Trying to pin down some fundamental concepts in biology

The Devil's in the Definitions

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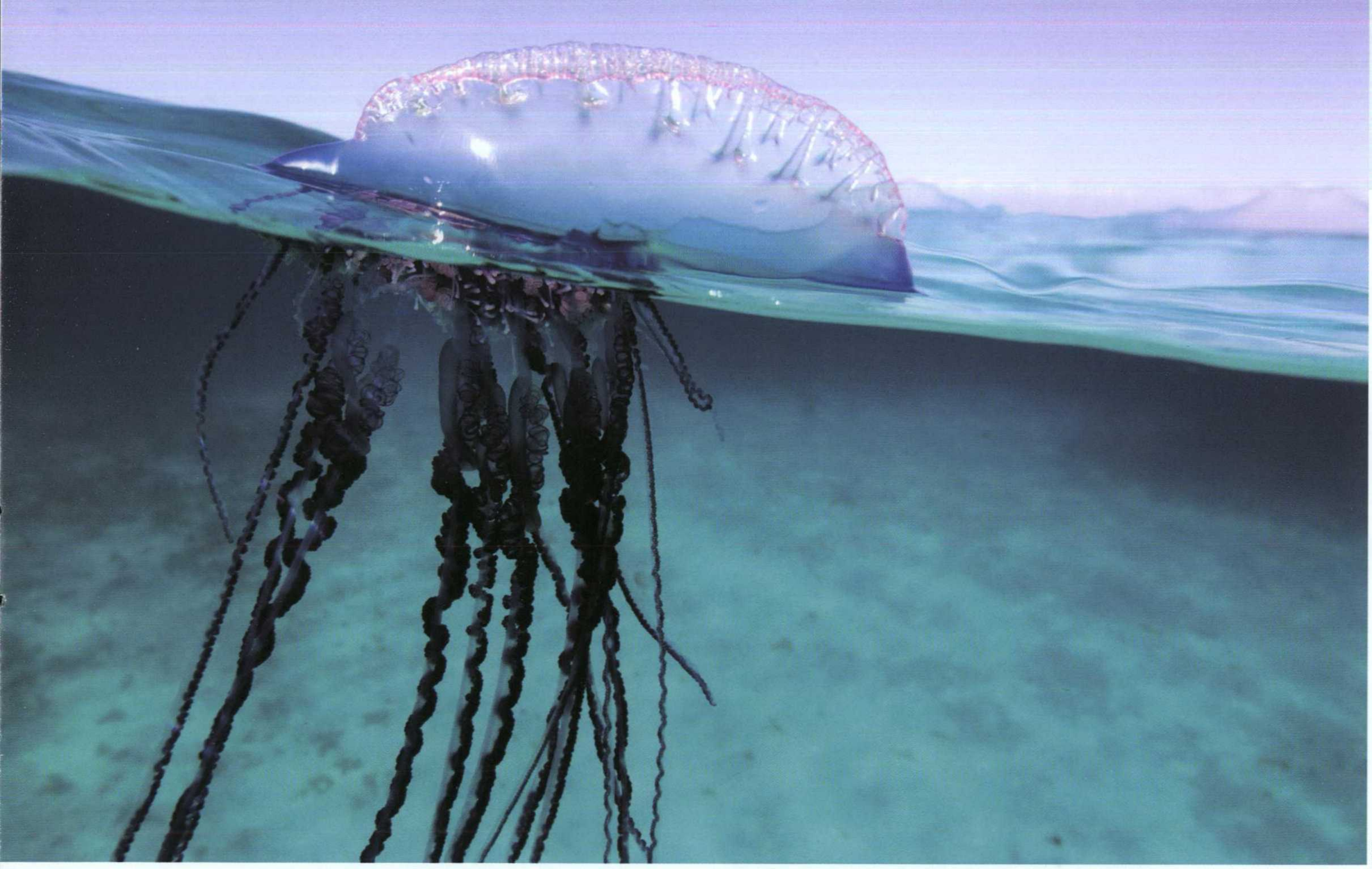
Every scientific field is centered around a few core concepts, serving as the foundation for the formulation of basic laws and scientific theories. In biology, these include such concepts as "individual" and "species" - which may seem simple, but only deceptively so

A leading encyclopedia of biology in Poland, *Encyklopedia Biologiczna*, compiled by Profs. Czesław Jura and Halina Krzanowska in 1999, defines an individual as "a living organism, distinct from others in terms of structure and function, forming a part of a population of other organisms of the same species." This definition is based on three criteria: structure - "distinct from others in terms of structure," function - "distinct from others in terms of function," and belonging to a particular group - "forming a part of a population of other organisms of the same species." We will proceed to analyze these criteria below and try to assess how they can be best applied.

The eminent Polish biologist Józef Nusbaum-Hilarowicz wrote at the turn of the 20th century, "In nature, we see an extraordinary diversity of organic forms which we call individuals. These individuals are something real existing in nature..." It is certainly true that life on Earth exists as distinct organisms, able to function independently to varying degrees. Each one is a discrete biological unit, regardless of whether it comprises a single or just a few cells or has a highly complex structure with a high degree of internal differentiation. If we assume that an individual is a distinct entity, it should follow that we can separate it from others, move it from place to place, measure and weigh it, describe its appearance, and so on. But is this always the case? Biologists' lives would be far too straightforward if we could give a simple "yes" answer.

The kingdoms of plants and animals include structures comprising multiple organisms in which individual, distinct forms perform all living functions of an individual organism. However, the problem is that in fact they are built of many interconnected individuals. One example can be found in siphonophores - marine animals from the Hydrozoa order which exist as colonies composed of many individuals. The individuals perform different functions (reproduction, feeding, defense, etc.) and as such they are structured accordingly. More to the point, they would not be able to function independently. This begs the question: should siphonophore colonies, which are physiological and functional wholes, be treated as a single organism, or perhaps something structurally different, something that is an aggregation of separate individuals?

The situation is even less clear-cut in plants, in particular those that reproduce vegetatively; in their cases it is extremely difficult to define what an individual "specimen" is. The colony (known as a genet) is a group of genetically identical individuals (known as ramets) originating from a single plant and forming a single modular organism. Individual ramets have their own root systems and stems above ground; when they are separated from the rest of the genet, they can continue growing independently and give rise to new genets. The structures can be extensive, and some species form enormous aggregates with vast numbers of ramets. There exist entire forests numbering hundreds of trees which are in fact a single genet.



A Portuguese man o' war, *Physalia physalis*. Its "body" is actually a colony made up of minute interconnected individuals, each specialized to play specific role

Clonal colonies are formed by asexual/vegetative reproduction, for example by budding (as in siphonophores) or by rhizomes (as in plants). Perhaps, then, individuals should be defined not according to having a distinct structure ("structural individual") but a distinct genetic makeup ("genetic individual")? In the latter case, individuals would be structures that are genetically distinct from other similar structures. However, we immediately encounter problems here, too: how would we define monozygotic twins, who are after all genetically identical? The definition would classify them as a single structurally "duplicated" individual. And that would surely not go down well with twins!

Let's leave the genetic criterion aside and return to the structural definition to ask whether clonal colonies, which we want to describe as individuals, must comprise "individuals" representing the same species. The first obvious answer is yes, since surely we can't have an "individual" that is made up of representatives of different species. And yet biology turns out to be more complex again: lichens are composite organisms that arise from algae or cyanobacteria living symbiotically with fungi. Contemporary science does not list lichens as a distinct taxonomic rank, although there is no doubt that lichens form distinct colonies of organisms of different species, which in morphological terms could be described as structural individuals.

What is a species?

The definition of individuals described above invokes the concept of a "species," as represented by the individual. The two concepts are closely interrelated, and it seems impossible to define one without referring to the other.

The concept of species is fundamental to biology; Charles Darwin focused on it in his seminal work "*On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life.*" However, the term is not all that clear-cut, and in fact it is even more difficult to define than that of "individual." The literature offers many definitions, the most important of which are based on morphological, genetic and evolutionary criteria.

Morphology is perhaps the oldest way of describing species, dating back to long before biology was formally defined as a discipline. It is the simplest definition, and it states that a morphological species is a group of individuals similar to one another and distinct from other groups. However, this intuitive definition frequently fails in practice. To start with, which morphological traits should we use? Do we include morphological traits only, or do we also look at elements of biology (reproduction, development, feeding, behavior, etc.)? The next problem concerns variation within the species - individual, geographical, seasonal, or developmental. In fact, variation between individuals of the same species is so widespread that species with particularly high variation are described as polytypic. So if individuals representing the same species do not have to resemble one another, what degree of variation do we allow? The answer is based on an in-depth understanding of their biology, although different developmental stages have sometimes been mistakenly described as distinct species, given their variation in terms of morphology, physiology, feeding and living environment.

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The greenish warbler (*Phylloscopus trochiloides*) and its distribution around the Himalayas. The colors denote individual subspecies: yellow - *P.t. trochiloides*, orange - *P.t. obscuratus*, red - *P.t. plumbeitarsus*, green - *P.t. ludlowi*, blue - *P.t. viridanus*

And that is not the only problem when it comes to defining what a species is. There are also opposite cases in which individuals representing different species are nearly identical in appearance. These are known as cryptic species, and they occur in a range of different organisms, mainly invertebrates. In spite of their similarities, cryptic species cannot interbreed. This has led to the introduction of the genetic criterion, according to which individuals of a single species must be able to breed.

The genetic (or biological) notion of species was proposed by the evolutionary biologist Ernst Mayr (1904-2005), who defined species as "groups of interbreeding natural populations that are reproductively isolated from other such groups." Species form reproductive populations with separate gene pools for different populations. The criterion seems to be significantly more accurate than the morphological definition, and it makes a reference to a species' evolutionary community. And yet this definition also fails in practice. The first limitation is that it cannot be used to describe agamic species, which only reproduce asexually. Even in organisms that reproduce sexually, free cross-breeding of individuals within the gene pool can be difficult or impossible, as is the case in isolated local populations. Additionally, gene pools are dynamic and subject to constant change due to natural selection, therefore the genetic definition means it can be difficult to mark out boundaries between species. Mayr himself noted this when he described the variation and distribution of the greenish warbler (*Phylloscopus trochiloides*) - a small bird widespread in northeastern Europe and central and northern Asia, including the Himalayan foothills. Individual populations, described as subspecies, have been expanding their range to create a ring around the Himalayas. Within the ring, individuals from the first subspecies breed with their neighbors from the next population along and so on until the last subspecies meets the first population again. And here is when something odd happens: the first and last subspecies cannot interbreed, so according to the genetic definition they should be regarded as separate species. However, they do interbreed indirectly, via individuals from the intermediate local populations, raising the question of where we draw the boundaries around species.

The example shows how differences within a single species lead to speciation - the formation of new species. It also shows how difficult it is to impose a rigid framework on biological diversity, and how the genetic definition of species can lead us astray. This led to the formulation of the evolutionary notion of species, defined by the American biologist Prof. Edward O. Wiley as "a lineage of ancestral descendant populations which maintains its identity from other such lineages and which has its own evolutionary tendencies and historical fate."

Here, too, we encounter problems with the definition itself. During evolution, individual species undergo constant change, leading to the extinction of some species and the formation of others. When a new species arises from an existing one, leading to an increased number of species, we describe the process as adaptive radiation, although phyletic speciation is also possible, with one species evolving into another. During both processes, in the endless line of ancestors and descendants there comes a point when a new species "emerges from" another. Yet speciation processes are fluid in that regardless of the rate at which they occur, evolution of new traits never happens all at once. This raises the question: how do we pinpoint the precise moment when a new species arises during speciation? Is this even possible, and if so, should we use one of the criteria listed above, bearing in mind their imperfections?

A conundrum for biologists

Readers who are still with us may well ask themselves why formulating basic definitions is so problematic in biology when it appears far more straightforward in other scientific disciplines. This is due to the vast diversity found in nature and the extraordinary abundance of living organisms and their ongoing changeability. We're incredibly proud of humankind's scientific achievements that have allowed us to land on the Moon, send probes to the far reaches of our solar system and elucidate the genomes of many species including our own. And yet we are still struggling to answer the seemingly simple question of how many species currently live on our planet, or even give a precise definition of what we mean by a species. The estimates given by different authors are so divergent that none of them can be taken as reliable. The numbers have been estimated as falling somewhere between 4 and 30 million, with some authors claiming they may be as high as 100 million! What we do know is that so far we have catalogued only around 1,350,000 species, and biologists are in agreement that this is only a small part of the Earth's extraordinary diversity. This gives us an idea about how much more we have to learn about our planet. ■

Further reading:

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The yellow archangel (*Lamium galeobdolon*) forms polycorms (plant structures encompassing multiple stolons and roots)