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Consilience and a Hierarchy of Species Concepts: Advances Toward Closure on the Species Puzzle[1]

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Abstract: Numerous concepts exist for biological species. This diversity of ideas derives from a number of sources ranging from investigative study of particular taxa and character sets to philosophical aptitude and world view to operationalism and nomenclatorial rules. While usually viewed as counterproductive, in reality these varied concepts can greatly enhance our efforts to discover and understand biological diversity. Moreover, this continued ''turf war'' and dilemma over species can be resolved if the various concepts are viewed in a hierarchical system and each evaluated for its inherent level of consilience. Under this paradigm a theoretically appropriate, highly consilient concept of species capable of colligating the abundant types of species diversity offers the best guidance for developing and employing secondary operational concepts for identifying diversity. Of all the concepts currently recognized, only the non-operational Evolutionary Species Concept corresponds to the requisite parameters and, therefore, should serve as the theoretical concept appropriate for the category Species. As operational concepts, the remaining ideas have been incompatible with one another in their ability to encompass species diversity because each has restrictive criteria as to what qualifies as a species. However, the operational concepts can complement one another and do serve a vital role under the Evolutionary Species Concept as fundamental tools necessary for discovering diversity compatible with the primary theoretical concept. Thus, the proposed hierarchical system of primary and secondary concepts promises both the most productive framework for mutual respect for varied concepts and the most efficient and effective means for revealing species diversity.

Key words: biodiversity, consilience, evolution, hierarchy, philosophy, speciation, species, species concepts, systematics, taxonomy.

The conceptualization of species has received an enormous amount of attention for many years—entirely with good reason. Few concepts can be viewed as more fundamental to the natural sciences than that of the species. The entities that we envision as species represent fundamental components or ''building blocks'' in the natural sciences. They are the atoms or atomic particles of atomic theory or the celestial bodies of planetary theory. In the history of this planet, through natural selection, speciation has produced natural entities, called species, that we endeavor to discover. As Wilson (1992) surmised, a conceptual view of species, that can accommodate the diversity of life, represents the ''Holy Grail'' of the natural sciences because so much is dependent upon our ability to discover and study naturally occurring entities. Because of this fundamental significance we must strive to find species in nature and accurately reflect this biodiversity in classifications. These two objectives will not only help us understand species but will be fundamental to the advancement of many fronts in the sciences. If errors are made in the accurate discovery and representation of diversity, then information derived from these flawed ''building blocks'' will also be flawed.

There is no doubt that the conceptualization of species (as taxa and category) has been, for many, a source of puzzlement, confusion, and argument for many years. The issue of species is a difficult premise, primarily by virtue of their nature as Individuals. Because of conflict and confusion

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over species in nature as Individuals vs. Classes (Ghiselin, 1966, 1974, 1989, 1997; Hull, 1976), and how we treat them in practice, biologists have become frustrated, leading to considerable inconsistency as to how species are recognized and viewed in science. Some scientists have abandoned interest and critical thought on the notion and have adopted concepts that ''seem reasonable'' or that seem to be ''most in favor at the time.'' I offer an alternative perspective on the species issue that, when employed, can abate much of the confusion and conflict associated with this problem. The hierarchical concept proposed in Mayden (1997) and discussed herein provides the biological community with some closure on the issue. This perspective involves the unification of knowledge, or consilience, on the species issue and encourages a cooperative approach toward understanding biological diversity. Consilience of concepts of biological species draws from facts about species in nature, from which the hierarchical arrangement is developed. A highly consilient, theoretical primary concept of species can unify many other secondary concepts serving as operational tools in the discovery process of species under this concept. This perspective on the ''species puzzle'' highlights the pitfalls of simply adopting a ''favored'' or ''reasonable'' view of species for convenience. It also emphasizes the negative impact of such an attitude on taxonomic, systematic, and biodiversity studies (Mayden, 1997; Mayden and Wood, 1995).

Consilience and Species Concepts

The idea of consilience, or the unification of knowledge, was developed by the English philosopher of science William Whewell in his work *The Philosophy of the Inductive Sciences, Founded upon their History* (1840), and recently resurrected by E. O. Wilson (1998). For Whewell, the production of a scientific theory through the simple collection of facts or observations was inadequate. Rather, what was necessary was a colligation of facts through an appropriate conception. In his efforts he essentially described the hypothetico-deductive method wherein the success of the scientific method comes from developing multiple tentative hypotheses and selecting the ''right'' one. The scientific method begins with the superimposition of an idea or concept on data, or a colligation of facts, leading to a new way of seeing these facts or a new general concept. This process results in unification of knowledge regarding the facts or data. As we see in the diversity of life forms, some of these facts (life forms, reproductive modes, etc.) may appear to be ''similar types'' while others may not, but they all will be colligated under the new conceptualization. The hypothesis or theory that provides the greater unification of knowledge and explanatory power is said to be more consilient relative to other hypotheses that offer lesser unification of knowledge and explanatory powers. According to Whewell (1840), consilience characterizes theories or concepts that achieve unification, generality, simplicity, and deductive strength, and represents a test of the necessary truth of theories. Thus, what many consider simple, pragmatic virtues of theories, such as generality, simplicity, and unification properties, have epistemic and ontologic status.

Consilience is a critically important view of the natural world, and it should be seriously considered in our deliberations of species and species concepts. Species in nature and their inherent attributes (such as reproductive mode, morphology, DNA, and behavior) resulting from descent with modification are facts for colligation. The processes of anagenesis and cladogenesis have produced a vast array of different ''types'' of attributes of different ''kinds'' of species and a vast array of divergent lifestyles and life cycles. These divergent life forms represent, in many instances, evolutionarily independent lineages of sexual or asexually reproducing organisms. Given this extensive array of diversity recognized as biological species by specialists of different groups of organisms, we are presented with a vast array of facts (attributes, ''kinds'' of species) for colligation in developing our theory or concept of species. Following Whewell, those concepts that offer the greatest unification of this array of knowledge (or diversity) will be those with the highest level of consilience with respect to species. As we will see below, not all of the various concepts of species are equivalent in their abilities to provide unity of the observed facts drawn from nature. Only one concept, the Evolutionary Species Concept (ESC), can be said to have the highest level of consilience, given the currently observable facts of nature and available concepts. The other concepts are operational in nature and provide only partial unification of known facts and are thus less consilient.

The Proposed Hierarchical Approach

As a resolution to the species puzzle, Mayden (1997) proposed a hierarchical account of the various proposed concepts of species having differential levels of consilience (Fig. 1; Table 1). The general argument presented was that we must view the various species concepts in a hierarchical fashion involving both primary and secondary concepts. Only one primary concept should be used as a guiding theory of diversity thought to represent biological species. In this sense I argue for monism at the level of the primary concept. This concept must have a high level of consilience with biological diversity. That is, it must have the greatest ability to account for the enormous array of diversity. It must be a theoretical concept of natural entities consistent with our knowledge of natural sciences and the different types of diversity currently identifiable as species. This concept also must (i) have a dimensional component; (ii) view species as Individuals, not as Classes; (iii) be unbiased as to the type of organism, data, or sexual tendencies of the organisms; and (iv) be non-operational. As noted in earlier works on species (Mayden, 1997; Mayden and Wood, 1995; Wiley and Mayden, 1999), it is clear that the only concept satisfying these strict criteria is the ESC (sensu Wiley, 1978; Wiley and Mayden, 1999). The ESC provides the theoretical, philosophical, and metaphysical basis for the recognition of diversity known as species. It is not as restricted in these regards as are other available concepts that are less consilient.

Mayden (1997) argued that the alternative concepts of species should be considered secondary to and must be theoretically consistent with this primary concept. These secondary concepts are operationally driven, offer clear and restrictive definitional criteria as to what constitutes a species, and therefore individually provide strict boundaries on one's ability to recognize diversity not consistent with a concept's definition. Individually, all of these concepts exclude some types of species diversity and, therefore, are less consilient. None of these concepts should be used as a primary concept. These concepts are nonetheless critical to science because together they form a diverse network of operational guidelines that permits us to discover and investigate biodiversity consistent with the primary concept. Secondary concepts serve an important role as fundamental, operational surrogates to the primary concept. Because different concepts emphasize different aspects of biodiversity and because of their critical nature in the discovery process, I argued for pluralism with respect to secondary concepts in the hierarchy.

One of the most important factors fueling the debate over species concepts has been the widespread notion that the various concepts of species are equivalent in their operational, ontological, and epistemological merits. Because of this opinion and other factors related to the formulation and application of concepts, some researchers continue to debate the species concept while other frustrated scientists have abandoned any interest in the issue. The notion that various concepts proposed for species are equivalent in their operational and metaphysical merits for discovering and understanding species is a grievous misconception (Mayden, 1997; Mayden and Wood, 1995). Not all concepts of species are equally valuable in providing unity of knowledge on biological diversity.

Several other factors involved in the traditional problems with the species issue encompass important philosophical and meta-

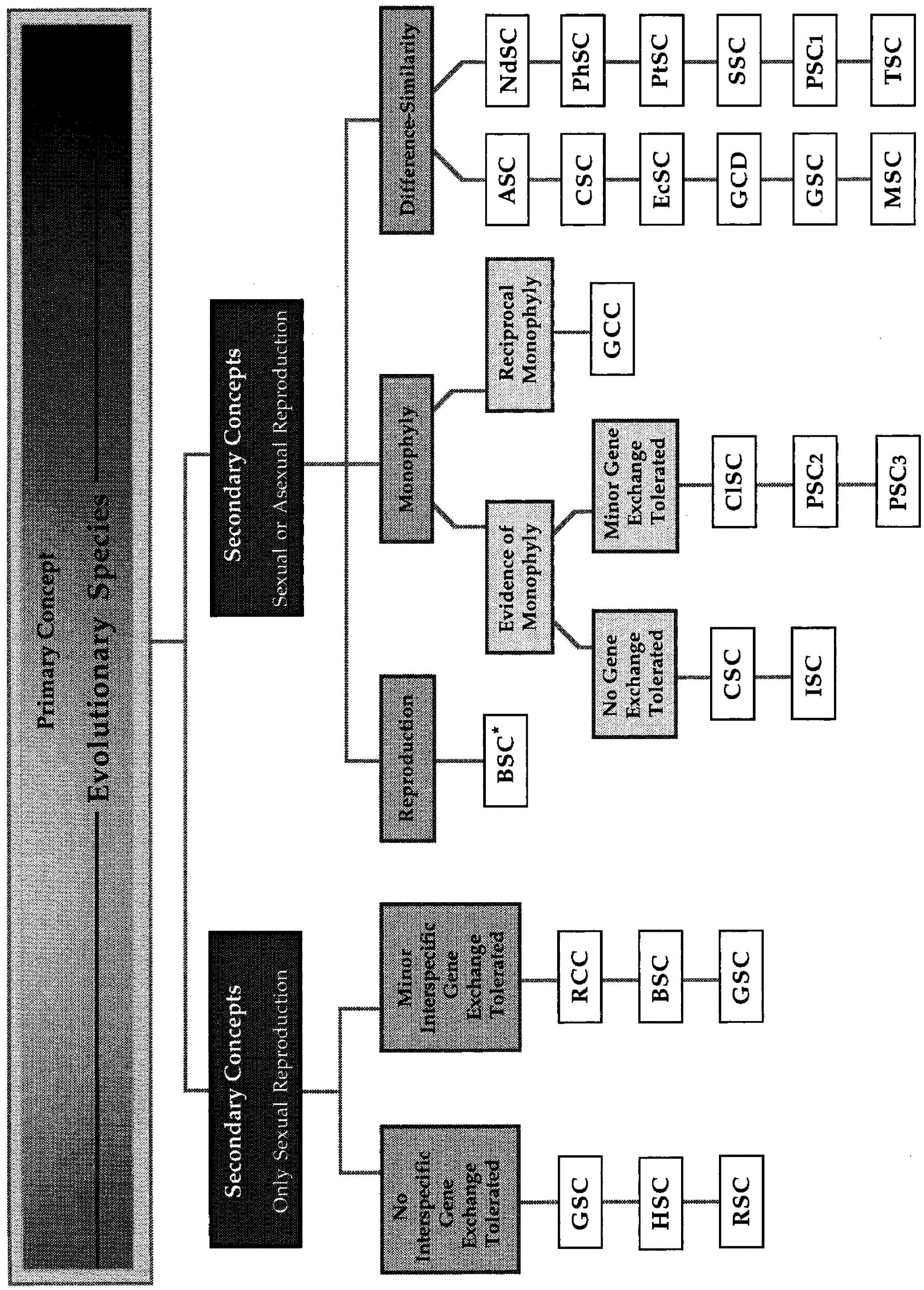

Primary Concept
Evolutionary Species
Secondary Concepts
Sexual or Asexual Reproduction
Secondary Concepts
Only Sexual Reproduction
Reproduction
Monophyly
Difference-Similarity
BSC*
Evidence of Monophyly
Reciprocal Monophyly
GCC
No Gene Exchange Tolerated
Minor Gene Exchange Tolerated
CSC
ISC
ClSC
PSC2
PSC3
ASC
CSC
EcSC
GCD
GSC
MSC
NdSC
PhSC
PtSC
SSC
PSC1
TSC
Minor Interspecific Gene Exchange Tolerated
RCC
BSC
GSC
No Interspecific Gene Exchange Tolerated
GSC
HSC
RSC

TABLE 1. Various species concepts, abbreviations used in text, and authors promulgating individual concepts. Concepts and abbreviations are from Mayden (1997). Superscripts correspond to authors employing or describing the concept. All concepts are reviewed in Mayden (1997).

Agamospecies Concept (ASC)[a]	Morphological Species Concept (MSC)[n]
Biological Species Concept (BSC)[b]	Nondimensional Species Concept (NdSC)[o]
Cladistic Species Concept (ClSC)[c]	Phenetic Species Concept (PhSC)[p]
Cohesion Species Concept (CSC)[d]	Phylogenetic Species Concepts (PSC):
Composite Species Concept (CpSC)[e]	Diagnosable Version (PSC1)[q]
Ecological Species Concept (EcSC)[f]	Monophyly Version (PSC2)[r]
Evolutionary Significant Unit (ESU)[g]	Diagnosable/Monophyly Version (PSC3)[s]
Evolutionary Species Concept (ESC)[h]	Polythetic Species Concept (PtSC)[t]
Genealogical Concordance Concept (GCC)[i]	Recognition Species Concept (RSC)[u]
Genetic Species Concept (GSC)[j]	Reproductive Competition Concept (RCC)[v]
Genotypic Cluster Definition (GCD)[k]	Successional Species Concept (SSC)[w]
Hennigian Species Concept (HSC)[l]	Taxonomic Species Concept (TSC)[x]
Internodal Species Concept (ISC)[m]	

[a] Stuessy (1990); [b] Mayr (1940, 1957), Mayr and Ashlock (1991), Mayden and Wood (1995); [c] Ridley (1989); [d] Templeton (1989); [e] Kornet (1993), Kornet and McAllister (1993); [f] Van Valen (1976); [g] Waples (1991, 1995), Mayden and Wood (1995); [h] Wiley (1978), Frost and Hillis (1990), Mayden and Wood (1995), Wiley and Mayden (1999); [i] Avise and Ball (1990); [j] Simpson (1943), Dobzhansky (1950), Mayr (1969); [k] Mallet (1995); [l] Hennig (1950, 1966), Meier and Willmann (1999); [m] Kornet (1993); [n] Cronquist (1978), Shull (1923), Du Rietz (1930), Regan (1926); [o] Varied concepts that lack a lineage perspective to interpreting the origins and evolution of characteristics, including reproductive isolation; [p] Sneath (1976); [q] Eldridge and Cracraft (1980), Cracraft (1983), Nixon and Wheeler (1990), Wheeler and Platnick (1999); [r] Rosen (1978, 1979); [s] McKitrick and Zink (1988); [t] Various concepts that employ a combination of characteristics to diagnose or define species with no temporal or lineage perspect to the evolution of species and their attributes; [u] Paterson (1993); [v] Ghiselin (1974); [w] Paleospecies concept of Simpson (1961) and chronospecies concept of George (1956); [x] Blackwelder (1967).

physical aspects related to the nature of species as well as how we treat them in our disciplines. These include confusion over or lack of appreciation for (i) conceptualism vs. operationalism, (ii) the notion of species as category and taxon, (iii) the philosophical notion of species as classes or individuals, (iv) occupational biases of the person studying species regarding the types of organisms and data used, and (v) the influence of rules of nomenclature superimposed on nature. Each of these factors contributes to a lack of resolution of the species problem.

Currently, there are multiple conceptualizations of species, nearly all of which are operational concepts, surviving as strict definitions in recipes prescribed for discovering a restricted set of things that we think are species (Table 1; Mayden, 1997). These operationally based concepts have evolved without an appreciation of the factors listed above. These concepts, and often persons using them, treat species as classes, and confuse the species as a taxon and a taxonomic category. They are commonly employed by researchers with an occupational and organismal bias, which also may be influenced by various formalized rules of nomenclature. Many are rooted in notions of superiority of some sexual tendencies or data types that qualify as evidence of species validity. Operational concepts are required in the empirical discovery process. However, all operational concepts are inherently restrictive in their theoretical contribution and application. Operational concepts provide only restricted theories as to the kinds of species that exist in nature. Thus, these concepts

FIG. 1. Generalized hierarchical arrangement of primary and secondary species concepts as outlined originally by Mayden (1997). In this arrangement the most consilient concept, the Evolutionary Species Concept, serves as the primary concept because it offers the greatest unification of facts about species. The less consilient, secondary concepts of species are each operational in nature and offer lesser levels of unity of knowledge about species. These secondary concepts are arranged below the primary concept in only one of possibly several ways. In this instance, arrangement is based on tolerances or requirements for particular modes of reproduction, gene exchange, monophyly, and diagnosability. Concepts could appear more than once in the hierarchy because there are different, hybrid versions with mixed criteria. Abbreviations for concepts are provided in Table 1; within the hierarchy, concepts are listed alphabetically within any one category. Asterisk denotes a version of the BSC modified to accommodate asexual species.

have low consilience with regard to the nature of species. They do aid in the discovery process of certain ''kinds'' of species thought to be consistent with the theory of descent and a particular worker's predilections. Because not everyone works with the same formula for discovering species, much controversy over species is rooted in a myopic view of the natural world created through strict applications of operational definitions.

The proposed hierarchical approach (Mayden, 1997) resolves much of the above difficulties with the theoretical and operational concepts, and can alleviate much of the tension associated with the debate over the species issue. Because only the ESC can colligate known biological species as valid species, it is the most consilient of the variously proposed concepts and must serve as our primary concept in this hierarchy. Because the ESC is consistent with our understanding of descent with modification and is not operational, it provides the theoretical basis and guidance for the process of discovering species using other operational concepts. Operationally based concepts do have a fundamental role in the exploratory and discovery processes for determining biological diversity. They are diverse in their development, application, and emphasis. Thus, they serve as useful recipes for discovering species in nature that are consistent with the primary concept. However, they do have theoretical and operational limitations. I will discuss some of the problem areas mentioned above that fuel the species debate and preclude development of consilience. Finally, using two heuristic examples, I will illustrate the importance of consilience and the hierarchical approach for theoretical and operational concepts of species. Both the hierarchical and consilience approaches are considered necessary if we are to arrive at a more productive solution to the species issue.

The Variety of Concepts

An abundance of literature exists on the various conceptualizations of species. At least 22 different concepts of species have been presented since Darwin (see Table 1 for concepts and principal proponents of each; also see Adams [1998] for additional concepts). Mayden and Wood (1995) have reviewed and evaluated five of the most frequently cited conceptualizations of species (BSC, three versions of the PSC, and ESC) and the recently developed Evolutionarily Significant Unit (ESU). Recently, Mayden (1997) reviewed and evaluated 22 different species concepts. Adams (1998) provides a review of four commonly used concepts (Linnaean concept, BSC, PSC, and ESC) and offers a combined ESC/PSC concept of species.

In reviewing these concepts both Mayden and Wood (1995) and Mayden (1997) evaluated each for its ontological and epistemological merits with regard to understanding and discovering species in nature. Epistemology deals with the nature of knowledge and ontology deals with the nature of being. Those concepts emphasizing the epistemological approach deal largely with discovery operations or the question, ''How do we know there are species?'' Concepts emphasizing the ontological approach deal mainly with the question, ''Are there species?'' (Adams, 1998; Frost and Kluge, 1994). Important in this evaluation was the consideration of each concept's ability to recognize the variety of known types of biodiversity currently considered species by researchers. The principal objective of this evaluation was to determine if there are some concepts of species that are better suited as primary theoretical concepts of species in nature. If so, they could be used as guiding theoretical concepts for understanding and discovering diversity of this nature. Of the remaining concepts, can any of them serve as fundamental operational concepts useful in aiding in the discovery process of species? If so, then these concepts must serve as important tools or guidelines for discovering taxa that are consistent with the primary concept of species. Mayden (1997) showed that most species concepts adopted a strongly epistemological approach to the species question, and these concepts possessed various degrees of essentialism inherent in their formulation or application (see also Adams, 1998). Other concepts adopted a more strongly ontological approach to the species question and were better as primary concepts.

Only one of the 22 concepts examined was found to possess a high level of consilience relative to our current understanding of species as products of descent with modification. This concept, the ESC, was considered the most robust and theoretically significant concept of diversity known as species and was identified as the primary concept in the hierarchy of species concepts (Fig. 1; Mayden, 1997). This concept emphasizes a strongly ontological perspective. It is a nonoperational concept that provides a lineage perspective and is tolerant of a vast array of forms of divergence, sexual tendencies, geographic distributions, types of data, and modes of speciation. It is also the only concept that provides the appropriate theoretical basis and fundamental unit for phylogenetic analysis sensu Hennig (1950, 1966) (Wiley and Mayden, 1999).

Of the remaining concepts, all have varying levels of consilience relative to biological species and exclude some species diversity from recognition. These concepts also advocate varying degrees of essentialism and are nonevolutionary if their discovery operations are unintentionally abused (Adams, 1998). Each of these operational and potentially essentialistic concepts excludes some types of diversity that may be recognized by researchers holding to alternative operational concepts of species. For instance, no asexual species will be recognized with the BSC, HSC, or RCC, but they will be recognized with the ASC and PSCs. Interbreeding between species, despite their sister-group relationships, is not tolerated for species under the BSC, HSC, RCC, and RSC. Cryptic species divergent only at the molecular or behavioral level will not be considered valid with a strict application of the MSC and TSC, and possibly also the BSC, HSC, GCC, and RSC. Also, all operational concepts requiring the identification of apomorphic traits in their prescribed operations will necessarily exclude all ancestral species (PSC). Thus, it is clear that all of these concepts are less consilient with respect to species diversity relative to the ESC because only the latter is capable of colligating the diverse array of natural facts.

All of the alternative concepts are identified as secondary concepts to the ESC. Each is operational and each provides specific definitions as to what constitutes a species. These concepts emphasize an epistemological approach, and their operations help to answer the question of ''How do we know there are species?'' All of these concepts are thought to be consistent with the primary ESC and the theory of descent with modification and speciation. However, some applications of the ASC, CpSC, ISC, NdSC, PSC1, PtSC, and SSC may result in some types of diversity termed ''species'' but which represent artifactual diversity consistent with the operational concept itself. These concepts, if not appreciated for their inherent operational and potentially essentialistic nature, have discovery operations that can lead to the identification of non-evolutionary byproducts. Some of these concepts have the potential to permit researchers to identify and study unrelated groupings of organisms that are ''diagnosable'' as a group on the basis of convergent analogues or combined plesiomorphic and apomorphic homologues. For example, the SSC is inconsistent with the proposition of descent and the ESC because it permits researchers to arbitrarily divide a lineage into different elements of convenience referred to as ''species'' (Wiley, 1978).

Conventional Difficulties in Resolving the Species Puzzle

Because of the nature of species and the educational and occupational histories of researchers, it is likely that each has a different perception of what a species is; these perceptual differences often have fueled the species debate. Our perception of species differs because species are individuals, not classes, and individuals cannot be defined. Our perception of a species also depends upon the importance that we place on metaphysics and philosophy, our practical experiences with species, the taxonomic groups of organisms that we study, the data we use to study them, and other considerations. As with learning about any individual-like thing, the skilled taxonomist learns about species in specialized group (nematodes, flatworms, mammals, fishes, etc.) through experience.

In considering the various concepts, one discovers several interesting things about them that have contributed to the lack of resolution. First, many of the concepts are occupation and organism-biased. That is, they have been developed over the years by researchers specializing on sexual versus asexual organisms, multicellular vs. unicellular organisms, fossil versus extant diversity, birds versus flatworms or fishes, etc. Second, some of the concepts are inherently data-dependent and derive from a researcher's background and experience with different data used for particular groups (morphology, allozymes, behavior, etc.). Third, nearly all of the concepts are operational, which may be appealing but is actually detrimental to a concept intended to aid in discovery of all naturally occurring entities that are species as individuals. Fourth, these same operational concepts treat species in nature as classes, not individuals. Finally, concepts that consider species to be classes are essentialistic concepts. These concepts theoretically prohibit the evolution of species and lack a lineage or temporal perspective for interpreting patterns of descent with modification for species.

In the above discussion regarding the hierarchical approach to the species issue I identified five topics that have contributed to the species concept controversy: (i) conceptualism vs. operationalism, (ii) the unique nature of species as individuals or classes and species as taxa or categories, and (iii) potential occupational biases involving different groups of organisms, sexual tendencies of organisms, and evidence in the form of data. Each of these areas has contributed to our ongoing species problem. Further appreciation of the contribution of these topics to the species issue is critical to resolving the long-standing issue.

Conceptualism and Operationalism

Philosophy and metaphysics as they relate to the issues of evolution, systematics, species, and speciation offer a foundation and requisite perspective to resolving the issue of species (see Ghiselin, 1997). Ignorance of the basic issues related to conceptualism and operationalism will preclude one from being able to make informed decisions about species and other important topics related to biodiversity, systematics, taxonomy, and evolution.

Concepts are ideas or theories that are general and may or may not be based on empirical observations. However, they form essential links relating pattern and process, and help guide our perception of natural systems. Concepts about species must be able to accommodate various forms of diversity produced through descent; otherwise, our effort to discover, understand, and evaluate natural systems will be misguided. A concept is relayed from one person to another by adapting it into a statement or definition verbally, graphically, or in writing; it is hoped that the representation, precisely worded and understandable, will accurately reflect the same concept to others. For some concepts (e.g., round, square) one may compare the concept definition with statements developed by different observers and the objects to see if they agree. For other concepts like species, it is difficult to know with certainty that statements represent the same transient or hypothetical things, and definitions can be compared only by using previously agreed-upon definitions or words.

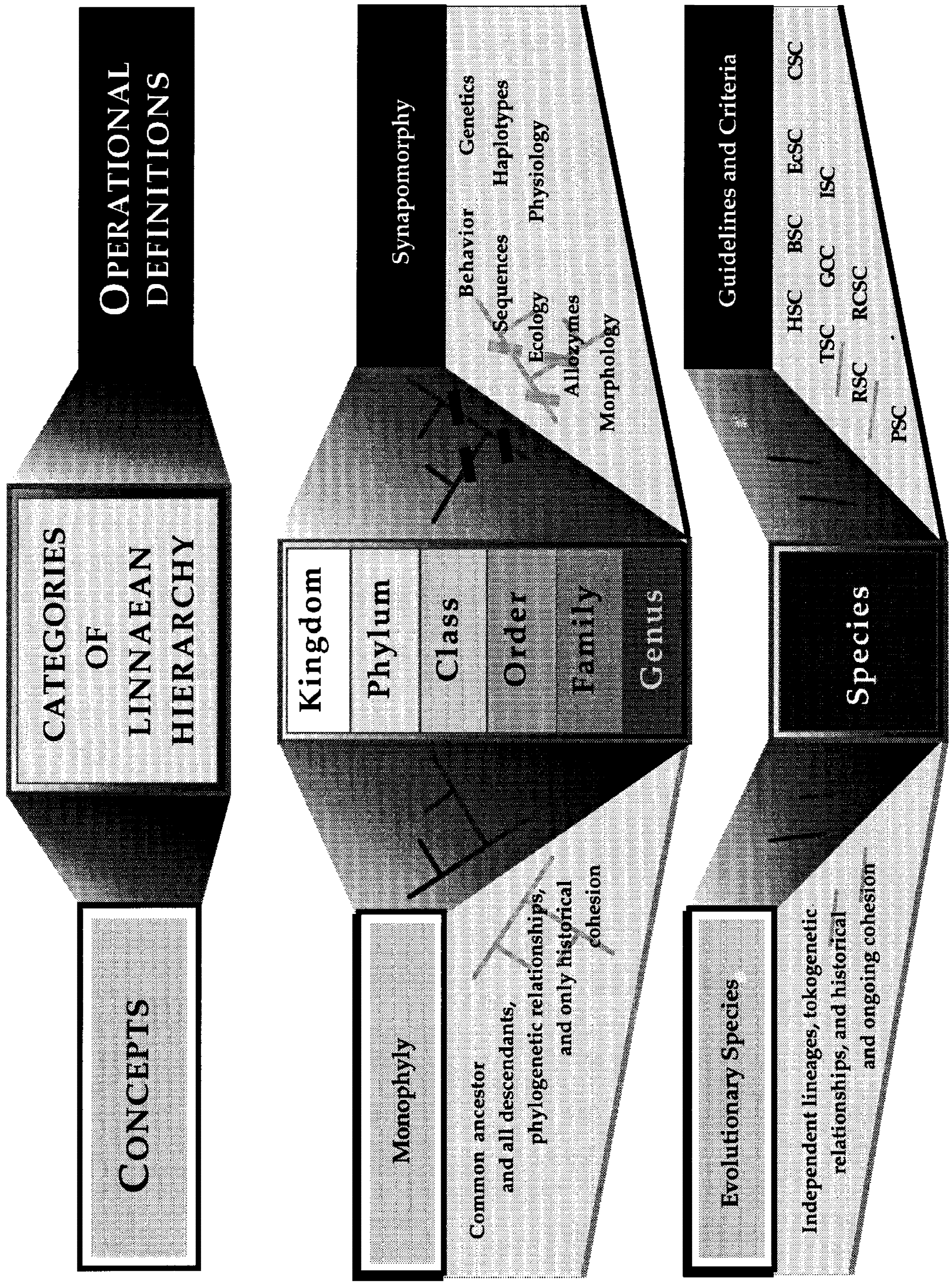
Operationalism is a quality desired by many for species concepts. That is, one should be able to follow a prescribed set of identifiable and repeatable operations and at the end of these operations be able to tell with a certain level of confidence if what they have is a species. Operationalism often excludes metaphysical issues. The ''species'' is defined by a set of operations (number or type of characters, genetic distance, mode of reproduction, etc.). The sets of things outlined in an operational definition typically are classes or natural kinds. Operational definitions are easy to use but can be misleading. The requirement of operationalism limits what is recognizable by criteria outlined in the operational concept. While this may be convenient, convenience is not necessarily a criterion that should be optimized when attempting to discover pattern and process in a natural world. What is operational is determined strictly by the perceived reality of the viewer, and this perception may be only a portion of reality. A simple example of the problems associated with the reliance upon an operational concept as a primary concept of species involves birds, bees, fishes, and data bias by a researcher. All of these organisms can be brightly colored and may use their color patterns in mate recognition and mating rituals to ensure successful mating. It would be a mistake for someone who is color-blind to develop an operational concept of species based solely on the requirement of different color patterns for different species. Such a concept would automatically exclude a large amount of biological diversity that can be seen, discovered, studied, and thought to exist by other researchers who are not color-blind. The same logic applies to any reliance upon particular data sets, reproduction modes, recognition systems, distributional criteria, and levels of divergence for the validation of species.

Species as Classes and Individuals; Species as Categories and Taxa

Inextricably linked to a sound understanding of the philosophical and metaphysical issues regarding species are the associated notions of classes vs. individuals and categories versus taxa. Here I discuss species as categories and taxa and demonstrate that species must be thought of as individual-like things rather than class-like things. However, the system is complicated because in reality we must think of species as individuals and employ a theoretical primary concept for the taxonomic category species. In practice we tend to treat species as classes because finding species in nature requires an important bridge to operational concepts that treat them as if they are classes, hence the important linkages inherent in the hierarchical approach.

Historically, species have been considered class-like objects or natural kinds, dating back to Aristotelian naturalness and the general idea of essentialism. Species were thought to possess essential, immutable features; any variation in these attributes was simply imperfect manifestation of their essence. To consider species as classes creates serious logical inconsistencies with higher-level theories of the natural world. First and foremost is that essentialism is inconsistent with descent with modification because through descent the ''essence'' of a species changes and one species with one ''essence'' can produce multiple species with necessarily different ''essences''. The idea of species as individuals was first introduced by Ghiselin (1966, 1974, 1980) and supported by Hull (1976), Wiley (1978), Ghiselin (1997), and many others. That the natural world consists of species as individuals is highly consistent with the theory of descent, and only by viewing species as individuals can one begin to study, interpret, and understand descent with modification and speciation. This transformation in the perception of species revolutionized the way we think of species and opened doors to many additional interesting areas of the natural sciences.

The term species has two different meanings that cause confusion. Species is used for the taxonomic category plus those naturally occurring particulars or things that we hope to discover, diagnose, and study. Confusion over these two meanings is most detrimental to productive discussions of species because each has a very different ontological status (see Hull, 1976 and Mayden, 1997). While the differences may sound trivial, much of the confusion over the species issue stems directly from the conflation of these different meanings. So, what is the furor over spe-


CONCEPTS
CATEGORIES OF LINNAEAN HIERARCHY
OPERATIONAL DEFINITIONS
Monophyly
Common ancestor and all descendants, phylogenetic relationships, and only historical cohesion
Kingdom
Phylum
Class
Order
Family
Genus
Synapomorphy
Behavior
Genetics
Sequences
Haplotypes
Ecology
Physiology
Allozymes
Morphology
Evolutionary Species
Independent lineages, tokogenetic relationships, and historical and ongoing cohesion
Species
Guidelines and Criteria
HSC
BSC
EcSC
CSC
TSC
GCC
ISC
RSC
RCSC
PSC

cies as categories or taxa and species as individuals or classes?

First, the two species terms (category and taxon) are aligned with different philosophical categories (classes and individuals, respectively). The taxonomic category species is one of several taxonomic categories and all categories are considered classes. Classes are spatiotemporally unbounded, lack cohesion as a group, are not self-replicating, do not change over time, do not participate in any natural process as a group, and can be defined. Classes have members, and members can include other classes. A class can exist anywhere in the universe so long as there is a definition for class membership. Obviously, if one adheres to the theory of descent with modification and speciation, it is very clear that species as taxa cannot be considered classes or natural kinds, but the category species can be. Species evolve, are self-replicating, mutate, participate in processes, and have beginnings and ends. Based on our understanding of species, they cannot be classes. What we understand about species and speciation violates the requirements for being a class. For example, classes have definitions whereas species mutate, evolve over time, and change. Common examples of natural classes include a class referring to taxonomic categories—one for planets, one for stars, one for people, one for organs, one for cells, and one for flatworms. All of these classes have definitions associated with them, and anything fitting the definition will be included. However, the members of these different classes often will be individual-like things; for instance, a particular species, the planet Earth, or a particular star are all individuals in their respective classes.

Individuals are spatiotemporally bounded, have intrinsic cohesion, are self-replicating, can participate in natural processes, and have part-whole relationships but cannot be defined. Individuals can only be described and diagnosed following their discovery by some means. Individuals exist throughout the universe, and because they do not have definitions, they have no members. Individual organisms are considered individuals and they form part of the whole species that, as a group with a unique history, is also an individual. While individual-like things exist throughout the universe, each individual is also necessarily spatiotemporally confined. Thus, even if a life form is found on another planet in another galaxy that looks, talks, and acts like *Homo sapiens,* if it is not a direct descendant from the lineage of *H. sapiens* on Earth then it is not part of the same whole of *H. sapiens* from Earth. However, if we treated species as classes and had a morphological or behavioral definition for *H. sapiens,* then both life forms would be considered the same if they fit the definition, even if one used DNA for its information storage system and the other used microchips and processors. Species as individuals (Ghiselin, 1966, 1974, 1980; Hull, 1976) represent a unique level of organization of the natural world; they are self-organizing entities or particulars. This level of universality is the uppermost limit involving tokogenetic relationships and the lowermost level participating in phylogenetic relationships. Species as in-

FIG. 2. A heuristic diagram illustrating conceptualism and operationalism with respect to the categories of the Linnaean hierarchy. Supraspecific groups are separated from species because the former represent historical groups and the latter represent individuals (Wiley, 1981). On the left are highly consilient, non-operational concepts that have been formulated based on facts in nature about both supraspecific groupings and species. The concept of monophyly relates to groupings of species united by phylogenetic relationships that have only historical cohesion. The concept of species relates to independent lineages of organisms possessing tokogenetic relationships, each of which has its own evolutionary tendencies and trajectories. Neither of these concepts is operational for discovering supraspecific groups or species. In the right column are the required operational definitions that serve as fundamental tools or guidelines for discovering entities conceptualized for supraspecific groups and species in the left column. Currently, the concept of synapomorphy serves as the best tool for identifying monophyletic groups. With regard to species, all secondary species concepts (Fig. 1) serve as equally valuable tools or guidelines for identifying species as conceptualized by the ESC in the left column. In the right column under synapomorphy several different types of data sets are appropriate for evidence; these same types of data are equally relevant to validating species. Abbreviations for species concepts in the lower right column are in Table 1.

dividuals are the highest level of integration to participate in natural processes while being spatiotemporally constrained. Hence, species as individuals represent fundamental units of evolution.

Discovering things in nature thought to be genuine species requires more than the theoretical concept (Figs. 1,2). It requires bridging to secondary concepts that are more operational to help us identify groups of things that are consistent with the ideas presented in the primary concept for the category species (Figs. 1,2; Table 1). The number of these concepts will vary depending upon the growth of our understanding of biological diversity and should as our perceptions improve.

Problems associated with differences between theoretical and operational concepts exist in many areas of the natural sciences. A parallel example of theoretical and operational concepts exists for supraspecific categories and taxa in the Linnaean hierarchy. This particular problem serves as an example to illustrate the significance of identifying the distinctions. This example (Fig. 2) includes the ideas of supraspecific categories, monophyletic groups, and discovery processes for monophyletic groups. This example parallels what I have proposed for the hierarchy of species concepts and the issues of conceptualism and operationalism in dealing with individual-like things, with one difference. Supraspecific groups that are natural monophyletic groups are not individuals like species but are special types of individuals known as historical groups (Wiley, 1978). Historical groups possess some individual and some class-like characteristics. However, the fact that the entities are historical groups does not alter this example as a parallel to the species issue. It is most interesting that so much controversy has been centered around the species issue but so little discussion has revolved around the similar situation dealing with natural supraspecific taxa, all of which begin as species!

It is the job of the systematist or taxonomist to discover and defend historical groupings of organisms (Fig. 2) that share historical cohesion via a common ancestral species, and to place groupings into various taxonomic categories. Among supraspecific categories more-inclusive groups have higher rankings than do less-inclusive groupings. Ranking should not be based on degree of distinctiveness but on genealogical relationships. Just as in the species issue, what theories, principles, or concepts do we employ when we ask the questions, ''Are there natural supraspecific groups of individual-like things?'' and ''How do we know that groupings like this exist?'' The left-hand column of Figure 2 provides the theoretical concept that we most often invoke for naturally occurring, historically derived supraspecific groupings. The concept of monophyly is usually the guiding theory for what is thought to represent naturally occurring products of historical descent. Monophyly is thus the most consilient concept.

How do we find supraspecific groups, which should exist in nature if descent with modification occurs? We should be able to recover patterns of descent and group organisms. That is, natural groups should exist and we should be able to find them. Interestingly, the concept of monophyly is entirely theoretical and lacks any operational qualities useful in the discovery process. It only states that such groups should include the ancestor and all of its descendants. With this theoretical concept, just as with the primary concept of species, we need one or more operational, secondary concepts for discovery. These secondary concepts must be consistent with the primary concept. In the case of supraspecific groupings, many people would argue that the operational concept for indicating monophyly is synapomorphy of qualities, features, or attributes of organisms that become modified and are passed on to descendants. These anagenetic changes represent the synapomorphies that we use as clues for historically derived groupings of individual-like things, and definite criteria exist for discovery of synapomorphies. A synapomorphy, or shared derived character, is evidence for the existence of a supraspecific grouping, or a monophyletic group. There is nothing implied in the definition of a synapomorphy as to where the evidence must be obtained. Evidence for a synapomorphy can be molecular data, morphological data, behavioral data, ecology, etc. All data should provide equivalent evidence for synapomorphy, which in turn provides evidence for monophyly. Interestingly, because all supraspecific, historical groups begin as a single species, then any type or number of attributes that serve as evidence for synapomorphy (monophyly) should be equally valid in the discovery process of a species. If a synapomorphy for a group is discovered based on morphological evidence but no synapomorphies are discovered based on DNA sequences for a particular favored gene, is there inconsistency and should the group be questioned? The same question may also be asked about the discovery and validation process of species. The answer is no. Not all character types are expected to undergo a constant rate of anagenesis or change with every speciation event, otherwise our ability to reconstruct patterns of descent would be hopelessly difficult (Mayden, 1997; Mayden and Wood, 1995). Rather, anagenesis in the common ancestor in this example apparently occurred only with regard to morphological data, and the particular molecular data examined were uninformative with respect to the question at hand. However, both data sets can be considered completely consistent with the hypothesis of monophyly although one data set, the molecular data, is less informative.

Future research may show that some theoretical concept other than monophyly is more consistent with natural order. Likewise, there may be operational concepts discovered that are better than synapomorphy to assist in discovering monophyletic groups. If such new concepts can identify supraspecific groupings that are consistent with the primary concept of monophyly, then they should be considered valid and useful in the discovery process. For example, at one time overall phenetic or genetic similarity were proposed as operational concepts useful in identifying monophyletic groups. Later, however, after the discovery that rates of anagenesis are not equal, these operational definitions and criteria were abandoned by systematists (Wiley, 1981), although some investigators with training in population-level studies incorrectly use phenetic methods for assessing higher-order relationships. Character analysis and synapomorphy remain the most productive means for discovering monophyletic groupings for supraspecific taxa.

It is clear that, like the relationship between the theoretical and operational concepts of monophyly and synapomorphy, we need both theoretical (primary) and operational (secondary) concepts of species (Fig. 1). The theoretical concept must be highly consilient and provide a natural perspective of biodiversity. With regard to species, a number of operational concepts exist that may be employed for the discovery of diversity thought to represent species (Figs. 1,2). The ESC is a non-operational concept that is the most consilient of the various concepts. All of the alternative concepts consistent with this primary concept are considered general methods, guidelines, or criteria, just like synapomorphy, for researchers to use to discover different types of diversity consistent with the ideas presented in the primary concept. These latter concepts have varied criteria for the recognition of species and, as such, the diversity recognized by them will exhibit various levels of inconsistency depending on what is considered valid by researchers holding to a particular concept. This need not be a problem when one adopts the hierarchical perspective involving primary and secondary concepts. While the diversity recognized using the various secondary concepts may be inconsistent at times, this diversity will not necessarily be inconsistent with diversity considered valid under the primary theoretical concept. As with the example on monophyly and the various data types through which a synapomorphy can be identified, species can be discovered in nature using differing general criteria or operational concepts.

Occupational, Organismal, and Data Biases

Because people generally feel more comfortable thinking of class-like things, various formalized rules or practices of the disciplines of taxonomy and systematics tend to lead one to think of species as classes and not as individuals. As such, operational definitions of species seem consistent with the system. For example, taxonomic keys, synonyms, and the practices of type designation and comparisons with other species all tend to treat species as members of classes that have an essence or definition. Thus, when one sets out to identify a species and distinguish it from possible close relatives, one looks for easily used and discrete differences to separate them. These differences serve as definitions (or essences) of species when they are treated as Classes.

Because of the demands of nomenclatorial rules that we superimpose upon nature, it follows that many view species as classes of things rather than as individual-like things. Formalized rules of nomenclature are necessary for the proper functioning of our nomenclatorial system. However, everyone practicing taxonomy and systematics needs to be aware that species are individuals and that nomenclatorial policies or rules with species and supraspecific taxa were contrived by us to simplify bookkeeping in our lives. We like to work with operational definitions that some concepts provide and that ''feel good'' to us. However, we must not forget that individuals do not have definitions—they can only be described and diagnosed, and we only treat them as classes because of operational needs.

Biases in concepts can also be introduced through the types of organisms that particular researchers study, and most concepts derive from sexually reproducing organisms. Some concepts derive from organisms (e.g., birds) with generally good dispersal capabilities, a quality that presumably permits many sister species to exist in sympatry for ''tests'' of the BSC (for an alternative perspective see McKitrick and Zink, 1988). Other organisms have highly fragmented ranges and sister species are largely allopatric, making them inappropriate examples for ''tests'' of the BSC. It is also true that for different groups of organisms, taxonomists and systematists traditionally derive evidence for species validity from different gene or anatomical complexes, behavioral or ecological parameters, or developmental characteristics. Given the differential rates of anagenesis known to exist between or within different groups of organisms for different characters, it is easy to see how researchers of different groups of organisms can easily become focused on a particular species concept, whether or not it is appropriate. The tradition of formulating concepts based on the unique attributes of the groups of organisms studied has contributed to the competition and confusion about species. Under the hierarchy model of species concepts, the existence of multiple operational concepts derived from researchers working with different groups of organisms and types of characters can be productive.

The idea of data impartiality is a big issue and is directly related to the above discussion on organismal bias. When the focus on species is operationally driven and species are treated as classes, data prejudice can result in controversy. Data serve as evidence for heritable markers indicative of common descent or lineage independence, and confidence in different types of data will differ among researchers. Many feel more comfortable with morphological characters, the traditional character base for species identifications. However, not all species differ in external morphology, but rather may differ in breeding coloration, unique behaviors, species-specific calls, chromosome morphology, or genetic information. All of these represent classes of attributes that signify lineage independence through descent. Some may not have confidence in such non-traditional, non-morphological characters, but rather may prefer to have set levels of distinctiveness in order to consider a species ''valid.'' However, technology for identifying lineages has advanced from the hand lens to DNA sequencing, and our theories and concepts must advance as well. The scale has changed and how we interpret these changes in our character bases is critical for identifying species. Thus, our philosophy about character evolution and its implication for lineage independence must also evolve from the day when only those entities that were morphologically distinct in a defined set of characters or a sufficient ditance value represented natural species. Today, genes thought to be useful for the question are selected and sequenced on the basis of availability, or one may rely on a few traditional morphological features to evaluate the evolutionary validity of a species. Because it is clear that not all attributes (genes, morphology, behavior, etc.) of species change at a constant rate or with every speciation event, we should not assume that our ''favored'' types of characters are the only reliable characters for detecting species differences and validating their existence. Because evolutionary modifications may occur on any number of attributes of species during their descent and because species are individuals and not classes, this tendency toward a myopic view of descent and species evolution is inappropriate and has precluded our resolution of the species puzzle.

Returning to the Hierarchy Model

It should be clear from the above discussions that strictly operational conceptualizations of species focused on the identification or discovery of species should not serve as a primary, theoretical concept of species. Because of their operational nature, they are all inherently less consilient with respect to biological diversity than the primary concept. If any of these concepts are identified as the ''best'' and the one to be used in the discovery of diversity known as species, then all we can hope to find will be things that fit this single concept with specific definitional criteria inherent in the operational concept. For example, we might imagine that species include only those that are reproductively isolated from sympatric sister species. If they are sister species but are not sympatric, then they are not species (BSC). Given that most speciation occurs in allopatry, if we accept this notion we miss a sizable number of valid species. We might also imagine that species are only those things that must possess an autapomorphy within a parental pattern of descent (PSC). This requirement automatically excludes all ancestral species because none of them, existing or surviving, will exhibit such attributes (Mayden and Wood, 1995; Wiley, 1981), and limits our ability to describe biodiversity without a phylogeny. We might also imagine that species are only those things that are sexually reproducing and are divergent in specified morphological characters. In this case we exclude all asexual species, whether they are morphologically distinct or not. Thus, all operational concepts taken individually will naturally restrict diversity that can be discovered. However, taken together, these concepts are an important resource in the discovery process within the theoretical constraints of the primary concept of species.

The significance of this hierarchical approach to viewing species concepts and an efficient discovery or inventory of species as byproducts of descent can be illustrated in two simple examples. In the first example (Fig. 3) the bold-lined box represents a ''hypothetical biodiversity space'' conceivable with a primary concept such as the ESC. That is, under the ESC there are varied ''types'' of species that exist in this hypothetical space—some that are genetically divergent for some genes, some that are morphologically divergent, some that are asexual, some that are behaviorally divergent, etc. This box represents the limits of our theoretical primary concept within the constraints of descent with modification. In this same example we first include three operational concepts of species (Fig. 3A) represented by different shapes, concepts I, II, and III. Each of these represents a different area of biodiversity space consistent with what the separate concepts can validate. One should first note that none of these concepts covers as much of the biodiversity space as does the primary concept; each concept is thus incapable of recognizing all of the diversity consistent with the ESC. One should also note that these concepts are compatible with one another in some parts of this biodiversity space (overlapping areas), but that other areas of this space are covered either by only a single concept of species or none of the operational concepts. Using only these three hypothetical con-

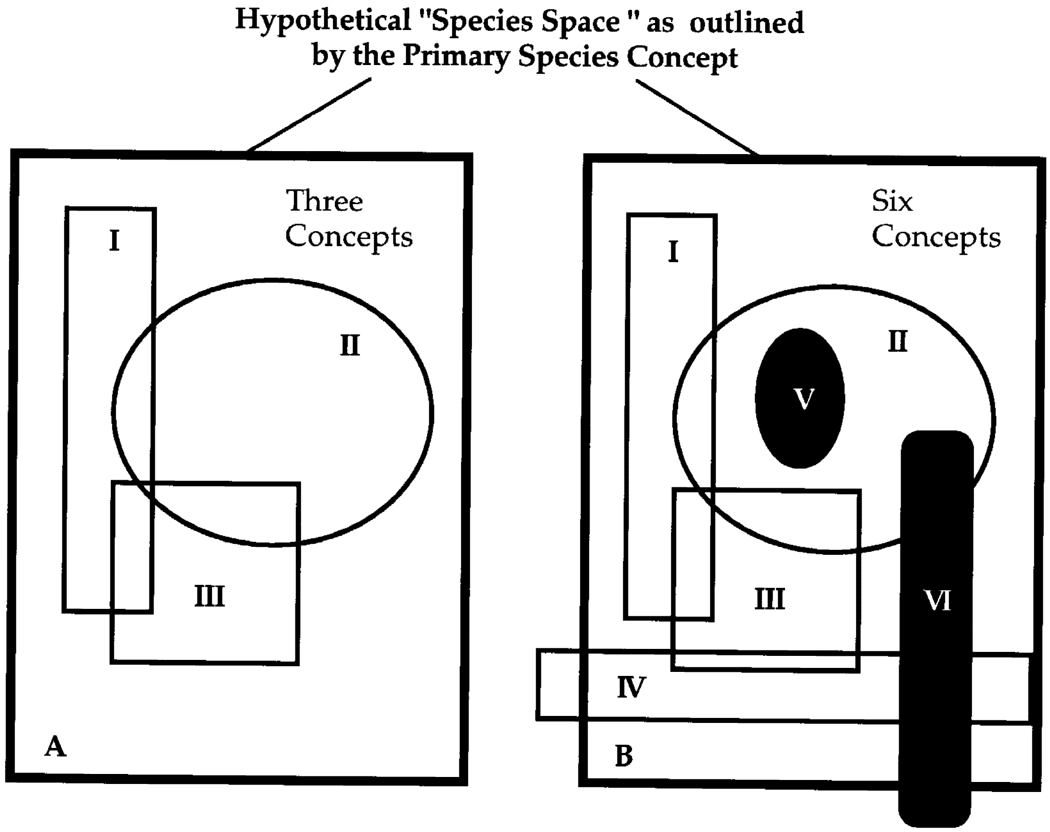


FIG. 3. Graphic representation of a hypothetical "species space" that is conceptualized by the most consilient, primary concept of species (thick border) and how much of this space can be accounted for by operational concepts that are less consilient. A) Three operational concepts, each outlining unique areas of the "species space" and each overlapping where they account for the same species diversity as other concepts. B) Three additional operational concepts are added in the discovery process for species, and we see that more of the hypothetical "species space" can be accounted for, making the process of discovery more effective and efficient. Those concepts accounting for areas that extend beyond the bounds of the primary concept are those that, if misinterpreted, can result in the identification of artifactual things thought to be species but are not because they are inconsistent with the primary concept. An example of this problem would include chronospecies.

cepts one can see that a considerable amount of species diversity can go unrecognized if one adheres to a single operational concept. However, as we incorporate concepts into the discovery process that are consistent with the primary concept, more and more of our natural diversity will be recoverable using these working concepts (Fig. 3B). In adding three additional concepts we see that some of the concepts overlap completely (V vs. II) and the new concepts account for more of the biodiversity space. Concept II may represent morphologically distinct species, and concept V may represent morphologically divergent sister species that are sympatric. This example also includes two concepts that display a peculiar pattern. That is, concepts IV and VI account for diversity outside of the hypothetical space outlined by the primary concept. The extension outside of the area delineated by the primary concept represents artifactual diversity and recognition of invalid species, owing to poorly conceived concepts (e.g., artificial constructs like chronospecies or successional species).

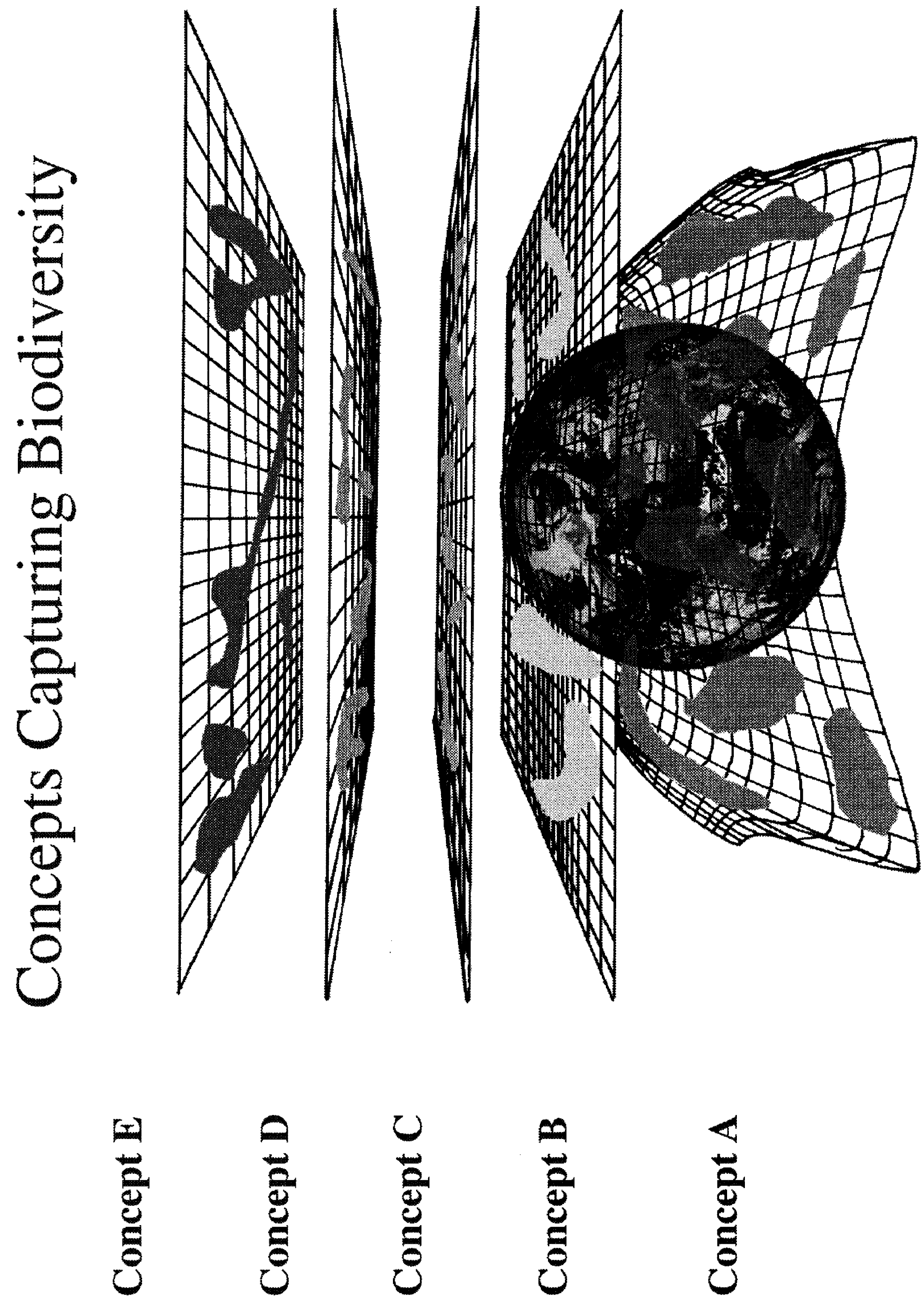
This example demonstrates that if one adheres strictly to any of the various operational species concepts that are demonstrably less consilient in their accounts of biodiversity than the ESC, then the amount of diversity that can be recognized will be much less than what actually exists. However, if one accepts that these concepts are simply operational tools or guidelines that we use to discover diversity consistent with the primary concept, then our ability to account for natural diversity produced through descent will be much more efficient and productive. Nearly all of the various operational concepts of species are good at discovering species, but each has its limitations.

The second example also illustrates the importance of the hierarchical approach to understanding species concepts and the importance of having a primary, highly consilient concept of species. Consider Earth to represent our current understanding of the location or spatial limits of species. How do we capture or recover this information on biodiversity from our planet? Here again, a primary, theoretical concept of species like the ESC plays a critical role in this process in that it provides the important unified conceptual framework. In this example the ESC, being the most consilient of the concepts and capturing the unity of all of the various species in nature, serves as a conceptual net that is complete and can be ''cast out'' over Earth and provide the broad conceptual framework necessary to discover diversity thought to represent species. If we drop this net onto Earth all types of species diversity will be colligated under this concept. However, this diversity can be found only if we have appropriate operational concepts to serve in the discovery process.

All of the secondary concepts are also represented as nets that can be cast upon Earth to ''capture'' species diversity (Fig. 4). How effective are these types of concepts in accounting for biodiversity on Earth? Each concept, of course, has inherent limitations as to the type of biological diversity, or species, that it will recognize. These limitations in discovering the varied types of species are graphically illustrated here as holes in the operational nets where diversity cannot be accounted for with a given concept. Each operational concept is, represented by a net and will have a unique pattern of ''holes or openings'' prescribed by the concept's discovery methods, where it is incapable of accounting for known biological diversity. For example, if a concept is applicable only to sexually reproducing species, it is unable to account for the abundance of asexually reproducing species. If the concept, like the BSC, is applicable only to sexually reproducing sister species that are sympatrically distributed, then it will have a much larger series of holes because so few species actually exist in nature under these conditions. If a concept requires the presence of autapomorphies, then holes will exist in its net where all ancestral species will be missed in the discovery process.

Theoretically, if any of these nets is cast upon Earth (Fig. 4) with the intent of recovering diversity, the only species that will be recognized will be those in the regions where the net is intact. All five of the hypothetical concepts (A-E) have areas where they are unable to recover naturally occurring species diversity (Fig. 4). Individually, each net is incomplete in its ability to discover all species-level biodiversity. In a theoretical sense, however, the holes in each net could be in different locations, making many concepts compatible.

The ''discovery nets'' of the same five concepts can be illustrated without Earth (Fig. 5). In this example the vertical lines with arrows represent four typical species that might be found in nature. For example, one may represent an asexually reproducing clone vector that is divergent morphologically, one may represent a species divergent chromosomally, a third might be behaviorally divergent, and the fourth could be a sexual species with morphological divergence. Each represents an independent lineage consistent with the primary ESC. As the various nets (Fig. 5) are dropped over this species diversity, some will recognize them as species, others will not. In this example, species I will be recognized only by concepts B and E; concepts A, C, and D have definite criteria that will not permit the recognition of these lineages as species. Species II will be recognized only by concepts A, B, and C. Because divergence in traits is a random phenomenon in the process of descent, it is highly unlikely that any species will ever be


Concepts Capturing Biodiversity
Concept E
Concept D
Concept C
Concept B
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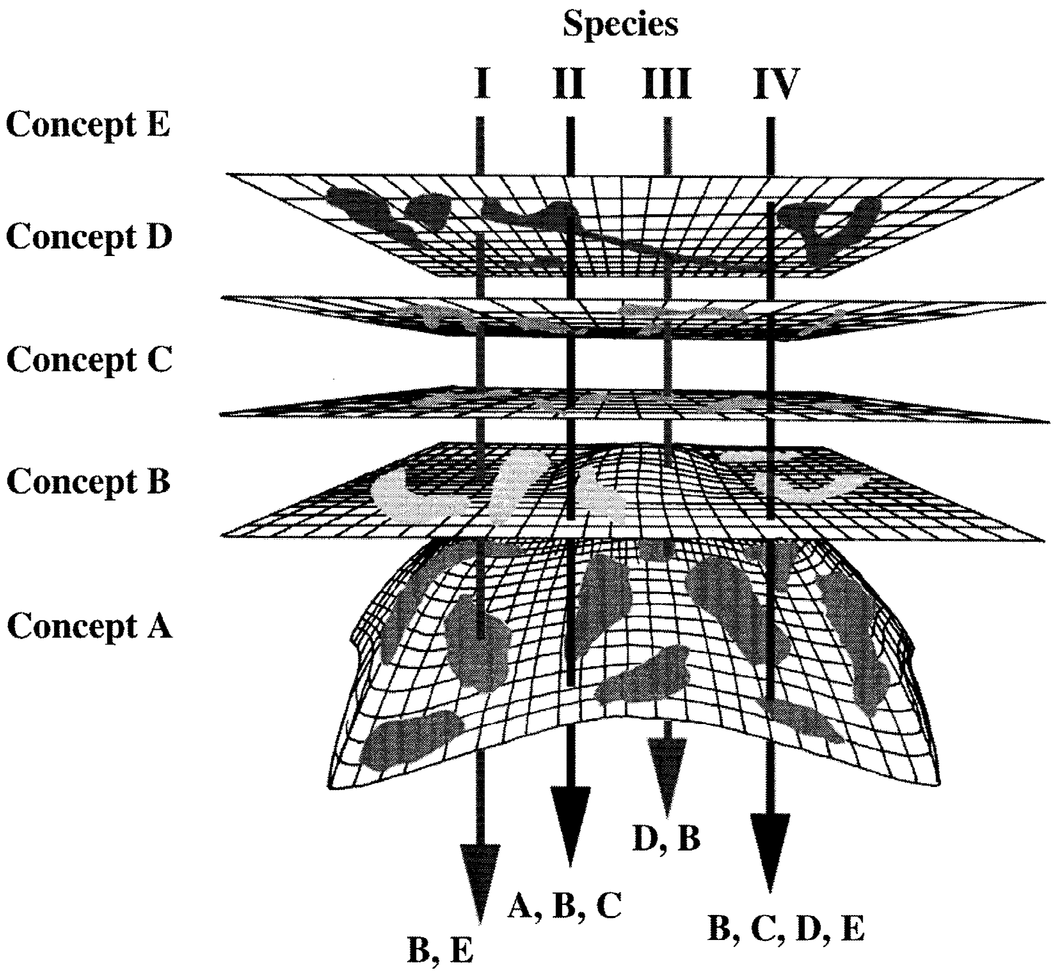

FIG. 5. Five secondary, operational concept nets used to examine how effective each is in recognizing four hypothetical species (vertical lines). The holes in each net represent areas where individual concepts are incapable of recognizing species diversity because of operational criteria. Where the species (vertical line) passes through a hole in a net, the species will not be recognized by that concept. In this example the four different species would never be consistently recognized by all of the concepts. However, with the nets combined, all of the species are recognized by one or more of the concepts. Concept B is useful in recognizing all four of the species; concept A is only useful in recognizing one of the four known species.

consistently recognized by all available operational concepts.

The nets complement one another in an effective discovery process, and those areas where holes exist in one net likely will be covered by other nets. In this hierarchical system invoking a highly consilient primary concept (ESC), it should be obvious that the various individual operational concepts of species are incomplete in their abilities to aid in the discovery of species. Taken in combination, the nets (concepts) provide a more complete network to account for diversity under the primary concept and make

FIG. 4. Five secondary, operational species concept nets being cast on Earth to ‘‘capture’’ or discover diversity thought to represent species. Note that because each net represents a different operational concept, each will possess a unique set of holes where biological diversity inconsistent with the operational concept will not be recognized. As compared with the net in Figure 5, this illustrates how operational concepts are inherently less consilient. However, if these nets are combined and used to complement one another, the holes of one net will be ‘‘covered’’ by another concept or net, making the discovery process of species more effective and efficient.

the discovery process more effective and efficient. Thus, I propose that all of the applicable operational concepts consistent with the theory of descent with modification and the ESC be considered equally important in the discovery process of species. These operational concepts, along with new ones that will be developed, have the potential to form a complete network that can account for species diversity on Earth.

Too Many Species, or Is There a Glass Ceiling on Biological Diversity?

Following from the above argument for a hierarchical system and the unity of operational concepts, some may fear one logical and possible outcome—*there will be just too many species recognized as valid*. This may well be one of the most obvious ramifications of my arguments and will cause some to reject the idea. They may ask, ''How is it possible for all of the various concepts of species to be equally valid in the process of discovering species?''

Descent with modification is a theory that predicts that various attributes of organisms become modified in unpredictable manners. Nothing in the theory argues that speciation is a process that produces species that are morphologically distinct. Nor does the theory require species to have minimum levels of divergence for specific genes that we can sequence, chromosomes that we can visualize, recognition systems that we ''think'' serve as isolating mechanisms to limit gene flow, three or more divergent attributes, or at least one autapomorphic character. The theory of descent is highly consilient because it is capable of colligating the tremendous array of facts regarding the biodiversity that has resulted from the process. The various operational concepts of species that have been developed over the last century have individually focused on some of this diversity. These concepts were developed by scientists working with certain taxonomic groups of organisms and particular types of data.

If these various concepts were developed from naturally occurring diversity, why would it be a problem to use them all as methods, tools, or guidelines for discovering diversity? An accurate account of diversity and its classification is critical to many areas of science. Persons from many disciplines look to taxonomists and systematists for accurate information on species diversity. For some, species are only convenient groupings of organisms that we impose on nature. Others are confident that species exist regardless of whether we ignore them based on selected operational criteria. In a review of the RSC and its comparison with the BSC, Paterson (1993) noted that physicians, especially those practicing tropical medicine, are more interested in knowing great details of species diversity and less interested in how many species there may be based on different concepts than are many taxonomists and systematists. Why is this so? Physicians practicing tropical medicine often must deal with species that are vectors of diseases and do not care if these species have one vs. three diagnostic traits or if they are morphologically distinct based on characters of the genitalia. They are happy to know that in a complex of similar organisms there are different species, of which only some may serve as vectors for disease. The case of cryptic species of *Anopheles* and malaria in Europe serves as another important example of how accurate accounts of species diversity are critical to many areas of science (Mayr, 1969).

In my opinion those who will have the most difficulty recognizing the validity of the various operational concepts for discovering species are those who worry too much about ''Where will it all end?'' These same people ask, ''How many species can there possibly be?'' It is almost as if they worry about not having the security of being able to know all of the species names. Alternatively, they may be unconvinced that descent with modification and speciation produces biological diversity in a tremendous array of attributes. Whatever form the divergence takes, the descendants are species even if an ecologist, conservation biologist, or taxonomist favoring a particular suite of characters may not understand this. It may be inconvenient to identify something that differs only by genetic characters or slightly different morphological characters, or by characters found only in breeding males for only 3 weeks out of the year. However, these ''inconveniences'' that nature throws at us should not cloud our thinking or our mission.

The mission of the science of taxonomy and systematics is to discover, describe, and classify biological diversity, regardless of how much there may really be out there. As researchers and teachers of these disciplines, we are all engaged in science and we should not work in a philosophical vacuum on this important issue. To artificially limit the amount of biological diversity, for whatever bias, only limits our ability to understand natural patterns and processes associated with it. Such a mind-set places an artificial ceiling on biodiversity, impedes progress, and has major ramifications for the eventual loss of biological species because of neglect. No other discipline has the power or desire to place limits on the number of species; artificial limits to diversity are being set by practitioners of taxonomy and systematics. Researchers in many fields desire knowledge of diversity because it makes their own experimental designs more effective. If the patterns of biodiversity are inaccurate, then the processes derived from these artifactual patterns will likewise be inaccurate. Thus, as taxonomists and systematists we must abandon any possible fears of too much diversity and use our available tools and knowledge to recover the natural diversity that has resulted from the processes of descent with modification and speciation.

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