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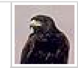

Why Should We Care about Species?

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The questions "What are species?" and "How do we identify species?" are difficult to answer, and have led to debate and disagreement among biologists. See how consensus on answers to these questions can steer global, political, and financial pressures that affect conservation efforts.

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Most people have a basic idea of what species are, even if they are not sure of the best way to define the word species. Quite simply, species are kinds, or types, of organisms. For example, humans all belong to one species (the scientific name of our species is *Homo sapiens*), and we differ from other species, such as gorillas or dogs or dandelions. But defining, identifying, and distinguishing between species really isn't that simple. In fact, it is often a complex and difficult process-especially in cases of new or previously unknown species. Biologists frequently disagree about species, and even argue over how best to define the word species. This disagreement is so well known, and so much discussed, that it is sometimes referred to by biologists as the "species problem" (Hey 2001).

This article explores the idea of species, including both the meaning of the word species, and how biologists think species can be identified in nature. It also examines why an understanding of species is important, both for the study of biology and for our society.

Why Are Species So Confusing?

The central difficulty when studying species is that, even though all species are kinds of organisms, all kinds of organisms are not species. For example, birds are a kind of organism, but birds are not a species --there are many thousands of species of birds. For scientific purposes, it is not enough to identify a kind of organism. As a biologist you must also determine what level or rank of kind to assign to an organism. If you discover a new kind of organism then you must decide if it should be called a new species, or if it falls within an already described species. For example, the common chimpanzee species, *Pan troglodytes*, appears to include several slightly different kinds of chimpanzees. Each of these have been given the rank of sub-species. Alternatively, a newly discovered kind of organism might be so different from other known species that it receives not only a designation as a new species but also a ranking as a new genus.

To help understand the confusion and uncertainty over species, let's look at the most basic idea of Darwin's theory of evolution by natural selection. Darwin figured out a process by which species could change over time, and he believed that evolution was a slow and gradual process that played out over eons of time. So if species are changing slowly, and if new species are formed at the slow pace of evolution, then we absolutely expect there to be cases where we struggle to decide whether two kinds of organisms should be grouped as separate species or as a single species. In his book, On the *Origin of Species*, Darwin famously wrote, "I was much struck how entirely vague and arbitrary is the distinction between species and varieties." (Darwin 1859). In other words, Darwin did not believe that there was a definite point at which a species came into existence. Finally, because the large majority of species come into existence gradually, it is not surprising that we have difficulty deciding when to identify new species or what the best way to do so should be.

What Is a Species? How Do We Know a Species When We Find One?

Imagine you're a biologist on a research expedition to look for previously undiscovered kinds of butterflies. If you find some butterflies that seem different from those species that are already known (Figure 1), then you are faced with two questions. The first question is "what are species?", or to put it another way, "what makes a kind of butterfly an actual species of butterfly, rather than a sub-species or a genus?" The second question is "how should a species be detected?" The answer to this second question depends on the answer to the first question (i.e. "what are species?") but the two questions are not the same.

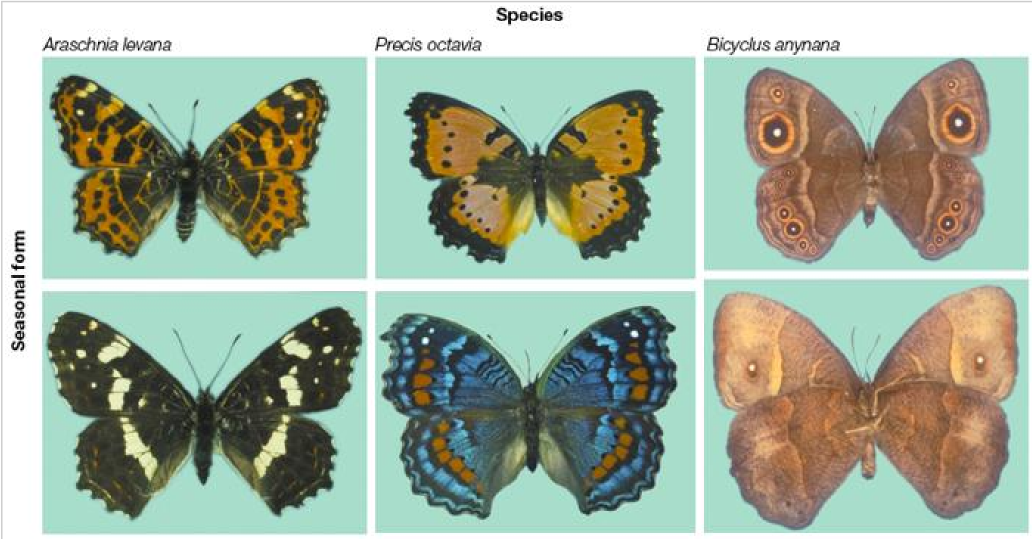

Figure 1: Variation within species

Within the same species, individual organisms can look very different. For all three species of butterflies, wing color and pattern varies depending on the season during which they were born. The butterflies at the top were born under different temperature and light conditions than the ones at the bottom.

A. levana and *P. octavia* photos courtesy of Fred Nijhout, Duke University, North Carolina, USA. *B. anynana* photos courtesy of Dr. Paul Brakefield.

Figure Detail

This business of having separate "what" and "how" questions about species is part of the confusion around species (de Queiroz 2005). In the past most biologists thought that knowing what species are (i.e., having an answer to the "what" question) was basically the same as knowing how to discover species (i.e., having an answer to the "how" question). The two questions are closely connected, but they are not really the same thing. For example, biologists might have a theoretical idea of what species are as well as a practical procedure for identifying species. The theoretical idea addresses the "what" question, while the practical procedure addresses the "how" question. It is possible that different scientists share the same theoretical idea about species, but actually rely upon different practical procedures for identifying them. The situation is similar to what a physicist faces when trying to detect unseen particles. The physicist may know what an electron is, but that is not the same as knowing how to detect an electron. The theoretical idea of the electron, when it is put into practical applications, has yielded multiple ways to detect electrons. In the same way there are multiple ways to detect species, and some may be better than others depending on circumstances.

Two Classic Viewpoints on What Constitutes a Species

Biologists struggled with questions on species identification even before Darwin introduced his theory of evolution by natural selection. Then, when Darwin showed how species change over time, species-related questions became even more difficult. In the mid-1900s the leading evolutionary biologists, Ernst Mayr and George G. Simpson, contributed two key ideas about the basic nature of species.

Ernst Mayr: Members of a Species Share Reproduction

In 1942 the famous biologist, Ernst Mayr claimed that what makes species different from sub-species and genera is that the organisms within a species can reproduce (i.e., produce fertile offspring) with one another, and that they cannot reproduce with organisms of other species (Mayr 1942). Mayr believed that individuals of the same species recognize each other as potential mates and are able to produce fertile offspring, but individuals of different species will either not attempt to reproduce with one another, or if they try they will not produce fertile offspring. The effect of this reproductive barrier is that different species do not exchange genes with each other and therefore evolve separately from each other. Mayr was not the first to state that this property of shared reproduction within species (and lack of reproduction between species) is what makes species different from genera and sub-species. But more than other biologists, Mayr emphasized using reproduction as the basis of species identification (see below); and more than most biologists before him, Mayr placed a strong emphasis on reproductive separation between species.

Did Mayr get it right? Is sexual reproduction the true essence of species? One significant problem with Mayr's idea is that some organisms, like bacteria and some eukaryotes, do not engage in sexual reproduction. For these organisms Mayr's ideas simply do not apply. But *kinds* of non-sexual organisms do exist, and biologists have divided them into a wide variety of different types or species, such as the thousands of species of bacteria that have been described. In these cases Mayr's idea that sexual reproduction defines species clearly is not appropriate. But for sexual organisms, such as most animals, plants, fungi and protists, Mayr's idea has been very useful.

George G. Simpson: Members of a Species Share an Evolutionary Process

Another idea was articulated by George G. Simpson. He said that something even more fundamental about species than Mayr's idea of shared reproduction is at work; that the members of a species have shared in an evolutionary process and an evolutionary history (Simpson 1951). Simpson's key idea is that a species is an evolutionary lineage that has evolved separately from other species. In other words, the organisms within a species all share in the processes of evolution. The processes of evolution, including genetic drift, migration and adaptation, cause there to be a *thing*, an entity made up of organisms evolving in concert and that collectively form a species (Templeton 1989).

Importantly, this property of evolving together does not apply to kinds of organisms above the species level. For example, birds are not evolving all together. There are many separate species of birds, each of which is on its own evolutionary path. The same goes for mammals and plants, and indeed for any inclusive kind of organism that includes multiple species. One nice point about the general idea of a species as an evolving unit is that it fits those organisms - such as many bacteria and some eukaryotes - that do not engage in sexual reproduction.

Mayr's and Simpson's Ideas Today

For the most part, biologists agree that species are made up of organisms that are evolving together. And they also agree that for sexual organisms, shared reproduction within species and the evolution of reproductive barriers between species, are major factors that cause species to exist. Where biologists tend to disagree is how these general theoretical ideas should translate into methods for detecting and identifying species. In other words, biologists agree that these ideas help us answer the question of *what* species are, but they are not in agreement about how much these ideas help answer the question of *how* to identify species.

Identifying Species with the Biological Species Concept

For Ernst Mayr the answer to the question of how species are identified also boiled down to reproduction. In other words, Mayr was using the idea of reproductive separation of species to answer both the "what" and the "how" questions about identifying species (Mayr 1957). To Mayr, the key to identifying species is determining whether there is shared reproduction within a population of organisms and whether there are barriers to reproduction with other organism. Mayr called this idea of defining species on the basis of reproduction the Biological Species *Concept*, or BSC.

The BSC has been very widely discussed and debated, and many biologists think that Mayr is essentially correct about what species are and how they should be identified. For example, while the western meadowlark and eastern Meadowlark of the U.S. (Figure 2) are very similar in appearance and have overlapping geographic ranges, their distinctly different songs prevent them from interbreeding. Under BSC rules they are classified as two different species. In this case, using the BSC to decide whether you have one or more than one species is very straightforward. However, in many BSC cases, the decision is not straightforward at all. This is particularly true if you're trying to determine whether two separate populations in different geographic locations belong to the same species. When geographical separation is involved, the individuals in the different populations have no chance to reproduce with each other. If the populations cannot interact under natural conditions you cannot know for certain if they would reproduce. Artificial conditions such as zoos and laboratories are not a valid way to determine whether individuals will reproduce in the wild, since members of a wide variety of species will reproduce with those of other species in a zoo, but not in their natural habitat.

Figure 2: Western meadowlark and eastern meadowlark: two distinct species

Even though they look alike and have overlapping ranges, the western meadowlark, *Sturnella magna* (left), and the eastern meadowlark, *Sternella neglecta* (right), have distinctly different songs. As a result, they do not interbreed and are classified as separate species.

The Phylogenetic Species Concept Is an Alternate Approach

Because of the limitations of using the BSC to make decisions about species, many biologists have proposed other ways to identify species. One popular approach is called the Phylogenetic Species Concept, or the PSC (Rosen 1979; Cracraft 1983; Donoghue 1985). There are actually several versions of the PSC, but they all agree that species can be identified on the basis of shared traits. A group of organisms that all share one or more features pointing to a unique common ancestor, which in turn is not shared by members of other species, would meet the criterion of species under the PSC. The traits used under the PSC are wide ranging and include color or shape, or behavior. For example, species of plants could be distinguished on the basis of the color and shape of their flowers.

Using traits under the *Phylogenetic Species Concept* is a very different way of identifying species than using shared reproduction under the *Biological Species Concept*. But like the BSC, using the PSC accurately can still be challenging. Consider a group of organisms that all appear to be in the same population (e.g., maybe they are interbreeding with one another) and yet some individuals in that population are of a different color than the others. When we find different distinct organismal types within the same population, and those types are not uncommon, it is called a polymorphism. Yet under the PSC polymorphism might be interpreted as the presence of multiple species.

The Importance of Understanding Species

Decisions about species and uncertainty about identifying species are not just issues for scientists. Everybody needs to be able to think about and talk about kinds of organisms. A fisherman, a hunter, a birdwatcher, a gardener, or even a person in the grocery store who shops for fruits and vegetables, is depending on being able to distinguish among kinds of organisms. So too must doctors and other medical professionals be able to identify different kinds of parasites, including bacteria and viruses; and farmers must be able to tell the difference between crop plants and weeds.

It is in the preservation of endangered species that many people are most likely to feel the impact of species questions. Many organisms of many kinds are affected by the societies and economies of human populations, often for the worse. For legal, ethical and economic reasons it is a big, and sometimes difficult, decision to conclude that a species is endangered. This is because in the United States, a species with endangered status receives protection that often affects the lives of the people in areas where protected species live.

Consider the case of the North Pacific Right Whale, which not very long ago was recognized as a distinct species based on genetic evidence and the Phylogenetic Species Concept (Rosenbaum et al., 2000). The genetic data--including mitochondrial DNA sequences--indicated that the North Pacific Right Whale has not been exchanging genes with other populations for a very long time. Because this whale population is so small, its new species status meant that the Endangered Species Act could be invoked. In 2008 the species was officially listed as endangered (Federal Register, 2008). However, there are thought to be only a few hundred of these whales still living and little has yet been done to protect their habitat. Habitat protection has wide-ranging governmental and political repercussions, including limits on shipping, fishing and oil-drilling activities in a part of the northern Pacific Ocean. In other words, it could be expensive to save the North Pacific Right Whale. Yet saving the Right Whale is important for ocean ecology, and thus for the thousands of other species that share the food web of the Pacific Ocean with the Right Whale. Saving the Right Whale is also important for strengthening peoples' connections to the beauty and wonder of the world's oceans and the life they contain.

Summary

Understanding species of organisms requires that we have insight into the the evolutionary processes that cause biological diversity, and that we develop practical methods for species identification. "What are species?" and "How do we identify species?" are difficult questions to answer, and have lead to much debate and disagreements among biologists. One prominent debate centers on whether shared reproduction-under the Biological Species Concept-is a more useful criterion for identifying species than shared features of organisms-under the Phylogenetic Species Concept. An understanding of what species are and how to identify them is critical, both for biologists and for the general public. Biological diversity is being lost as species go extinct, and it is only by understanding species that we can shape the social, political, and financial forces that affect conservation efforts.

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