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Species concept and speciation



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ABSTRACT

Defining and recognizing a species has been a controversial issue for a long time. To determine the variation and the limitation between species, many concepts have been proposed. When a taxonomist study a particular taxa, he/she must adopted a species concept and provide a species limitation to define this taxa. In this paper some of species concepts are discussed starting from the typological species concepts to the phylogenetic concept. Positive and negative aspects of these concepts are represented in addition to their application.

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1. Introduction

Since the early ages of the living world man has been using classification in his normal life. Having used plants for different purposes, he divided them to edible, medicinal, fuel and etc. The plant kingdom as other living kingdoms has a hierarchy structure ends mostly with species rank. The term “species” has been undefined precisely for more than three centuries. It has different meanings for different botanists including both systematist and taxonomist. Species are one of the basic units to compare in almost all fields of biology, from anatomy to behavior, development, ecology, evolution, genetics, molecular biology, paleontology, physiology, and systematics. Largely, the importance of species stems from its significance in systematics, which is a science all the branches of biology rely on (de Queiroz, 2005). A main issue in the field of Biological systematics is developing a theory to lead the taxonomic practices in building a persistent biological classification (Velasco, 2008). In addition, taxonomic and systematic literature are always referring to issues about species such as, speciation models, whether species even exist in nature is taxonomy, and delimitation of species which usually involve species concept. Species concepts do not only define what a species is,

but by defining what a species is, they also clarify what speciation is. Therefore, research programs result on speciation with concentrating on conditions and factors are relying on species concept. Moreover, many biological studies depend on delimitation of species. For instance, ecological and behavioral studies may examine the collaboration between species, including the interaction between species abundance with biotic and abiotic factors. Most works in conservation biology emphasize on species. Even in legislation, species is one of the most used biological units, not only in conservation and biology but also in agricultural and medical disputes. Therefore, a precise clear definition of the term “species” is needed for a larger spectators than just the academic biologists (Hausdorf, 2011). For a better understanding of the development of species concept, the history of major ones will be overviewed in the first section of this paper. Then, some of the modern species concepts will be discussed. Finally, a conclusion of the application of these concepts will be addressed.

2. History of defining the term “species

The earliest systematist to achieve a species definition was the English scholar John Ray (1627–1705). In his major work *Historia Plantarum* (Ray, 1686) he stated: “No matter what variations occur in the individuals or the species, if they spring from the seed of one and the same plant, they are accidental variations and not such as distinguish a species permanently; one species never springs from the seed of another nor vice versa”. Therefore, Roy attempt to define species as groups of plant truly breed within their limits of variation.

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Linnaeus (1707–1778), nearly 50 years later whose work was the most eminent and momentous in the taxonomy field, adopting a broader concept gave a new definition of species. In his work *Species Plantarum* (Linnaeus, 1753), using mainly the floral structure and sexual characters, Linnaeus described briefly and systematically approximately 5900 species of plants known to man then. So, he used a sexual system “natural system” for defining species. Linnaeus concept was simple, applicable and was accepted widely.

Both Ray and Linnaeus approaches in defining species were typological; they believed that under natural intraspecific variations exists a fixed unchangeable type of each species and this refute the Ancient Greek idea of transmission of species which was widely believed in those days (Briggs and Walters, 1984).

De Candolle (1778–1841) who was the first to introduce the word taxonomy through his book *Théorie Élémentaire de la Botanique* (De Candolle, 1813) defined species as “a species is a collection of all the individuals which resemble each other more than they resemble anything else, which can by natural fecundation produce fertile individuals, and which reproduce themselves by generation, in such a manner that we may from analogy suppose them all to have sprung from one single individual”. He divided plants into two major groups, non-vascular and vascular plants. A book in seven volumes covered all species of cotyledons in the world including 161 families and 58000 species was his main and most important work which is called *Prodromus Systematis Naturalis Regni Vegetabilis* (1823–1873). Most of taxonomist after him, before the next phase of taxonomy, used De Candolle's system sometimes with some modifications.

Years later, in his theory of evolution with Wallace (Darwin and Wallace, 1859) even before his famous book *On the origin of species by means of natural selection* Charles Darwin (1809–1882) considered species as the fundamental units of evolution, starting a new era of species definition. Darwin emphasized the fact that species could be produced rapidly if the conditions were appropriate and in the absence of such conditions, species might remain unchanged for a long time. All Darwin theories and studies were carried out before the establishment of the genetic science.

In the middle of the twenty century, exactly in 1920's, a new science was born. The science of genetics which focus on the mathematical expression of the properties of populations and the ways in which such properties could be maintained or altered has made powerful contribution in understanding the species evolution. Since then, many modern species concepts were developed.

3. Modern species concepts

Based on the previous theories and with more studies, taxonomist proposed different approaches of species concepts in modern science. To approach a satisfactory and acceptable classification the relationship between individuals should be considered. These relations could be phenetic or phylogenetic. The term phenetic is applied to classification system which relies on similarities between present properties of organisms with no consideration or references in how they possess them. Morphology, cytology, phytochemistry, anatomy, embryology and even some generic features are considered to be source data for phenetic way. On the other hand, when the relationship describes the pathways of ancestry (how the characters of organisms arose in evolution regardless their present day state) it is called cladistic which is the same as phylogenetic (Heywood, 1976).

4. Definition of species concepts

In the following a discussion of several species concepts known:

4.1. Biological species concept

In nineteenth century the first who produced the most quoted definition of what he called “biological species” was the zoologist Mayr (1942) who defined species as: “groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups”. Thus groups of related plants which are distinct at the level of biological species do not interbreed when growing in the same area in nature. This explains simply what is called now the Biological Species Concept (BCS) which is a non-phylogenetic species concept because it is potentially interbreeding process with no references of ancestry. In another words a species is a group of reproducing natural populations incapable to effectively mate or breed with other such groups, and which inhabits a particular niche in nature (Mayr, 1982; Bisby and Coddington, 1995). Although this theory is so simple and obvious, it has mainly two disadvantages. First it is inapplicable onto asexual organisms. Secondly, it is impractical in instances of allopatric populations (geographically isolated) (Cronquist, 1978; Stace, 1989).

Both isolating species concept and recognition species concept can be part of biological concept or genetic concept because both see the species as a field for gene recombination. While the *isolating concept* stresses on reproductive isolation as the mechanism responsible for discontinuity between species (each species is reproductively isolated from all other species, precluding them from mixing their genes and their traits), recognition concept stresses on reproductive coherence as the factor responsible for continuity within species. They also have the same disadvantages as the biological concept inapplicable on asexual organisms and impractical on allopatric.

4.2. Morphological species concept (MSC)

Cronquist (1978) adopting this concept he defined species as the smallest groups that are constantly and determinedly distinctive and distinguishable by average means. Thus, species are the smallest natural populations permanently separated from each other by a distinct discontinuity in the series of biotype (Du Rietz, 1930; Bisby and Coddington, 1995). In other words, morphological species concept states that “a species is a community, or a number of related communities, whose distinctive morphological characters are, in the opinion of a competent systematist, sufficiently definite to entitle it, or them, to a specific name” (Regan, 1926). It can be applied to sexual and asexual organisms and it is also useful for species concepts in the fossil record. However, sometimes morphological characteristics are subjective and depend on ‘expert’ opinion for key traits. And in some cases the species are sympatric (morphologically indistinguishable) but are clearly different lineages.

4.3. Ecological species concept (ESC)

The ecological species concept is mainly about ecological competition. Van Valen (1976) stated: “A species is a lineage (or a closely related set of lineages) which occupies an adaptive zone minimally different from that of any other lineage in its range and which evolves separately from all lineages outside its range”. Colinvaux (1986) also wrote: “A species is a number of related populations the members of which compete more with their own kind than with members of other species”. In other words, when two organisms are similar to each other, their needs are more likely to overlap, therefore, they are expected to contest, and consequently the more likely that they are of the same species.

Nevertheless, the *ecological species concept* has some complications subsequently it requires that the life histories for members of individual species are the same which practically is not always true. It also has a problem similar to the *morphological species concept* which is: “at what point does one stop the process of splitting divergent forms into new species?.” Finally, it is not always significant to determine the degree to which two or more entities are competing ecologically.

4.4. Evolutionary species concept

An evolutionary species “is a single lineage of ancestor-descendant populations of organisms which maintains its identity from other such lineages [in space and time] and which has its own evolutionary tendencies and historical fate” (Wiley, 1981). This concept was developed by Simpson (1951) in order to include asexual organisms and extinct species whom the biological species concept could not be applied to. The problem in this evolutionary concept arose when the gaps in the fossil record levy prejudice limits between species, especially those which experiencing regular size/shape evolution.

4.5. Cohesion species concept

A cohesion species is “an evolutionary lineage that serves as the arena of action of basic micro evolutionary forces, such as gene flow (when applicable), genetic drift and natural selection” (Templeton, 1994). Thus the cohesion concept is similar to the evolutionary species concept in a way that a population genetic stress on the origins of phenotypic similarity within species.

4.6. Phenetic species concept

Based on the idea that species concept shouldn't be bound to any precise theory Ridley (1993) gave this definition: “A species is a set of organisms that look similar to each other and distinct from other sets”. Thus, it would clarify some particular degree of phenetic resemblance, and similarity would be measured by a phenetic remoteness statistic.

Practically, the phenetic concept measures as many characters as possible in as many organisms as possible, and then identifies phenetic clusters by multivariate statistics. The smallest unit in these clusters has sufficient similarity to be called a species. The theory of phenetic species concept can be opposed on the bases of that, to a specific degree there is a resemblance between any two objects in the universe. Moreover, members of the same species can be significantly different (especially in polytypic species) and individuals of various species may look more related to each other than members of the same species. Therefore, to achieve a better classification based on phenetic similarity some principals should be followed (Stace, 1989):

- * A great content of information and more characters in the taxa concerned should be attained.
- * Each trait has an equal weight when forming natural taxa.
- * Overall similarity between two taxa (units) is a result of their individual resemblance among the many traits used to compare them.
- * Taxa can be identified and recognized because correspondences of characters differ in the groups of organisms under investigation.
- * Taxonomy is usually viewed and practiced as an empirical science.

4.7. Phylogenetic species concept (PSC)

With the presence of Darwin and Wallace theory of evolution, the rediscovery of G. Mendel's laws of inheritance in 1900 and the development of the modern theory of chromosome, all these led to the cladistic speciation. Simply it defines species as a group of organisms that share an ancestor. In other words species are individuals show a high degree of resemblances in many unique traits which give a monophyletic clusters based on discriminative phenotypes. This concept integrates character-based concepts that emphasize the presence of an apparent organism attribute with history based concepts that emphasize the degree of relatedness of a new isolate to previously characterized organism. Comparing with BCS this concept is applicable on both sexual and allopatric populations. However, it runs into two great practical problems, it is rarely possible to reconstruct with certainty the past evolutionary pathway; and if so, it is hardly possible to devise a satisfactory method of designation a branching pattern by means of a single linear sequence which is so important in flora and systematic treatment. However, many attempts have been made to produce such a system, the aim being to construct a sequence starting with the most primitive and ending with the most advanced; ensuring that each taxon recognized is a monophyletic or polyphyletic (Stace, 1989; Agapow et al., 2004).

4.8. Pluralistic species concept

When a given species concept is favored in a given conditions, that does not mean it could be universally applicable. For understanding all species living at all times, a broader concept of species should be applied. A comprehensive concept larger than any species concept indicated above. The need to use more than one species concepts in order to be applicable arose the idea of a pluralistic species concept. This recognizes, basically, that “the factors that are most important for the cohesion of individuals as a species vary” (Campbell and Reece, 2002).

5. Conclusion

These species concepts mentioned above are some of the others present in taxonomic world. There are many others (ex. composite, internodal, genetic and etc.). With this large number of concepts it is not an easy or simple decision to adapt one. Generally, it depends on the criteria and the aim of each project. For example, biological, isolation and recognition concepts can be used if the organisms were sexual breeding and from same community or geographical area. In addition, if a study is concerned on the similarity of a group of plant with enough information of characters (morphology, anatomy, cytology) with no need to a lineage, a morphological concept could be adapted. Sometimes more than one concept can be used, for example the ecological concept can be used with the morphological one.

Moreover, many concepts may be used with phenetic concept too. Although some taxonomists believe that phenetic classification represent a more practical solution than phylogenetic ones (Raven, 1976; Heywood, 1978) phenetic or numerical taxonomy does not generate new data and is not a new system of classification. It is only a new method of organizing data and obtaining classification or special presentation forms from them. Therefore, it can combine more than one concept by using their data in numerical forms.

On the other hand cladistic or phylogenetic basically view evolution as an ordered and divergent transformation of characters. So, it is trying to uncover populations' genealogical relationships

rather than their reproductive boundaries. It is been adopted widely by zoologist more than botanist. In some cases because of the lack of certainty in the past evolutionary pathway cladistic is not likely to replace other disciplines. Therefore, it could supplement them to approach a satisfied classification.

Finally, the process of species identification itself is not simplified by having a meaning of “species”. It may not be possible to identify species in many cases, but it is clearer why species can be so difficult to identify. This difficulty has led to the cynical definition of a species as a group of individuals *sufficiently distinct* from other groups to be considered by taxonomist to worth specific rank. The term “*sufficiently distinct*” here is the most important one. Since there is no agreed formula to decide this, taxonomists decide these sufficient distinct according to what information they have. Then, the species concept they adapt may become applicable. In the present time most taxonomists use one or more of the following main criteria as in (Stace, 1989):

- * “The individuals should bear a close resemblance to one another such that they are always readily recognizable as members of that group.
- * There are gaps between the spectra of variation exhibited by related species; if there are no such gaps then there is a case for amalgamating the taxa as a single species.
- * Each species occupies a definable geographical area (wide or narrow) and is demonstrably situated to the environmental conditions which it encounters.
- * In sexual taxa, the individuals should be capable of interbreeding with little or no loss of fertility, and there should be some reduction in the level or success (measured in terms of hybrid fertility or competitiveness) of crossing with other species.”

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