

LETTER TO THE EDITOR

FIVE KINGDOMS—REFLECTIONS UPON THE CLASSIFICATION OF ORGANISMS

For over the past 3 decades, there have been profound advances in the classification of organisms, both living and extinct. This is a matter of central importance to biology and biologists. Surprisingly, the fact seems to have escaped the notice of many of our more specialized colleagues. Therefore, as the relevant taxonomic changes clarify the true systematic position of various aquatic microorganisms intimately concerned with issues of larval mosquito ecology and biocontrol, topics presently receiving unprecedented attention, it seems timely to bring the implications of R. H. Whittaker's 5 kingdoms to the attention of all culicidologists.

The crux of the matter is that while it is self-evident that all of us must refer to precisely the same taxa under such group-headings as bacteria, algae and protozoa in ecologically oriented investigations, those concerning larval nutrition for example, whole phyla which until a couple of decades ago had been long-established within one of these 3 groups have lately been switched to another. A case in point is that of the "blue-green algae," the thousands of living species of which are now recognized as the blue-green bacteria. This particular change has been overdue since Ernst Haeckel first argued for it almost 125 years ago. Like many others, it has now been precipitated by the new technology of biochemistry and electron microscopy. All of which leaves the uninitiated in much the same situation as fairground visitors wondering which eggcup the coin will be under this time!

Before a simple demonstration of how chaos in the presentation of research findings relating to, e.g., larval mosquito nutrition must inevitably follow failure to face up to the present reality of 5 kingdoms, a brief review of the recent accretion from 2 is in order. Those first 2, the animal and vegetable ones recognized by the Greek fathers of zoology and botany some 2,300 years ago, remained the basis for biological classification long after not a few current AMCA members had completed their tertiary education. True, almost a century before Carolus Linnaeus had developed our system of binomial nomenclature, Antonie van Leeuwenhoek's homemade microscope was complicating matters by beginning to raise the curtain on a whole

new world of "animalcules." Knowledge of these microorganisms had progressed by the 1860s to the point where Ernst Haeckel commenced his lengthy campaign to have them recognized as a third kingdom of organized beings, the Protista (meaning "the very first").

Well aware that Haeckel was also credited with coining the word "oecology" (although Americans will be delighted to learn from Vol. 1, A-G of "A Supplement to the Oxford English Dictionary," 1972, that Thoreau had anticipated him, using the spelling "ecology" too, in a letter dated January 1, 1858), those of us completing our higher education in the 1930-40s were both appreciative of the obvious good sense of making appropriate provision for the classification of single-celled organisms as a separate kingdom from the Animalia and Plantae, and puzzled by the total neglect of the Protista in most of our textbooks. And so, by the mid-1950s, H. F. Copeland was, as technological improvements were gathering momentum, proposing a 4-kingdom arrangement of life forms that he had already been working on for 2 decades. From the rash of alternative schemes that followed, the 5-kingdom one unveiled in 1959 by R. H. Whittaker stands out. This system was improved by its author over the next decade; and in 1978, just 2 years before Whittaker's untimely death, he and L. Margulis presented a version that has since been steadily gaining widespread adoption.

Helpfully illustrated, a detailed account by Margulis and K. V. Schwartz, listing 91 phyla distributed among the 5 kingdoms, appeared in 1982. It retained the name that Haeckel had selected for anucleated organisms—the bacteria and "blue-green algae"—within a major group of his proposed kingdom Protista. This was Monera [= single (-celled)], now elevated to kingdom-status. The Fungi were likewise elevated, and the kingdoms Animalia and Plantae of course retained. However, Haeckel's euphonious Protista was replaced by the name Protoctista (= "very first establishment") which J. Hogg had published some 5 years before the great German protagonist for Darwinism, assigning it to a fourth kingdom; embracing both "Proto-phyta . . . and *Protozoa*" to reinforce the Animalia, Plantae and a long-abandoned inanimate

(Mineral) kingdom that had been proposed by M. R. Besler back in 1642.

As a designation for primordial plants and animals published in 1860, only a year after Charles Darwin's "The Origin of Species by Means of Natural Selection," the unhappily ugly name of Protoctista clearly merits consideration for retention, despite the fact that its meaning would be far more appropriate for the Monera. Personally, I should like to associate myself with R. S. K. Barnes and J. O. Corliss, both of whom, in 1984, opted for the retention of Protista. And really, the support of Margulis and Schwartz for Copeland's advocacy of Protoctista on the grounds of its being absurd to call giant kelp by a name (i.e., protist) "that had come to imply unicellularity and thus, smallness" is rather slight. For Haeckel's choice of a kingdom-name meaning "the very first" for the microorganisms, surely had evolutionary rather than size implications.

In the second, 1988, edition of the "Five Kingdoms . . ." of Margulis and Schwartz (see list of recommended reading below), these authors chose to replace Haeckel's other euphonious name, Monera, by the harsh-sounding and eminently forgettable "new name Prokaryotae (*pro*, before; *karyon*, seed, nucleus)" solely because this was introduced in "the new edition of *Bergey's Manual of Systematic Bacteriology*. . . ." Apter though it may be, surely Monera's precedence by a century and a quarter should prevail, if only to honor Haeckel in the slow sequence of events that he initiated towards our new and soundly based 5 kingdoms. I must hasten to add that soundly based though these are, there is as always internal and external disagreement among the currently active taxonomists. This makes it sufficiently confusing for us retired generalists with time on our hands to keep abreast of relevant happenings. For super-specialists, though, shutting one's mind to the whole thing seems understandable enough in a day when framing enticing grant proposals is increasingly time-consuming, and indeed essential to career prospects. Hence this letter.

Thus, the names of the kingdoms are (aside from the oldest-established ones, Animalia and Plantae, and the Fungi, of recent promotion—of which more anon) in a state of flux. To cite only 3 relevant books of the past decade, 2 of them by the same authors (references below), the 1982–88 versions of the system read rather like a reflection of some recently independent nations vs. the Founding Fathers in the UN:—

1982 (1st ed, Margulis and Schwartz) Monera
Protoctista Fungi Animalia Plantae
1984 (Sleigh et al., in Barnes, ed.) Monera
Protista Fungi Animalia Plantae

1988 (2nd ed, Margulis and Schwartz) Prokaryotae
Protoctista Fungi Animalia Plantae

Worse news is to follow. There is not only internal disagreement about the current number of recognizable phyla (Margulis and Schwartz plumped for "almost 100 phyla" in the preface to their 1982 edition, actually listing 91, augmented by a 92nd in 1988), but Barnes and his collaborators (1984) allowed only "the equivalent of 70 phyla."

Interestingly, too, Margulis and Schwartz (both editions) and Sleigh et al. (in Barnes, ed., 1984) each list 27 phyla in the kingdom Protista (or Protoctista?)—but less than half of their phyletic names correspond! Those that do are 10 with botanical terminations, the Chrysophyta, Haptophyta, Euglenophyta, Cryptophyta, Xanthophyta, Eustigmatophyta, Bacillariophyta, Phaeophyta, Rhodophyta and Chlorophyta, plus 2 protozoan ones, Ciliophora and Apicomplexa. The 2 last-mentioned ones are similarly presented in "An Illustrated Guide to the Protozoa" published under the authority of the Society of Protozoologists in 1985.

That book lists some of the above "algal" groups as protozoa, the Chrysophyta as order Chryomonadida, Haptophyta as order Prymnesiida, Euglenophyta as order Euglenida, Cryptophyta as order Cryptomonadida, Xanthophyta (in part) as order Heteromonadida, and Chlorophyta (in part) as order Volvocida. These orders are all placed within the class Phytomastigophorea (= "plant-like flagellates") of subphylum Mastigophora— = by derivation, whip-bearer, the "whips" having long been termed flagella (latterly, undulipodia). This subphylum and 2 others, the Opalinata and the Sarcodina, comprise the phylum Sarcomastigophora. A second class of the Mastigophora, the Zoomastigophorea (= "animal-like flagellates") includes such familiar genera as that containing the sleeping sickness parasites, *Trypanosoma*—with which Margulis and Schwartz lump the Opalinata in their phylum Zoomastigina, while another of their phyla, Rhizopoda, embraces all amoebae except those having axopodia, which become their phylum Actinopoda. The latter and Rhizopodea are superclasses of the phylum Sarcodina, according to the Society of Protozoologists' recent guidebook. Such disharmonies make it painfully clear why it took so long for Haeckel's kingdom Protista to be adopted. Now that it is up and running, surely a sensible step to keep things moving along progressively would be to settle the issue of Protista versus Protoctista by negotiation among all interested parties?

Happily, there is no argument whatsoever

about the phycological status of diatoms (Bacillariophyta), green algae (Chlorophyta)—minus the volvocids, but including many seaweeds—and those other brown (Phaeophyta) and red (Rhodophyta) seaweeds too. However, there is no longer any excuse for confusing the 800 or more (mostly grass-green) euglenids with microscopic chlorophytans. The latter, like other algae, are almost entirely photosynthetic. The vast majority of protozoans, though, derive their nutrition from *eating*, euglenids included. It is perfectly understandable in terms of evolutionary biology, that protistan protozoans and algae are separated by a twilight zone populated by representatives from both sides of the border practicing *both* nutrition strategies. And it is equally comprehensible that both phycologists and protozoologists striving for research grants in today's harshly competitive climate will continue to obfuscate the issue until the latter are inevitably vindicated in their rational views over the true status of the Chrysomonadida, Prymnesiida, Cryptomonadida, Heteromonadida and volvocid "green algae", not to mention the multitudinous fossilized and living Foraminiferida, as orders of the protistan phylum Sarcomastigophora, subkingdom Protozoa.

The recommended publications below contain good and sufficient reasons for that statement. However, a persuasive presentation of the relevant arguments would fill whole issues of AMCA's *Journal*, besides being less than absorbingly interesting to a readership which nevertheless, may not be startled to learn that 2 genera familiar for decades as fungal pathogens of mosquitoes and candidate biocontrol agents, are no longer what they were until recently represented as being.

These genera are *Coelomomyces* and *Lagenidium*. Both were lately banished from the kingdom Fungi for their possession of flagella (= undulipodia) at a certain stage of the life cycle. Both now cower in the kingdom Protista. There, *Coelomomyces* has taken refuge within the phylum Chytridiomycota while awaiting the development of a practical *in vitro* cultivation methodology; while the loyalties of *Lagenidium* have been transferred to the phylum Oomycota (according to Margulis and Schwartz) or Phycmycota (according to Sleight et al.).

Now, none of these taxonomic maneuverings are as irrelevant as not a few culicidologists may suspect. To establish this, let us consider a hypothetical case. Let us suppose that a researcher studying the potential food and ingestion practices of larval mosquitoes, and being unaware of the pertinence to her/his work of the recent eclipse of an archaic 2-kingdom classification system based on such plants and animals as were apparent to the ancient Greeks, is evalu-

ating lists of his/her microorganisms returned by equally time-warped colleagues each with profound taxonomic expertise in some particular discipline.

Let us further suppose that a phycologist has been helpful enough to provide species-names for, say, 11 of the legion of "blue-green algal" species (organisms which, being very ancient indeed, are nowadays largely cosmopolitan); and that a colleague of his with broader taxonomic interests has identified from the samples sent to her, 31 species of "Euglenophyta," 6 of Chlorophyta (including 2 volvocids) and 3 of "Chrysophyta." While all these and 11 Bacillariophyta worked upon by a diatomologist add up to 62 "algae," we must finally suppose that other systematists have augmented the list by other species of microorganisms—say, 5 free-living and filamentous bacteria, 11 of Ciliophora and 4 of Sarcodina.

Our culicidologist, lacking—as is not unlikely today—personal taxonomic abilities concerning microorganisms, will be delighted enough to receive these reports back while still young and enthusiastic enough to make use of them in a scientific paper. This, duly published, will indicate to the readers that the relative proportions of algal, protozoal and bacterial species in the samples in question were 75.6%, 18.3% and 6.1%, respectively. Submission of the overall list to a bacteriologist and state-of-the-art protistologist with particular competence in protozoology would, however, have produced a very different conclusion. For recognition of the 11 species of "Cyanophyta" as Cyanobacteria, and of the 31 euglenids, 3 chrysomonadids and 2 volvocids as protozoa would have transformed the relative proportions of the 3 major groups of microorganisms to: protozoa, 62.2%; bacteria, 19.5% algae, 18.3%.

At the very time when the growing demand for "environmentally friendly" solutions to pest and vector suppression problems is accelerating the development of integrated mosquito control methodologies and pest management strategies combining efficacy and ecological acceptability, it has therefore become vitally important that all those undertaking relevant investigations are adequately informed on how systematic changes resulting from the 5 kingdoms concept may affect their data analysis and conclusions resulting therefrom. Orientation workshops guided by advocates of the differing taxonomic viewpoints that have been touched upon in this letter would be one way of achieving the necessary dialogue. Meanwhile, some relevant sources are listed below (you will find the insects under phylum Arthropoda, subphylum Uniramia, in Margulis and Schwartz, and phylum Uniramia, subphylum Hexapoda, in Barnes).

RECOMMENDED READING¹

- Barnes, R. S. K. (ed.). 1984. A synoptic classification of living organisms. Blackwell Scientific Publications, Oxford.
- Copeland, H. F. 1938. The kingdoms of organisms. *Quart. Rev. Biol.* 13:383-420.
- Copeland, H. F. 1956. The classification of lower organisms. Pacific Books, Palo Alto.
- Corliss, J. O. 1984. The kingdom Protista and its 45 phyla. *BioSystems* 17:87-126.
- Laird, M. 1988. The natural history of larval mosquito habitats. Academic Press, London.
- Lee, J. J., S. H. Hutner and E. C. Bovee (eds.). 1985. An illustrated guide to the protozoa. Society of Protozoologists, Lawrence, Kansas.
- Margulis, L. and K. V. Schwartz. 1982, 1988. Five kingdoms. An illustrated guide to the phyla of life on earth. W. H. Freeman, New York.
- Sleigh, M. A., J. D. Dodge and D. J. Patterson. 1984. Kingdom Protista. pp. 25-88. *In*: Barnes, R. S. K. (ed.), A synoptic classification of living organisms. Blackwell Scientific Publications, Oxford.
- Whittaker, R. H. 1959. On the broad classification of organisms. *Quart. Rev. Biol.* 34:210-226.
- Whittaker, R. H. 1969. New concepts of kingdoms of organisms. *Science* 163:150-160.
- Whittaker, R. H. and L. Margulis. 1978. Protist classification and the kingdoms of organisms. *BioSystems* 10:3-18.

¹ Plus a very pertinent review, to hand since this Letter was submitted—Rothschild, L. J. 1989. Protozoa, protista, protocista: what's in a name? *J. History Biol* 22:277-305.

Marshall Laird
 "Awahware," Pahi Road, R.R. #1
 Paparoa, New Zealand