments in Panama's tropical forests; his results suggested that a million might be just the tip of the species iceberg.

For one year, Erwin collected insects from 19 trees from one small area during different seasons. Each tree provided 1,200 species of beetle.

Many of these species were, of course, new, but the most important result of the work was the enormous variation of species within such a small sample area. Also significant was Erwin's methodology. This was the first time the number of species was based on field research. Erwin multiplied the number of insect species per tree by the estimated total number of tree species found in the tropical forests. According to his calculation, the number of species on Earth must be at least twice as large as those we know. He later increased his estimate to 30 million. His more recent work suggests that there might be 40 million species of insects in the Amazon River basin alone. "Every single species has its own evolutionary history," Erwin says, "and the more pieces we have in the puzzle of life, the better we're able to look back in time and see how life developed on the planet."

Knowing which species, and how many of each, exist in a given environment is also key to understanding the ecosystem and to assessing how human activities might be affecting it. If scientists underestimate the diversity of a threatened coral reef, say, or a disappearing rainforest, it may be impossible to identify the keystone species whose conservation could preserve the whole ecosystem. There's another payoff, too. Understanding the rich diversity of life on the planet—and how groups of species relate to one another—will help us understand our own complex evolutionary history. ■

Some animals have received fanciful names from the scientists who described them. For example, this dinosaur,* Dracorex hogwartsia, *is named after a character and the school in the Harry Potter books.

Knowledge Aids Threatened Species

PERSPECTIVES

With computers and the Internet, it has become easier to gain an overview of groups of animals. Scientific organizations devoted to more or less every different group of plants and animals attempt to keep complete lists of their own chosen organisms. And global initiatives such as the Web-based Species2000 (*sp2000.org*) and the Encyclopedia of Life (*eol.org*) collect smaller species lists from universities and museums around the globe to get the bigger picture. Many individual compilations use different methods of classification, however, which complicates the amalgamated version.

The efforts are ultimately helpful: Once we have a working list of species, we can see if the various assemblages of species found in a given locale are changing, and if the environment, climate or other conditions may be changing there as well. Without this basic data, it is hard to preserve animals, protect environments, and evaluate areas to see if they can be used for mineral extraction or lumbering or similar development.

There are at least five species of kiwis in New Zealand—many of them in acute need of protection.

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