New Concepts of Kingdoms of Organisms

Evolutionary relations are better represented by new classifications than by the traditional two kingdoms.

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There are those who consider questions in science which have no unequivocal, experimentally determined answer scarcely worth discussing. Such feeling, along with conservatism, may have been responsible for the long and almost unchallenged dominance of the system of two kingdoms—plants and animals—in the broad classification of organisms. The unchallenged position of these kingdoms has ended, however; alternative systems are being widely considered (*1–18*) and are appearing in many introductory biology texts (*19–24*). My purpose in this article is to discuss the merits of two classifications which depart from the traditional two kingdoms, the systems of Copeland (*1–3*) and Whittaker (*4*, *5*).

Two-Kingdom System

Man is terrestrial, and he sees around him two major groups of organisms of very different adaptation to nutrition on land—the photosynthetic, rooted, higher plants, and the food-ingesting, motile, higher animals. So distinct in way of life, direction of evolution, and kind of body organization are these groups that a concept of dichotomy—plants versus animals—is almost inescapable if they are considered by themselves. The two groups became the nuclei around which concepts of the plant and animal kingdoms were developed by early naturalists. The kingdoms have been part of the formal classification of living things since Linnaeus (*25*).

Mosses, liverworts, and macroscopic algae are clearly plants in their photosynthetic and nonmotile way of life, and (though the photosynthetic process itself was not understood by early naturalists) these forms were grouped with the higher land plants. The higher fungi on land are nonmotile, and their apparently "rooted" manner of growth suggested the plants. It thus seemed reasonable to assign fungi to the plant kingdom, and some students believed that they had evolved from algae. The wealth of unicellular life discovered by microscopists offered greater difficulty. Some forms were motile and ingested food, however, and were naturally regarded as one-celled animals or protozoans. Others were nonmotile and photosynthetic, hence one-celled plants. There remained a wide range of unicellular forms in which nonmotility and flagellate or pseudopodial motility, and ingestive, photosynthetic, and absorptive nutrition, were combined in various ways which were neither clearly plant-like nor animal-like. In a number of cases plant-like and animal-like unicells were connected by a series of closely related intergrading forms within the same major taxon. There remained also the bacteria which, though few are photosynthetic and many are motile, seemed better treated as plants because of their walled cells. The plant and animal kingdoms are products of a process of concretion, by which groups of organisms which were aquatic, or fungal, or microscopic, or more than one of these, were added around the nuclear concepts of plant and animal derived from higher land organisms.

It was recognized that the two-kingdom system came into difficulties in treatment of the unicellular organisms, since some groups of these were claimed both for the plant kingdom by botanists and for the animal kingdom by zoologists. The system seemed, however, a reasonable treatment of the living world in terms of two kingdoms and evolutionary directions (Fig. 1). In time the system seemed not reasonable but axiomatic; suggestions of other kingdoms were regarded as the idiosyncrasies of individuals. There were such suggestions, however, as the limitations of the two-kingdom system became more evident. I have reviewed proposals for other kingdoms in more detail elsewhere (*5*).

Limitations of the Two-Kingdom System

The difficulties of the two-kingdom system may be summarized in relation to four points.

1) *The protists.* The most obvious difficulty is that for which we use *Euglena* and its relatives as the exemplar for students—the intergrading combinations of plant and animal characters, the fusion of the kingdoms, among unicellular organisms. Because of the impossibility of clear division of the unicells into plants and animals, a number of authors suggested third kingdoms of lower organisms (*26–32*). Hogg (*26*) observed the intergradation of plants and animals among lower forms and proposed for them the *Regnum Primigenum* and the term "Protoctista." Haeckel (*29*) proposed separating the lower organisms as the kingdom "Protista." Haeckel included the sponges in this kingdom in one treatment (*29*), and the fungi in another (*30*); but the kingdom comprised primarily, and in later treatments (*31*, *32*) only, the unicellular organisms.

Although content of the third kingdom of lower organisms and use of "Protoctista" and "Protista" have varied, two principal possibilities may be distinguished. The lower kingdom may either comprise only unicellular organisms (including those forming colonies of unicells), the kingdom Protista of Haeckel (*29–32*) and others (*33*, *20*, *21*, *5*, *14*), or the lower kingdom may comprise the unicells plus other organisms which lack the kind and degree of tissue differentiation characteristic of higher plants and animals, thus including fungi and most or all algae, the kingdom Protoctista of Hogg (*26*) and Copeland (*3*). (In either of these concepts bacteria and blue-green algae may be excluded as indicated below.)

Some authors (*10*, *12*, *15*, *19*, *22*) prefer the more familiar term "Protista" for the second concept. Different inter-

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pretations of the Protista are possible from Haeckel's own treatments of the kingdom. Protists are conceived (*29, 31*) as unicellular and as organisms which form no tissues [in a later statement (*32*), ". . . organisms which as a rule remain unicellular throughout life (monobia), less frequently they form loose cell communities (coenobia) by repeated cleavage, but never real tissues."]. They are contrasted with the tissue-forming organisms of the kingdom Histonia, comprising the Metaphyta (including higher fungi, higher algae, and higher land plants) and Metazoa (multicellular animals).

From this contrast of unicellular and tissue-forming conditions, the difficulty has resulted. Kingdoms defined by the unicellular condition and by somatic tissue differentiation exclude a broad middle ground, occupied by organisms which lack evident somatic tissue differentiation but are clearly multicellular or multinucleate as organisms, as indicated by cell differentiation and interdependence (sponges), or somatic organ differentiation (higher algae, mosses), or differentiation of reproductive tissues and organs (higher fungi). I suggest in consequence that the Protista may best be defined not by lack of tissue differentiation but by lack of tissue formation —absence of integration of cells (or nuclei and cytoplasm) into the one or more tissues of a multicellular (or multinucleate) organism. Tissue differentiation in some lower multicellular and multinucleate organisms (some algae, fungi, and sponges) is limited to a single somatic tissue, plus reproductive cells, tissues, or organs distinct from it. For clarity and consistency terms and concepts for the lower kingdoms will be distinguished throughout this article. The kingdom Protista comprises organisms which are unicellular or unicellular–colonial and which form no tissues. The alternative kingdom, Protoctista, will be conceived, as by Copeland (*3*), as a broader kingdom of unicellular, multicellular, or multinucleate organisms which mostly lack somatic tissue differentiation, including higher algae and fungi.

2) *The monerans.* Haeckel (*29–32*) regarded the bacteria and blue-green algae as protists without nuclei and placed them in the group Moneres or Monera, subordinate to the kingdom Protista. Recent work has made more evident the profound differences of organization between bacterial cells and those of other organisms (*19, 34*). Cells of bacteria and blue-green algae lack mitochondria and plastids, nuclear membranes and mitotic spindles, the endoplasmic reticulum and Golgi apparatus, vacuoles, and advanced (9+2-strand) flagella, among the organelles characteristic of the cells of other organisms. Nuclear material is probably a single strand of DNA without histones, dividing by means other than mitosis; sexual reproduction is apparently both infrequent and incomplete in the sense that only partial recombination of genetic material of cells may result from bacterial conjugation and other processes. Bacteria and blue-green algae also resemble one another and differ from other organisms in biochemical characteristics, including their method of ornithine synthesis, the apparently limited occurrence of sterols, sensitivity to antibiotics, and cell-wall composition (*35, 36*).

These contrasts between the procaryotic cells of bacteria and blue-green algae, and the eucaryotic cells of other organisms, define the clearest, most effectively discontinuous separation of levels of organization in the living world (*19, 37, 38*). The idea of ancient cellular symbioses, and the evolution of chloroplasts from blue-green algae and mitochondria from aerobic bacteria living within other unicells, offers an attractive suggestion on the origin of part of this difference of organization (*39*). Margulis (*38*) has added a further, more striking hypothesis—origin of the (9+2-strand) flagellum and the centriole and spindle figure of the eucaryotes from a symbiotic, spirochaete-like organism—and on the basis of this hypothesis and other cytological and biochemical evidence considered the phylogenetic pattern of the living world. Symbiotic origin of the eucaryotic cell is accepted as a hypothesis here, but the difference between procaryotes and eucaryotes remains a line of division deserving recognition in a current system of broad classification. The bacteria are not plants in either way of life or evolutionary relation to other plants; and the blue-green algae, which are functional plants, are widely separated in their cell organization from all other plants. Most authors who consider alternatives to the two-kingdom system separate the bacteria and blue-green algae as either a subkingdom of the Protista (*9, 5*) or more commonly as the kingdom Monera (*1, 7, 8, 10, 12–15, 22, 24*) or Mychota (*2, 3*).

3) *The fungi.* Are the fungi plants, if the bacteria are not? There are reasons to judge that they are not (*40–45*). (i)

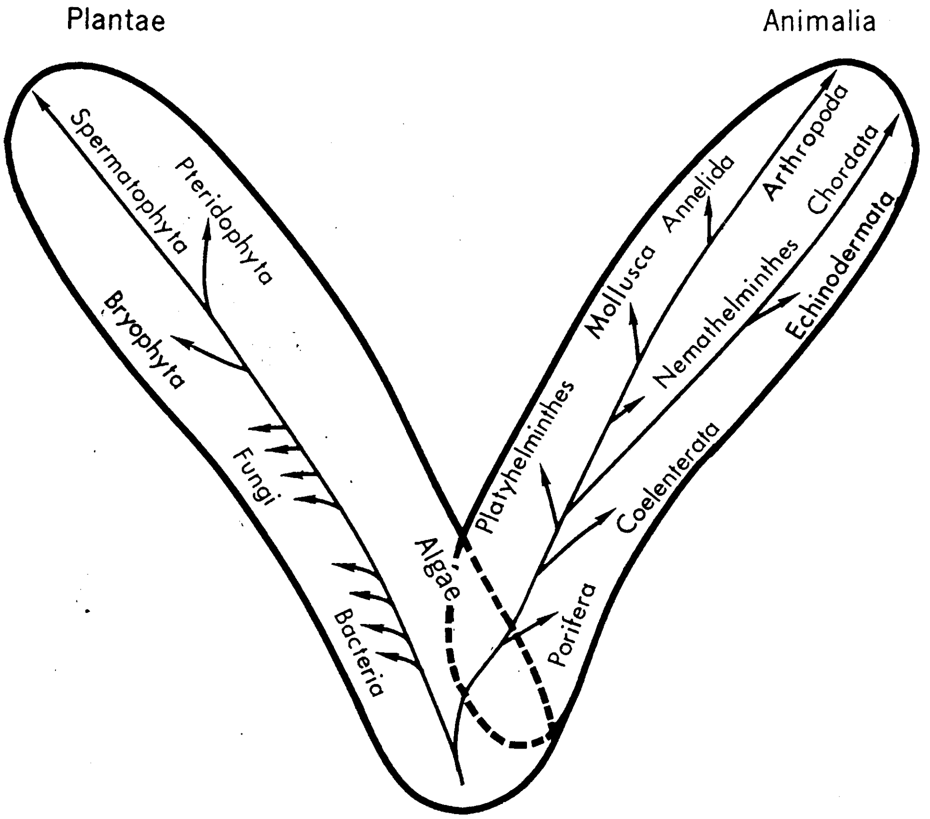

Fig. 1. A simplified evolutionary scheme of the two-kingdom system as it might have appeared early in the century. The plant kingdom comprised four divisions—Thallophyta (algae, bacteria, fungi), Bryophyta, Pteridophyta, and Spermatophyta. Only major animal phyla are indicated.

They were separately derived from the unicells. Although earlier authors speculated on derivation of fungi from algae (*46, 47*), it now seems likely that the lower fungi (chytrids and others) include a number of groups polyphyletically derived from different colorless flagellate ancestors, and that the higher fungi (Ascomycetes, Basidiomycetes) were derived from one of these groups of lower fungi (*40, 43, 48–50, 36*). (ii) Their organization is very different from, and nonhomologous with, that of the plants (*44, 45, 4, 5*). The characteristic somatic organization of the higher fungi, the syncytial mycelium with protoplasm flowing in a system of tubes, could hardly be less like that of the true plants. Reproductive structures and the dicaryotic condition (combining nuclei of different individuals in the same syncytial or multinucleate tissue without nuclear fusion) are different from, and nonhomologous with, the reproductive structures and diploid condition of the higher plants. Many lower fungi are not mycelial but have a different organization of the chytrid type—a globular spore-case with (in many species) slender protoplasmic rhizoids extending into the food source. The spore-case is at first unicellular, then becomes multinucleate, and finally many-celled as the flagellated zoospores or reproductive swarmers are formed and released. It is probable that only convergences relate the structures and life cycles of the fungi to the algae on the one hand, and to the mycelial bacteria (actinomycetes) on the other. (iii) The nutritive mode and way of life of the fungi differ from those of the plants. So far as is known the fungi have been wholly nonphotosynthetic from their origin from unicells to their present diversity of forms. Fungi characteristically live embedded in a food source or medium, in many cases excreting enzymes for external digestion, but in all cases feeding by absorption of organic food from the medium. Their organization, whether mycelial, chytrid, or the unicellular of yeasts, is adapted to this mode of nutrition.

Convenience still places the fungi in the plant kingdom in many textbooks. It may be fair, however, to observe the extent to which this is a position of convenience; for the fungi are a separate, major group of organisms of different origin, different direction of evolution, and different organization in adaptation to a different primary nutrition from that of the plants. The fungi are separated from the plants in most recent proposals on broad classification and are placed either in the kingdom Protoctista (*3, 9, 13, 19, 22*) or in a separate kingdom Fungi (*5, 8, 14*).

4) *Nutritional modes.* When the significance of bacteria and fungi in natural communities was unrecognized, it seemed reasonable to think of two major modes of nutrition for the kingdoms—ingestive in the animals, and in the plants primarily photosynthetic (and secondarily absorptive). There are, however, not two principal modes of nutrition but three—the photosynthetic, absorptive, and ingestive. The three modes largely correspond to three major functional groupings in natural communities, the producers (plants), reducers (saprobes, that is, bacteria and fungi), and consumers (animals) (*4, 5, 51*). The importance of the reducers in the cycling of materials in ecosystems appears to exceed that of the consumers. In evolution ingestive nutrition was a development secondary to the absorptive nutrition of most monerans and many eucaryotic unicells. Both protozoans with food vacuoles and metazoans with digestive tracts have probably evolved from absorptive flagellates, and in this evolution internalized the process of food absorption and added to it the process of ingestion. One may consider that the eucaryotic plants also have internalized the absorption of food through a membrane, that surrounding the chloroplast as symbiont and organelle. The three modes of nutrition imply different logics on which the evolution of structure in higher organisms was based (*44, 4, 5*).

Photosynthesis has implied evolution among higher plants of: (i) nonmotile life with structure based on walled cells differentiated into organs including (ii) blades or leaves as organs for concentration of chloroplast-containing cells and photosynthetic activity, and (iii) stipes or stems as organs to support these in favorable light conditions, with (iv) holdfasts to hold the plant in its place or roots to hold the plant and provide access to soil water and nutrients, and, (v) in the latter case, vascular tissue to conduct materials between roots and leaves by way of the stem, hence (vi) an intermediate level of somatic tissue differentiation (higher than fungi, lower than animals). The direction as stated has been realized to different degrees in a number of independent evolutionary lines of plants including higher green algae, red algae, brown algae, mosses, and vascular plants.

Ingestion in animals has implied evolution of: (i) a motile, food-seeking life in most cases, requiring evolution of both (ii) the sensory-neuro-motor complex of tissues, organs, and organ systems which make possible perception of and response to food and (iii) the digestive-circulatory-excretory complex for food and waste processing and transport, and in larger forms a system of external respiration; these systems implying, and serving to support (iv) a complexly differentiated structure of diverse, highly specialized tissues of wall-less cells, functioning at high metabolic levels in support of active life, the complex structure requiring in turn (v) highly developed mechanisms of integration and internal regulation through the nervous, circulatory, and endocrine systems. The logic has led to levels of structural and functional complexity among animals which are without parallel among other organisms, and ultimately toward complexity of inherited behavior or toward intelligence. It has led also to a diversification of structural designs without clear relation to one another, recognized by systematists in the large number of animal phyla, which is without parallel in other groups of organisms. (There are 20 phyla listed for the Eumetazoa in Table 1, and some authors recognize 25 to 30.)

In adaptation to absorption higher fungi have evolved: (i) nonmotile life embedded in the food supply, with (ii) mycelial organization combining maximum surface of contact with food with free movement of food and protoplasm through the mycelial system, while (iii) only the reproductive organs emerge from the food supply to release spores. The low level of somatic tissue differentiation in the fungi is as much a correlate of their way of life as the high level in the animals is of theirs. Diversification of the higher fungi is expressed, rather, in reproductive structures; and their classification is largely based on these.

These logics based on nutrition are the central meaning of the plant and animal kingdoms as long recognized, and of the fungi as a third major direction of evolution. The same nutritive modes necessarily appear among the unicells. Absorption is the principal nutritive mode among the bacteria; but blue-green algae and certain bacteria are photosynthetic or chemosynthetic, while *Bdellovibrio* and some of the myxobacteria are motile (but absorptive) predators on other unicells. All three modes and all possible transitions and combinations are developed among the eucaryotic protists, but specialized protists include plant-like walled cells with chloroplasts, diverse absorptive forms, and protozoans with organelles for ingestion and internal digestion, sensory perception, and movement.

Neither the intergradation of these modes among protists nor specialized exceptions among higher organisms—plants which catch insects or microcrustaceans, fungi which trap nematodes, animals and plants which feed as absorptive parasites, and the symbiotic relations of lichens, corals, and so forth—should obscure the significance of the nutritive modes in the broad evolutionary pattern of the living world.

The Copeland Four-Kingdom System

Given these developments, Copeland (*1–3*) has designed a successful and now rather widely followed system of four kingdoms. The kingdoms as Copeland (*3*) defines them are: (i) Kingdom Mychota or Monera. Organisms without nuclei, the bacteria and blue-green algae. (ii) Kingdom Protoctista. Nucleate organisms not having the characters of plants and animals, the protozoa, the red and brown algae, and the fungi. (iii) Kingdom Plantae. Organisms in whose cells occur chloroplasts, being plastids of bright green color, containing the pigments chlorophyll a, chlorophyll b, carotin, and xanthophyll, and no others; and which produce sucrose, true starch, and true cellulose. (iv) Kingdom Animalia. Multicellular organisms which pass during development through the stages called blastula and gastrula. They are typically predatory, and accordingly consist of unwalled cells and attain high complexity of structure and function.

Disposition of the green algae (Chlorophyta and Charophyta) in the four-kingdom system is a problem. In Copeland's (*1–3*) system they are assigned to the kingdom Plantae because they are part of the evolutionary line leading to the higher green plants, and by defining the kingdom by some biochemical characters shared by organisms of this evolutionary line. The systems of Rothmaler (*52*) and Barkley (*53*) correspond in design to that of Copeland, but use different names and definitions of the kingdoms; these authors and others (*9, 10, 15, 19, 22*) assign the green algae to the kingdom Protoctista or its equivalent. When the kingdom of higher plants is thus narrowed to include only the land plants (bryophytes and tracheophytes), the terms "Metaphyta" or "Embryophyta" seem preferable for this kingdom. Authors other than Copeland have used one of these terms, along with the coordinate term "Metazoa" for the higher animals, and have preferred the term "Monera" to "Mychota."

With these changes as Copeland's system has been applied by others (*15, 22*), the four kingdoms may be characterized:

1) Kingdom Monera. Procaryotic organisms, with unicellular or simply colonial organization (bacteria and blue-green algae).

2) Kingdom Protoctista (Protista of some authors). Lower eucaryotic organisms, with organizations which are unicellular, unicellular–colonial, syncytial, or multicellular without advanced tissue differentiation (algae other than the blue-greens, protozoans, slime molds, and fungi).

3) Kingdom Metaphyta or Embryophyta. Higher multicellular eucaryotic organisms with walled cells and green plastids. Levels of cell, tissue, and organ differentiation range from limited (Bryophyta) to intermediate (Tracheophyta); digestive cavities and motility by contractile fibers are lacking (land plants and aquatic plants derived from them).

4) Kingdom Metazoa. Higher multicellular eucaryotic organisms with wall-less cells and without plastids, mostly with internal digestive cavities, motility by means of contractile fibers, and advanced cell, tissue, and organ differentiation (multicellular animals).

Copeland recognizes a single phylum in the Monera and does not discuss phyla of the Metaphyta and Metazoa. His phyla in the Protoctista are: (i) Rhodophyta (red algae), (ii) Pyrrophyta (dinoflagellates and cryptomonads, plus the euglenoid organisms), (iii) Phaeophyta (yellow and brown algae, including the phyla Chrysophyta, Phaeophyta, Oomycota, and Hyphochytridiomycota of Table 1), (iv) Opisthokonta (chytrids and relatives, Chytridiomycota in Table 1), (v) Inophyta (higher fungi, including the Zygomycota, Ascomycota, and Basidiomycota), (vi) Fungilli (sporozoans, including the Cnidosporidia), (vii) Protoplasta (amoeboid and flagellate protozoans, slime molds, and plasmodiophores), and (viii) Ciliophora (ciliated protozoans and suctorians). To these, some authors would add (ix) Chlorophyta, (green algae, including the Charophyta). Others may prefer also to treat the euglenoid organisms separately, or in the Chlorophyta, and to treat the Oomycota as a fungal phylum separate from the algal line of the Chrysophyta and Phaeophyta [in which, as the Chromophyta, Chadefaud (*11*) also includes the dinoflagellates and cryptomonads].

The Copeland system has advantages over the two-kingdom system which have led to its acceptance in current textbooks. The traditional kingdoms, which extend through all levels of organization, are almost undefinable as units of classification. The traditional plant kingdom in particular, with its range of organization from monerans to higher plants and higher fungi and its inclusion of groups with fundamentally different directions of evolution in relation to nutrition, is difficult to define (see, however, *17*). In relation to it Dillon (*18*) has a point in carrying its inclusiveness one step further and suggesting that there is really only a single kingdom, that of the plants, within which are a number of lines of evolution toward the forms we regard as animals or as fungi. Copeland's four kingdoms are, in contrast (especially if the green algae are transferred to the protoctists), clearly definable in terms of kinds of organization. For the professional biologist they are workable taxa of broad classification; for the teacher of biology they are effective means of grouping phyla for discussion.

Limitations of the Copeland System

The system cannot, however, escape certain difficulties; three limitations affect it:

1) Of the three major nutritive directions two, photosynthesis and ingestion, provide the evolutionary meaning of the kingdoms of higher plants and higher animals. The third, absorption as the nutritive theme of the higher fungi, is not given coordinate recognition; and the place of these organisms in the broad evolutionary pattern of the living world is not clarified.

2) For the one undrawable line between plant and animal unicells which is done away with, another of almost equal difficulty is substituted, that between protoctists and higher organisms. The Protoctista may be thought primarily unicellular, but the kingdom includes evolutionary lines of varying development into multicellular or multi-

nucleate organization and some phyla which are primarily multicellular or multinucleate. The consequence for classification is illustrated in an excellent treatment by Hutchinson (*15*), in which the difficulties are clearly stated. The kingdom Protista is, however, defined as "single celled or colonial organisms." The kingdom includes the higher fungi and the green, red, and brown algae. The definition is that of the kingdom Protista but the content is that of the kingdom Protoctista and belies the definition. Hutchinson's (*15*) further specification, "if colonial usually with little tissue differentiation," does not help. An organism with tissue differentiation is not a colony of unicells; and the higher algae and fungi are by no means colonies of unicells despite low levels of tissue differentiation.

It is consequently appropriate to conceive the Protoctista as a very wide range of organisms with a very wide range of intermediate levels of organization—above the procaryotes, but below the vascular plants and higher animals. The line between protoctists and higher plants and animals is thus drawn primarily by degree of tissue differentiation. The brown algae are placed below this line for lack of marked tissue differentiation in most, even though organ differentiation (holdfast, stipe, and blade) appears in many, and a differentiated central vascular tissue occurs in some. The fungi are placed below the line because of their limited somatic tissue differentiation despite the elaboration of reproductive organs and tissues (and the specialized somatic rhizomorph tissue in some). Mosses, liverworts, sponges, and mesozoans are best grouped with more advanced members of the plant and animal kingdoms despite lack of or limited tissue differentiation. An uneasy boundary between protoctists and higher organisms results (Fig. 2).

3) The kingdom Protoctista lacks the unity and clarity of definition which the system achieves for the other three kingdoms. So wide is the range of organization among the protoctists that these may seem less a kingdom than a confederation of those excluded from the Monera, land plants, and multicellular animals. Copeland's phyla of protoctists are, however (even if some changes in them are desirable), an effective division of the lower eucaryotic organisms into broadly defined evolutionary lines and groupings.

In fairness these points should be recognized to reflect not so much faults of the Copeland system as faults of the living world as a subject of classification. There is no good way to separate the lower and higher eucaryotic orga-

Table 1. A classification of the living world from kingdoms through phyla.

Kingdom Monera (*70*)

Procaryotic cells, lacking nuclear membranes, plastids, mitochondria, and advanced (9 + 2-strand) flagella; solitary unicellular or colonial-unicellular organization (but in one group mycelial). Predominant nutritive mode absorption, but some groups are photosynthetic or chemosynthetic. Reproduction primarily asexual by fission or budding; protosexual phenomena also occur. Motile by simple flagella or gliding, or nonmotile.

- Branch Myxomonera (*71*). Without flagella, motility (if present) by gliding
  - Phylum Cyanophyta (*72*), blue-green algae
  - Phylum Myxobacteriae (*72*), gliding bacteria
- Branch Mastigomonera (*71*). Motile by simple flagella (and related nonmotile forms)
  - Phylum Eubacteriae (*72*), true bacteria
  - Phylum Actinomycota (*72*), mycelial bacteria
  - Phylum Spirochaetae (*72*), spirochetes

Kingdom Protista (*73*)

Primarily unicellular or colonial-unicellular organisms (but simple multinucleate organisms or stages of life cycles occur in a number of groups), with eucaryotic cells (possessing nuclear membranes, mitochondria, and in many forms plastids (9 + 2)-strand flagella, and other organelles). Nutritive modes diverse—photosynthesis, absorption, ingestion, and combinations of these. Reproductive cycles varied, but typically including both asexual division at the haploid level and true sexual processes with karyogamy and meiosis. Motile by advanced flagella or other means, or nonmotile (*74*).

- Phylum Euglenophyta, euglenoid organisms
- Phylum Chrysophyta, golden algae
- Phylum Pyrrophyta, dinoflagellates and cryptomonads
- Phylum Hyphochytridiomycota (*75*), hyphochytrids
- Phylum Plasmodiophoromycota (*75*), plasmodiophores
- Phylum Sporozoa, sporozoans
- Phylum Cnidosporidia, cnidosporidians
- Phylum Zoomastigina, animal flagellates
- Phylum Sarcodina, rhizopods
- Phylum Ciliophora, ciliates and suctorians

Kingdom Plantae (*76*)

Multicellular organisms with walled and frequently vacuolate eucaryotic cells and with photosynthetic pigments in plastids (together with closely related organisms which lack the pigments or are unicellular or syncytial). Principal nutritive mode photosynthesis, but a number of lines have become absorptive. Primarily nonmotile, living anchored to a substrate. Structural differentiation leading toward organs of photosynthesis, anchorage, and support, and in higher forms toward specialized photosynthetic, vascular, and covering tissues. Reproduction primarily sexual with cycles of alternating haploid and diploid generations, the former being progressively reduced toward the higher members of the kingdom.

- Subkingdom Rhodophycophyta (*77*). Chlorophyll a and (in some) d, with *r*-phycocyanin and *r*-phycoerythrin also present, food storage as floridean starch, flagella lacking.
  - Phylum Rhodophyta, red algae
- Subkingdom Phaeophycophyta (*77*). Chlorophyll a and c, with fucoxanthin also present, food storage as laminarin and mannitol, zoospores with two lateral flagella, one of whiplash and one of tinsel type.
  - Phylum Phaeophyta, brown algae
- Subkingdom Euchlorophyta (*78*). Chlorophyll a and b, food storage as starch within plastids, ancestral flagellation two or more anterior whiplash flagella.
  - Branch Chlorophycophyta (*79*). Primarily aquatic, without marked somatic cell differentiation.
    - Phylum Chlorophyta, green algae
    - Phylum Charophyta, stoneworts
  - Branch Metaphyta (*80*). Primarily terrestrial, with somatic cell and tissue differentiation.
    - Phylum Bryophyta (*81*), liverworts, hornworts, and mosses
    - Phylum Tracheophyta (*82*), vascular plants

nisms, there are only different choices with different difficulties. Given level of tissue differentiation as the choice, the assignment of the higher fungi and algae to the kingdom Protoctista and the heterogeneity of the kingdom will follow. The difficulties cannot be overlooked, but they should not prevent recognition that this is a reasonable and workable broad classification of the living world, with marked advantage over the two-kingdom system in its grouping of phyla by levels of organization. Copeland's is a major contribution to interpretation of the living world.

A Five-Kingdom System

A different response to the problems of the two-kingdom system is possible. In this solution: (i) The fungi are accepted as a third kingdom of higher organisms, coordinate with the higher plants and animals. (ii) The line between these higher organisms and the protists is placed at the transition from the unicellular to the multicellular and multinucleate conditions. (iii) The higher algae are then placed in the plant kingdom along with the green higher plants. There result the four kingdoms—Protista, Plantae, Fungi, and Animalia—of the system developed in an earlier paper (*5*). Somewhat related systems have been used by Simpson (*20*), who places the fungi as well as the unicellular and higher algae in the kingdom Plantae, and Pimentel (*13*), who separates the Monera as a kingdom, groups protozoans, slime molds, and fungi as the kingdom Protista, and assigns eucaryotic algae and land plants to the kingdom Plantae.

The Monera were a subkingdom of the Protista in the earlier treatment (*5*); current preference is for full separation

Table 1 (continued).

Kingdom Fungi (*83*)

Primarily (excepting subkingdom Gymnomycota) multinucleate organisms with eucaryotic nuclei dispersed in a walled and often septate mycelial syncytium, plastids and photosynthetic pigments lacking. Nutrition absorptive. Somatic tissue differentiation absent or limited, reproductive tissue differentiation and life cycle elaboration marked in higher forms. Primarily nonmotile (but with protoplasmic flow in the mycelium), living embedded in a medium or food supply. Reproductive cycles typically including both sexual and asexual processes; mycelia mostly haploid in lower forms but dicaryotic in many higher forms.

- Subkingdom Gymnomycota (*84*). Deviant organizations including in life cycles separate cells, aggregations of cells, and sporulation stages.
    - Phylum Myxomycota (*85*), syncytial or plasmodial slime molds
    - Phylum Acrasiomycota (*85*), cellular or pseudoplasmodial slime molds
    - Phylum Labyrinthulomycota (*85*), cell–net slime molds
- Subkingdom Dimastigomycota (*86*). Biflagellate (heterokont) zoospores present, chytrid to simply mycelial organization, cellulose walls.
    - Phylum Oomycota (*87*), oosphere fungi
- Subkingdom Eumycota (*88*). Predominantly mycelial organization, zoospores uniflagellate if present, chitin walls, other characters as stated for kingdom.
    - Branch Opisthomastigomycota (*89*). Uniflagellate (opisthokont) zoospores present, chytrid to simply mycelial organization, mainly aquatic.
        - Phylum Chytridiomycota (*89*), true chytrids and related fungi
    - Branch Amastigomycota (*90*). Flagellated zoospores absent, simple to advanced mycelial organization (but secondarily unicellular in yeasts), mainly terrestrial.
        - Phylum Zygomycota (*87*), conjugation fungi
        - Phylum Ascomycota (*87*), sac fungi
        - Phylum Basidiomycota (*87*), club fungi

Kingdom Animalia (*91*)

Multicellular organisms with wall-less eucaryotic cells lacking plastids and photosynthetic pigments. Nutrition primarily ingestive with digestion in an internal cavity, but some forms are absorptive and a number of groups lack an internal digestive cavity. Level of organization and tissue differentiation in higher forms far exceeding that of other kingdoms, with evolution of sensory–neuro–motor systems and motility of the organism (or in sessile forms of its parts) based on contractile fibrils. Reproduction predominantly sexual, haploid stages other than the gametes almost lacking above the lowest phyla (*92*).

- Subkingdom Agnotozoa (*93*). Nutrition absorptive and ingestive by surface cells, internal digestive cavity and tissue differentiation lacking. Minute, motile by cilia.
    - Phylum Mesozoa, mesozoans
- Subkingdom Parazoa (*94*). Nutrition primarily ingestive by individual cells lining internal water canals. Cell differentiation present but tissue differentiation lacking or very limited; cells with some motility but the organism nonmotile.
    - Phylum Porifera, sponges
    - Phylum Archaeocyatha (extinct)
- Subkingdom Eumetazoa (*95*). Advanced multicellular organization with tissue differentiation, other characteristics of the kingdom.
    - Branch Radiata (*96*). Animals of radiate or biradiate symmetry.
        - Phylum Cnidaria, coelenterates
        - Phylum Ctenophora, comb jellies
    - Branch Bilateria (*97*). Animals of bilateral symmetry.
        - Grade Acoelomata (*98*)
            - Phylum Platyhelminthes, flatworms
            - Phylum Nemertea or Rhynchocoela, ribbon worms
        - Grade Pseudocoelomata (*98*)
            - Phylum Acanthocephala, spiny-headed worms
            - Phylum Aschelminthes, diverse pseudocoelomate worms
            - Phylum Entoprocta or Kamptozoa, pseudocoelomate polyzoans
        - Grade Coelomata (*98*)
            - Subgrade Schizocoela (*99*)
                - Phylum Bryozoa or Ectoprocta, coelomate, ectoproct polyzoans
                - Phylum Brachiopoda, lamp shells
                - Phylum Phoronida, lophophorate, phoronid worms
                - Phylum Mollusca, molluscs
                - Phylum Sipunculoidea, peanut worms
                - Phylum Echiuroidea, spoon worms
                - Phylum Annelida, segmented or annelid worms
                - Phylum Arthropoda, arthropods
            - Subgrade Enterocoela (*99*)
                - Phylum Brachiata or Pogonophora, beard worms
                - Phylum Chaetognatha, arrow worms
                - Phylum Echinodermata, echinoderms
                - Phylum Hemichordata, acorn worms
                - Phylum Chordata, chordates

of the Monera and the eucaryotic protists into different kingdoms. Such separation was suggested as a possibility (*5*), and has been carried out in Grant's (*14*) treatment. The resulting five-kingdom system is similar to that of Jahn and Jahn (*8*) who, however, grouped the higher algae with the protists and recognized a kingdom Archetista for the viruses. It is convenient, and may be justifiable, not to treat the viruses as organisms. The five-kingdom system of this author and Grant (*14*) may then be formulated as in Table 1. For clarification of taxa above the level of phylum, definitions of these are stated, and (though rules of taxonomic priority do not apply to them) sources and partial synonymies of names are given. The relation of the kingdoms to levels of organization and directions of evolution affected by nutrition is shown in Fig. 3.

The system differs from that previously presented (*5*) in (i) separation of the Monera from the Protista at the kingdom level, (ii) recognition of five phyla, at least, in the Monera, (iii) suggestion of branches as groupings between major subkingdoms and their phyla, and (iv) treatment of the fungi. For the last, the logic of evolutionary lines characterized by type of flagellation and biochemical characters (*49, 54–59, 36*) has been carried through in a manner paralleling that now widely accepted for major groups of algae (*36, 60–64*).

The lower true fungi (Phycomycetes) are believed to include four evolutionary lines of separate deprivation from flagellated unicells. These lines (with their types of flagellation, the orders of Phycomycetes in many treatments of this group which they comprise, and the phyla to which they are here assigned) are: (i) The true chytrid line, zoospore with a single posterior whiplash or acroneme (naked) flagellum, the order Chytridiales (of walled chytrid organization), together with the Blastocladiales and Monoblepharidales (with simple hyphae or mycelia) derived from them; phylum Chytridiomycota [phylum Opisthokonta of Copeland (*3*), Uniflagellatae of Sparrow (*49*)]. (ii) Hyphochytridiales, zoospore with a single anterior tinsel or pantoneme (plume-like) flagellum, limited to wall-less chytrid organization; phylum Hyphochytridiomycota. (iii) Plasmodiophorales, two anterior whiplash flagella of unequal length, naked plasmodial organization; phylum Plasmodiophoromycota. (iv) The biflagellate line, zoospores with one whiplash and one tinsel flagellum, the walled, chytrid-like Lagenidiales and the more advanced, mycelial Saprolegniales, Leptomitales, and Peronosporales derived from them; phylum Oomycota [Biflagellatae of Sparrow (*49*)]. An additional group (v) comprises forms which lack flagella and have mycelial organization and hyphal conjugation, Mucorales and Entomophthorales; phylum Zygomycota.

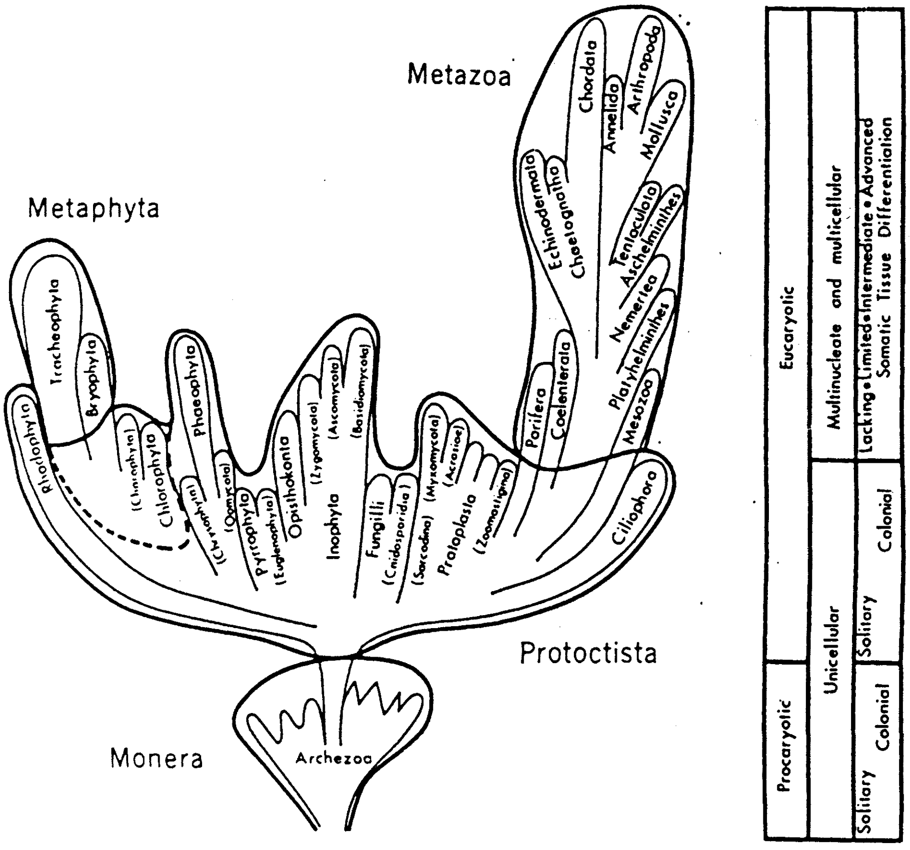

Fig. 2. The Copeland system, with relationships of phyla to kingdoms and levels of organization. In the Protoctista the names not in parentheses are Copeland's phyla; some major groups of protoctists that Copeland includes in these are indicated in parentheses. The Opisthokonta equal the Chytridiomycota, the Inophyta equal the Amastigomycota, and the Fungilli equal the Sporozoa of Table 1 and Fig. 3. Only major animal phyla are indicated. Alternative treatments of the Chlorophyta and Charophyta are indicated; these are included in the Metaphyta by Copeland (*3*), but in the Protoctista by other authors.

There is suggestion in biochemical evidence, notably sharing of the aminoadipic pathway for lysine synthesis, that the Chytridiomycota may have been derived from flagellates related to the Euglenophyta and are related also to the higher fungi (*58, 36*). It seems likely that the Zygomycota are derived, with loss of flagellate swarmers and further evolution of mycelial organization, from the Chytridiomycota, and that the higher fungi (Ascomycota, Basidiomycota) are derived from the Zygomycota. The Chytridiomycota, Zygomycota, Ascomycota, and Basidiomycota in consequence represent the main axis of evolution into the higher fungi, corresponding to that of the Chlorophyta, Charophyta, Bryophyta, and Tracheophyta in the plants. Flagellation and biochemical evidence indicate that the Oomycota are a separate evolutionary line, and that they more likely originated from colorless forms related to the Chrysophyta (*58, 59, 3, 36*).

The Oomycota and Chytridiomycota both include progressions from chytrid to mycelial organization. Although I consider chytrids to be protists, I have placed these transitional phyla in the Fungi, in parallel with the Chlorophyta in the Plantae. The main axis of fungal evolution, from Chytridiomycota to Basidiomycota, is designated the subkingdom Eumycota; whereas the biflagellate line of the Oomycota is separated from these into the subkingdom Dimastigomycota (in parallel with treatment of the Rhodophyta and Phaeophyta in the plant kingdom). The two lines which do not achieve mycelial organization, the Hyphochytridiomycota and Plasmodiophoromycota [which together are the Archimycetes of Gäumann (*65, 57*)] become phyla of protists, adjacent to absorptive and spore-forming organisms regarded as protozoans, the Sporozoa and Cnidosporidia. Other wall-less fungi, the slime molds, probably include at least three separate evolutionary lines from the unicellular condition (*66*), the true slime molds (Myxomycetales), cellular slime molds (Acrasiales), and cell-net slime molds (Labyrinthulales). These have, for their separate origin and different organization, been treated as three phyla and grouped in a polyphyletic subkingdom Gymnomycota.

This treatment results in a considerable elevation of taxa; groups which are orders and classes in most other classifications become phyla here, in some cases separated into different branches and subkingdoms. Recognition of three phyla of slime molds and seven of chytrid and mycelial fungi is not, however, undue taxonomic inflation. The range of forms comprised in the fungi is wide, and the evidence of independent origin of various fungal and slime mold groups is clear. It is suggested that true fungi and slime molds are not best treated as two phyla, that their designation as such is in part a consequence of the effort to treat these groups within the plant or the protoctist kingdom, and that the expansion of each into a number of phyla is more reasonable.

I believe that this system better represents broad relationships in regard to both levels of organization and nutritive modes affecting kinds of organization than the two-kingdom and Copeland systems. The red and brown algae and the fungi may seem better placed, the former as the higher plants of the sea, the latter as the third major evolutionary direction among higher organisms. The system may further have much advantage over the two-kingdom system and some over the Copeland system in the coherence and definable character of the kingdoms as units of classification.

Limitations of the Five-Kingdom System

1) The distinction of the unicellular versus the multicellular and multinucleate conditions becomes the line of division and difficulty. The phylum Chlorophyta includes intergrading unicellular, colonial–unicellular, and multicellular forms and consequently violates the definition either of the Plantae (in which it is placed here) or of the Protista (in which it could with equal justice be placed). The slime molds cross the distinctions of the kingdoms in both nutrition and organization, and offer a free choice of treatment as aberrant fungi, eccentric protists, or very peculiar animals. The line from the unicellular to multicellular and multinucleate organization has been crossed by a number of independent phyletic lines. I suggest that the transition between the unicellular and multicellular–multinucleate conditions is a better conceptual division between lower and higher organisms than degree of tissue differentiation. The practical difficulties with borderline groups are at least as great, and may be greater, when the separation is based on the unicellular condition rather than degree of tissue differentiation. There is room for different judgments on the merits of the two lines of division.

2) The three higher kingdoms are polyphyletic. The Rhodophyta and Phaeophyta are recognized to have come from different unicellular ancestors than the Chlorophyta; the resemblance of these three groups as higher plants results from convergence. There is reason also to suspect that these algae supplement photosynthetic nutrition by absorption (*67*). Judged by the criterion of monophyly, the Plantae as treated here may seem less a kingdom than an alliance of separate groups which are multicellular and predominantly photosynthetic. It is also true that the Metazoa in its traditional form is polyphyletic, with separate derivation to be assumed for two and probably all three of its subkingdoms. The kingdom Fungi includes, as indicated, probably two convergent groups of chytrid and mycelial fungi and three of slime molds.

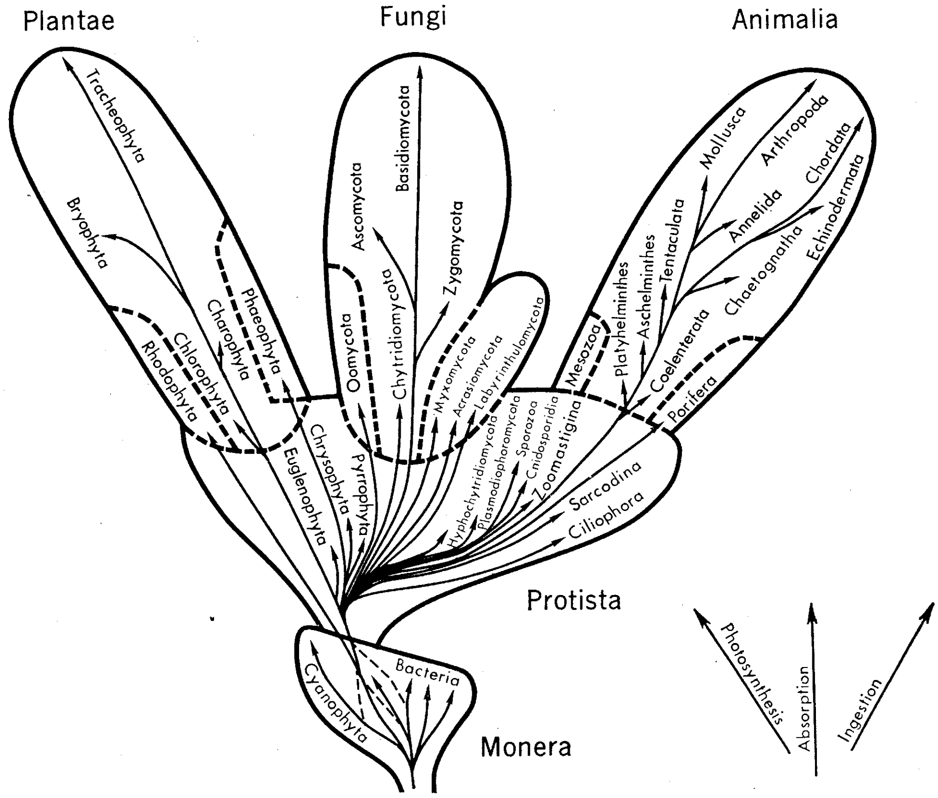

Fig. 3. A five-kingdom system based on three levels of organization—the procaryotic (kingdom Monera), eucaryotic unicellular (kingdom Protista), and eucaryotic multicellular and multinucleate. On each level there is divergence in relation to three principal modes of nutrition—the photosynthetic, absorptive, and ingestive. Ingestive nutrition is lacking in the Monera; and the three modes are continuous along numerous evolutionary lines in the Protista; but on the multicellular–multinucleate level the nutritive modes lead to the widely different kinds of organization which characterize the three higher kingdoms—Plantae, Fungi, and Animalia. Evolutionary relations are much simplified, particularly in the Protista. Phyla are those of Table 1; but only major animal phyla are entered, and phyla of the bacteria are omitted. The Coelenterata comprise the Cnidaria and Ctenophora; the Tentaculata comprise the Bryozoa, Brachiopoda, and Phoronida, and in some treatments the Entoprocta.

3) Even with the multicellular algae and higher fungi excluded, the Protista is a grouping of diverse organisms of disparate directions of evolution. Necessarily, some protist phyla are more

closely allied to phyla of the three higher kingdoms than to some other phyla of the protists. Yet the kingdom Protista is definable by a level of organization (eucaryotic, unicellular); whereas the higher kingdoms are defined by kinds and evolutionary directions of organization on the multicellular–multinucleate level. Such horizontal and vertical classification, horizontally separating an ancestral base-taxon from the several taxa as evolutionary lines derived from it, may be preferable to dividing up the intergrading members of the ancestral taxon and assigning them to the descendent taxa (*68*). The protists are a complex of variously interconnected evolutionary lines, of many evolutionary developments in parallel and convergence, and of phyla which have been difficult to delimit and some of which are doubtless polyphyletic. So much has been learned of detailed structure and biochemical characteristics which suggests relationships and permits grouping into phyla, that we may hope there is much more understanding of the protists to be gained from further study. The protists as a kingdom have seemed monophyletic; but the implications of possible independent acquisition of symbiotic algae which became chloroplasts, if this process is accepted, for origin of the kingdom and its phyla are still to be explored (*38*).

Monophyly is a principal value of systematics (*68*, *69*), but like other values is not absolute and will not always be followed to the sacrifice of other objectives. I have chosen to base classification on three levels of organization—the procaryotic, eucaryotic unicellular, and multicellular–multinucleate—and three principal directions of evolution related to nutrition, which on the multicellular–multinucleate level are expressed in the evolutionary divergences of the three higher kingdoms. The three higher kingdoms are polyphyletic in parallel fashions. Each includes a dominant evolutionary line to higher organisms as its major subkingdom, and minor subkingdoms which are independent experiments in multicellular or multinucleate organization in one of the three nutritive directions. In each case these minor subkingdoms are less widely successful than the principal subkingdom, represent somewhat lower and different organization from it, and may to some degree depart from the typical nutritive mode of the kingdom.

Conclusion and Summary

The proposals for revised broad classification are consequences of greatly increased knowledge of the evolutionary relations of organisms since the time of the early naturalists. There is advantage in considering competing systems of kingdoms of organisms. None of these systems can be wholly satisfactory; but it may in time be apparent which one best expresses the broad relationships of the living world. For the present, the systems deserve scrutiny by professional biologists to assess their merits and the bearing on them of information available or still to be sought. The new systems also have value in teaching, for the additional interest and coherence they can give to discussions of the diversity of life. There is no unequivocal answer to the choice of a system of broad classification, but the question is well worth discussing.

The division of the whole living world into plant and animal kingdoms is a consequence of a limited view of that world, based on familiarity with higher plants and animals. The two-kingdom system (i) imposes an unnatural division on the one-celled organisms, (ii) does not treat adequately the place and distinctiveness of bacteria and higher fungi, and (iii) by its neglect of great differences in levels of organization produces kingdoms which are nearly undefinable.

Many of these difficulties are resolved in the system of Copeland, with four kingdoms: Monera (procaryotic cells—bacteria and blue-green algae), Protoctista (eucaryotic organisms without advanced tissue differentiation—unicellular and multicellular algae, protozoa, and fungi), Metaphyta (multicellular green plants), and Metazoa (multicellular animals). A five-kingdom system is proposed here, based both on levels of organization and on types of organization as evolved in relation to three principal means of nutrition—photosynthesis, absorption, and ingestion. The kingdoms are the Monera, Protista (unicellular eucaryotic organisms), Plantae (multicellular green plants and higher algae), Fungi (multinucleate higher fungi), and Animalia (multicellular animals). Revised broad classifications deserve wide consideration, for they may better express major relationships in the living world and more effectively classify the phyla than the two-kingdom system.

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70. Stamm Moneres, Haeckel (*29*) Monera (*30, 31*), Kingdom Monera, Copeland (*1*); Kingdom Mychota, G. Enderlein, *Bakterien-Cyklogenie* (de Gruyter, Berlin, 1925); and Copeland (*2, 3*).
71. Branch Myxomonera and Mastigomonera are new designations for divisions of the Kingdom Monera as indicated; the divisions (but not the designations) following E. G. Pringsheim, *Bacteriol. Rev.* **13**, 47 (1949); Stanier (*12*), and Hutchinson (*15*). E. C. Dougherty, *J. Protozool.* **4** (suppl.) 14 (1957) has termed these two groups phylum Schizophyta. F. Cohn, *Beitr. Biol. Pflanz.* **1**, 3, 201 (1875); R. von Wettstein, *Handbuch der systematischen Botanik* (Deuticke, Leipzig & Wien, 1901–1908), and phylum Archephyta (*29*), but the suffix -phyta seems inappropriate for bacterial groups.
72. In addition to the Cyanophyta (= Myxophyta), widely accepted as a phylum, three major bacterial groups, the classes Eubacteriae, Myxobacteriae, and Spirochaetae of Stanier and van Niel (*7, 19*) are given phylum status. The mycelial bacteria [actinomycetes as defined by Stanier *et al.* (*19*)] are regarded as also deserving phylum status as the Actinomycota, despite the occurrence among them (as in certain phyla of true fungi) of nonmycelial forms and the difficulty of the boundary between them and the gram-positive eubacteria.
73. Kingdom Protista, Haeckel (*29–32*) and others (*33, 20, 5, 14*); Kingdom Protozoa, Owen (*27*).
74. The phyla of the Protista form a spectrum from primarily photosynthetic (Protophyta), through primarily absorptive and spore-forming (which may be designated Protomycota), to primarily ingestive or otherwise animal-like (Protozoa). The evolutionary continuities and overlap in nutritive adaptations of the phyla discourage suggestion of subkingdoms or branches. An intermediate treatment of protist phyla has been sought. The algal phyla follow the pattern set by Conard (*6*), Tippo (*62*), and others (*17, 60*). Chadefaud (*11*), F. E. Round, *Brit. Phycol. Bull.* **2**, 224 (1963), and T. Christensen, *Alger* (Munksgaard, Copenhagen, 1962, 1966) group the Chrysophyta, Pyrrophyta, and Phaeophyta into the phylum (or superphylum) Chromophycophyta or Chromophyta, and group the Euglenophyta, Chlorophyta, and Charophyta into the phylum Chlorophycophyta or Chlorophyta s. l. Some other authors [C. J. Alexopoulos and H. C. Bold, *Algae and Fungi* (Macmillan, New York, 1967)] divide some of the algal phyla given into additional phyla. Despite the continuities of the Zoomastigina and Sarcodina with one another and protophyte groups, recognition of these two polyphyletic form-phyla of protozoans has been preferred to combining them with the Chrysophytes into the very diverse group Sarcomastigophora or Rhizoflagellata (*15*); B. M. Honigberg *et al.*, *J. Protozool.* **11**, 7 (1964).
75. New designations at the level of the phylum for class Hyphochytridiomycetes or order Hyphochytridiales and class Plasmodiophoromycetes or order Plasmodiophorales.
76. Linnaeus (*25*); subkingdom Metaphyta, Haeckel (*29–32*); kingdom Phytalia, Conard (*6*); Plantae, Simpson (*20*); Whittaker (*5*).
77. New subkingdom designations, phylum Rhodophycophyta and Phaeophycophyta, Papenfuss (*61*); phyla and subkingdoms Rhodophyta and Phaeophyta, Whittaker (*5*).
78. New designation, Whittaker (*5*), equals phylum Chlorophyta of Conard (*6*); kingdom Plantae of Copeland (*1–3*).
79. With the phylum Chlorophyta defined to exclude the Charophyta, the term Chlorophycophyta, Pappenfuss (*61*), Chadefaud (*11*) [Phycophyta, Conard, (*6*)], has been applied to the branch comprising both.
80. Haeckel (*29–32*), narrowed in content to include the land plants as indicated, thus narrowed equals Embryophyta; A. Engler, *Das Pflanzenreich* (Engelmann, Weinheim, 1900), vol. 1; Conard (*6*), Tippo (*62*), and Cormophyta; S. Endlicher, *Genera plantarum secundum ordines naturales disposita* (Beck, Vienna, 1836–1840).
81. H. C. Bold, *Morphology of Plants* (Harper, New York, 1957), separates the liverworts and hornworts from the Bryophyta as phylum Hepatophyta.
82. Division of the tracheophytes into several phyla is preferred by some botanists (*17, 81*).
83. Order Fungi, C. Linnaeus, *Species plantarum* (Salvius, Stockholm, 1753), vol. 2; phylum Fungi, Martin (*42*); kingdom Fungi, Jahn and Jahn (*8*); Whittaker (*5*); Regnum Mycetoideum, E. Fries, *Systema mycologicum* (Mauritii, Lund, 1821–32); Kingdom Mycetalia, Conard (*6*).
84. New designation; subkingdom Myxomycota, Whittaker (*5*); division Myxomycota, Bold (*81*); Mycetozoen, A. de Bary, *Bot. Zeitung*, **16**, 357 (1858) and *Z. Wiss. Zool.* **10**, 88 (1859); Myxomycetes of Haeckel (*29*) and others; division Myxothallophyta, Engler (*80*); phylum Myxomycophyta, Tippo (*62*).
85. New designations at phylum level for classes or orders of slime molds (*56, 66, 81*). A fourth group of slime molds have been described as the Protostelida [L. S. Olive, *Mycologia* **59**, 1 (1967)]. The group multinu- from strictly unicellular to simply multinucleate in both vegetative and spore-forming stages; nutrition is ingestive. I interpret these as protists most closely allied to the Gymnomycota (in parallel with the relation of the hyphochytrids and plasmodiophores to the Eumycota), best placed in phylum Sarcodina.
86. New designation, Biflagellatae of Sparrow (*49*), phylum Dimastigomycetes of Moreau (*55*).
87. Equal classes Oomycetes, Zygomycetes, Ascomycetes, and Basidiomycetes of authors; the last two are divisions Ascomycota and Basidiomycota in Bold (*81*).
88. New designation; group Eumycetes, A. W. Eichler, *Syllabus der Vorlesungen über specielle und medicinisch-pharmaceutische Botanik* (Borntraeger, Berlin, ed. 4, 1886), phylum Eumycophyta, Tippo (*62*), and subkingdom Eumycota, Whittaker (*5*), minus the Dimastigomycota.
89. The phylum or class Phycomycetes, A. de Bary, *Vergleichende Morphologie und Biologie der Pilze, Mycetozoen und Bakterien* (Engelmann, Leipzig, 1884) has been divided into five phyla, and given new designations on this level: The primitive Hyphochytridiomycota and Plasmodiophoromycota, transferred to the kingdom Protista, the advanced Zygomycota, transferred to the branch Amastigomycota, the intermediate Oomycota, transferred to the subkingdom Dimastigomycota, and the Chytridiomycota. The branch comprising only the last of these is here designated the Opisthomastigomycota [Uniflagellatae, Sparrow (*49*); phylum Opisthomastigomycetes, Moreau (*55*); phylum Opisthokonta, Copeland (*3*); class Chytridiomycetes, Alexopoulos (*56*)].
90. New branch designation; phylum Carpomycetes, Bessey (*47*), plus Zygomycetes; phylum Inophyta, Haeckel (*29*), Copeland (*3*).
91. Linnaeus (*25*), Metazoa of Haeckel (*29–32*), and others.
92. Division of the animal kingdom follows L. H. Hyman, *The Invertebrates: Protozoa*

through Ctenophora (McGraw-Hill, New York, 1940) in most respects. Some authors [for example, R. E. Blackwelder, *Classification of the Animal Kingdom* (Southern Illinois University, Carbondale, 1963)] divide the Aschelminthes into several phyla and separate additional phyla from the Arthropoda and Chordata.

93. Branch Mesozoa, Hyman (*92*); branch Agnotozoa, R. C. Moore, C. G. Lalicker, A. G. Fischer, *Invertebrate Fossils* (McGraw-Hill, New York, 1952); subkingdom Agnotozoa, Moore (*9*).
94. Phylum Parazoa, W. J. Sollas, *Quart. J. Microscop. Sci.* **24**, 603 (1884).
95. W. G. Kükenthal and T. Krumbach, *Handbuch der Zoologie* (de Gruyter, Berlin, 1923–5).
96. Animalia radiata of G. Cuvier, *Le règne animal distribué d'après son organisation* (Déterville & Crochard, Paris, 1816) with narrowed content; grade Radiata, Hyman (*92*); phylum Coelenterata of authors.
97. Heteraxonia or Bilateria of B. Hatschek, *Lehrbuch der Zoologie* (Fischer, Jena, 1888); grade Bilateria of Hyman (*92*).
98. W. Schimkewitsch, *Biol. Zentralbl.* **11**, 291 (1891).
99. T. H. Huxley, *Quart. J. Microscop. Sci.* **15**, 52 (1875).

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NEWS AND COMMENT

National Data Bank: Its Advocates Try To Erase "Big Brother" Image

The computer, for all its promise and achievements as a tool of modern technology, is viewed with distrust by many people who have considered its implications for personal privacy. They are uneasy at the possibility that someday, perhaps well before 1984, there will exist a master computer center, a Big Brother, with voluminous and instantly retrievable data on every American who has lived long enough to get a social security number, a traffic ticket, or even a birth certificate, or a report card from school. The fact that private credit-rating bureaus and insurance investigators already have dossiers on tens of millions of Americans itself gives substance to these fears and is beginning to receive attention from Congress. However, insofar as the computer and personal privacy is concerned, the question which has received the most congressional attention to date is that of whether the United States government should establish a statistical data center or "national data bank."

Such a data center—first proposed in 1965 by a committee of the Social Science Research Council, a nongovernmental group, and later endorsed by a government task force—would be intended to serve, not investigators seeking information about individual persons, but, rather, scholars and other users of gross statistics. One of its principal aims would be to help economists, other social scientists, and government specialists investigate major economic and social problems, such as those of persistent unemployment and social disorganization in the big-city slums.

A score of federal agencies, such as the Census Bureau, the Internal Revenue Service, and the Social Security Administration, collect data of various kinds. The national data center would store the more statistically significant data collected by these agencies, and, as required for special studies, data from two or more agencies would be matched up and integrated. In a study of the causes of poverty, for example, it might be useful to have census data integrated with data obtained from the social security and internal revenue systems. Most social scientists who use federal statistics extensively probably support the data-bank concept, though there now appears to be a general belief that special efforts must be made to safeguard privacy.

Fearing that establishment of such a statistical center might lead to abuses, the House Government Operations Committee's Special Subcommittee on Invasion of Privacy held 3 days of hearings on the matter, in July 1966. The subcommittee, headed by Representative Cornelius Gallagher (D–N.J.), was concerned at some of the testimony of government witnesses, who said the data center could not integrate or update data from the collecting agencies without knowing the identities of individual persons.

Last August, the Gallagher subcommittee issued a report recommending that the "priority of privacy" be asserted in designing and setting up the data bank. The subcommittee suggested, through a series of questions, that the data center itself keep data largely in the aggregate and keep none on identifiable individuals. It recommended that the data bank not be set up in any existing federal agency, but that it be placed under its own supervisory commission and removed as far as possible from the political pressures of an incumbent administration.

These proposed safeguards reflected fears expressed by the subcommittee's lead-off witness, Vance Packard, author of *The Naked Society*, whom Gallagher credits with being one of the first Americans to warn that the computer poses a threat to privacy. In Packard's judgment there is a real danger that the efficiencies attainable through assembling more and more data in one place may prove irresistible, with the result that a data center designed as an innocuous tool for statisticians would become a kind of electronic Frankenstein's monster. "My hunch," Packard said, "is that Big Brother, if he ever comes to these United States, may turn out to be not a greedy power seeker, but rather a relentless bureaucrat obsessed with efficiency."

Although the Nixon administration might conceivably decide otherwise, the outgoing Johnson administration has concluded that, in view of the widespread mistrust of the national data bank concept, Congress should not be asked this year for authority to establish the data bank. According to Raymond T. Bowman, an assistant director of the Bureau of the Budget who is responsible for coordinating all federal statistical services, the administration's decision was to continue the interagency review of tentative plans for a data bank and to have those plans reviewed also by an advisory committee, its members to be made up of such people as constitutional lawyers, computer experts, businessmen suppliers of statistical data, and statistics users (Gallagher would also have the