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PERSPECTIVE

How many species of algae are there? A reprise. Four kingdoms, 14 phyla, 63 classes and still growing

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Abstract

To date (1 November 2023), the online database AlgaeBase has documented 50,589 species of living algae and 10,556 fossil species here referred to four kingdoms (Eubacteria, Chromista, Plantae, and Protozoa), 14 phyla, and 63 classes. The algae are the third most speciose grouping of plant-like after the flowering plants (≈382,000 species) and fungi (≈170,000 species, including lichens) but are the least well defined of all the botanical groupings. Priority is given to phyla and class names that are familiar to phycologists and that are nomenclaturally valid. The most species-rich phylum is the Heterokontophyta to which 18 classes are referred with 21,052 living species and which is dominated by the diatoms in three classes with 18,673 species (16,427 living; 2239 fossil). The next most species-rich phyla are the red algae (7276 living), the green algae (6851 living), the blue-green algae (Cyanobacteria, 5723 living), the charophytes (4950 living, including the Charophyceae, 511 species living, and the Zygnematophyceae, 4335 living species), Dinoflagellata (2956 living, including the Dinophyceae, 2828 extant), and haptophytes (Haptophyta 1722 species, 517 living).

KEYWORDS
algae, AlgaeBase, classification, diatoms, genus numbers, species numbers

INTRODUCTION

Nearly 12 years ago (Guiry, 2012), I published the numbers of described algal species then included in the online database AlgaeBase (AB; https://www.algaebase.org, Guiry & Guiry, 2023). At that time, AB included 33,260 species, and I estimated that about 44,000 species of algae had been described up to that time. I discussed the universal difficulties in assessing what a species is and what an alga is conceptually, and these issues have not changed. I also gave a brief account of the numbers of species in the various taxonomic groupings of algae.

Here, I update the numbers in AB in the context of the various phyla (and in the larger phyla, classes) of algae and in relation to the numbers of other organisms that have been subjected to expert assessment. It should be noted that in this account I use the term "grouping" in discussions of each taxonomic category; the word "group" is often employed but represents a particular taxonomic category (an infrageneric one). The term "ambiregnal" is employed for organisms that have been treated under multiple Codes of Nomenclature and that create difficulties in each Code (Corliss, 1995; Turland, 2019, p. 113). Some or all of the included organisms are also treated under another

Abbreviations: AB, AlgaeBase; ICN, International Code of Nomenclature for algae, fungi, and plants; ICZN, International Code of Zoological Nomenclature; INA, *Index Nominum Algarum*.

nomenclatural code, sometimes with the same names but not always.

Phycologists will not be surprised that their calling is based on the most ill-defined (or ill-definable) grouping of organisms on Earth. Most other such groupings are well defined (flowering plants, insects, fishes, birds, mammals, etc.) and are usually, although not always, monophyletic. Algae include very diverse organisms: prokaryotic and eukaryotic, plant-like and animal-like in the classical sense, and related and unrelated to other organisms conceived by the general public as "plants" or by some researchers as "protists" (sometimes "protoctists"), a similarly difficult grouping to define well. Some algal groupings have lost their plastids, and some have regained them; some have "captured" plastids from different, unrelated groupings, often repeatedly.

The *International Code of Nomenclature for algae, fungi, and plants* (ICN; Shenzhen Code, Turland et al., 2018). Preamble 8 specifies "The provisions of this *Code* apply to all organisms traditionally treated as algae, fungi, or plants, whether fossil or non-fossil, including blue-green algae (Cyanobacteria), chytrids, oomycetes, slime molds, and photosynthetic protists with their taxonomically related non-photosynthetic groups (but excluding *Microsporidia*)." The phrase "traditionally treated as algae" is critical for inclusion in AB as it is for *Index Nominum Algarum* (INA; see Silva & Moe, 1999), which aspires to produce and maintain "… an index of scientific names of algae, both living and fossil, at all ranks." Deciding "…their taxonomically related non-photosynthetic groups" is particularly difficult as is interpreting "…traditionally treated as algae." So, while some names are included in AlgaeBase and INA for purposes of priority, we do not necessarily regard these as algae, and they are not included here.

There are some ambiregnal wording conventions that require clarity, as they are not well understood by some phycologists and protistologists. Under the ICN (Turland et al., 2018) a designation is nomenclaturally valid or invalid, i.e., it meets or does not meet the requirements of the ICN to exist as a name. Once a designation is valid under the ICN it becomes a name that may be legitimate (mostly that it is not pre-empted by a homonym or includes taxonomically another name with priority) or illegitimate. Once a name is valid and legitimate, it can then be assessed taxonomically to establish if it is the correct name for the taxon (i.e., that it is not a taxonomic synonym of another taxon). Under the *International Code of Zoological Nomenclature* (ICZN), however, a name is "available" (equivalent to "valid" under the ICN) or "unavailable" (equivalent to "invalid" under the ICN), and a "valid name" is the taxonomically correct name for the taxon. So, when a zoological taxonomist refers to a "valid name" this refers to its *taxonomic* validity but to a botanical taxonomist a "valid name" refers to *nomenclatural* validity, and taxonomic acceptance is generally referred to as the "correct name." The important point is that for some organisms "traditionally treated as algae," "availability" under the ICZN results in "validity" under the ICN and inclusion in AB despite not being generally considered as algae by today's phycologists (e.g., highly evolved, non-photosynthetic parasites such as *Trypanosoma*).

HOW MANY SPECIES ARE THERE?

The consensus (Table 1) is that for all organisms, about 2.2 million species have been described to date, surprisingly close to the early estimate of 1.75 million species by Hawksworth and Kalin-Arroyo (1995). Even these numbers are often unclear as to whether they include extant and extinct species.

Experts in just about every grouping listed in Table 1 claim that the numbers of "their" described species is an underestimate, especially for the fungi, insects, and arachnids. Some authors are now reporting a decline in the rates of description of new taxa in well-researched groupings such as the Isopoda (Hartebrodt et al., 2023). Numbers seem to be relatively stable in birds, mammals, and fishes, although there is annually some well-publicized discovery of a previously unknown (often tiny) vertebrate in some remote, understudied region of the planet often receiving far more attention than it deserves. By far, the largest grouping of organisms is the Insecta, particularly the Coleoptera (beetles, with >380,000 known species, or about 40% of all arthropods; Stork et al., 2015), the radiation of which in tropical rainforests is truly astonishing, and there are estimates of 1–1.5 million extant beetle species (Stork et al., 2015). Largely as a result of arthropod radiation, animals currently outnumber plants by nearly three to one. Nevertheless, one assessment (Mora et al., 2011) concluded that "some 86% of existing species on Earth and 91% of species in the ocean still await description."

Of the organisms falling under the aegis of the ICN, the flowering plants, unsurprisingly, are by far the largest grouping with some 382,000 extant species, mostly terrestrial with very few representatives in marine environments (currently, there are about 100 species of seagrasses, excluding fossils, which are currently included for convenience in AB) followed by the Fungi with around 167,000 living species, including lichens, mostly in terrestrial habitats. There are estimates of 1.5–13.2 million species of fungi (Hyde, 2022). Assessments (May, 2011 and others) of 5–10 million species for all organisms, in this context, are perhaps more believable, although I wonder where all the taxonomists are going to be found and trained.

The third most species-rich grouping of plant-like organisms is the algae (Table 1). Table 2 gives updated figures for species in AB for 14 phyla. In this table, some 3000 species are in a sort of phylogenetic "limbo," in

TABLE 1 Number of living species (excluding viruses and most bacteria) in general categories of plants and animals with sources.

Grouping	Number (rounded)	Habitats	Source
Algae	50,000	MFT*	https://www.algaebase.org
Fungi	150,000	M* FT	Hyde (2022)
Lichens	17,000	M* T	https://ourworldindata.org
Mosses	22,000	F* T	https://ourworldindata.org
Ferns and Allies	12,000	F* T	https://ourworldindata.org
Gymnosperms	1000	T	https://www.conifers.org
Flowering plants	382,000	M* FT	http://www.worldfloraonline.org
Corals	6000	M	https://ourworldindata.org
Crustaceans	80,000	MFT*	https://ourworldindata.org
Mollusks	84,000	MFT	https://ourworldindata.org
Insects	1,050,000	M* FT	https://ourworldindata.org
Arachnids	111,000	T	https://ourworldindata.org
Other invertebrates	158,000	MFT	https://ourworldindata.org
Amphibians	8000	FT*	https://amphibiaweb.org
Reptiles	12,000	M* FT	https://reptile-database.reptarium.cz
Birds	11,000	MFT	https://ourworldindata.org
Fishes	35,000	MF	https://www.fishbase.de
Mammals	7000	MFT	https://www.mammaldiversity.org
Plants	634,000	MFT	Total here
Animals	1,560,000	MFT	Total here
Total	2,194,000		

Note: Numbers have been rounded to the nearest thousand. (Habitats: M = Marine; F = Freshwater; T = Terrestrial. Asterisks indicate less favored habitats).

that the phyla to which they have been referred are not familiar to phycologists or are treated as animals (or "protists") by zoologists, but they are treated under the ICN for the purposes of nomenclatural priority as explained above. In Table 2, it should be noted that some phyla names end in "-phyta" as required by ICN Art. 16.3 for automatically typified names, but descriptive names (such as "Dinoflagellata" or "Cyanobacteria") are not required to have such an ending but are nomenclaturally valid names under the ICN. For most phyla, we give more familiar names ("-phyta"), and the numbers given are those treated as algae by phycologists. Difficulties exist in respect of organisms resulting from single or multiple endosymbiotic events (e.g., Cournoyer et al., 2022). The classification employed here is partly that of Ruggiero et al. (2015), an integrated classification intended for use in the on-line *Catalogue of Life* (https://www.catalogueoflife.org) but with some more recent modifications or additions. It should be noted that in the AB classification, every effort is made to fit with the taxonomic ranks of the ICN (Art. 3; Turland et al., 2018 and earlier editions) where possible. I frequently receive emails asking what classification AB uses. The answer is that no single classification is used, but we try to use names that are at least familiar to most phycologists and that are also valid nomenclaturally.

The five most species-rich groupings of algae (Table 2) are, in order, the heterokont algae (Heterokontophyta, 23,314 species, 21,052 extant), the chlorophyte green algae (Chlorophyta, 7934 species, 6851 extant), the red algae (Rhodophyta, 7554 species, 7276 extant), the blue-green algae (Cyanobacteria, 5723 species, 4669 extant), and the charophytes (including the conjugating algae, 5544 species, 4940 extant), making up nearly two-thirds of all algae. Diatom species alone account for nearly one-third of all algae (Table 6). The most genus-rich phylum is the Heterokontophyta (1781; Table 6), followed by the Chlorophyta (1513, Table 4), and then the Rhodophyta (1094, Table 7). Many new generic names for diatoms were introduced from the 1970s onward as more taxonomically useful morphological characters become apparent under SEM and were assessed in relation to phylogenetic data. The Rhodophyta, similarly, have rich, complex reproductive systems that facilitate phylogenetic hypotheses, although recent molecular studies are revealing even more variation at the genus level, particularly in the Ceramiales (e.g., Barros-Barreto et al., 2023).

The following is a brief summary for the 14 phyla of algae in alphabetical order (as in Table 2) and their classes (some in separate tables). Authorities for each phylum and class are included for information and follow

TABLE 2 Number of current genera and species living and fossil in each of the 14 phyla of algae.

Phylum	Kingdom	Genera	Species	Living species	Common name	Includes	Habitats	Forms	% species
Charophyta (see Table 3)	Plantae	236	5644	4940	Charophytes	Charophytes, desmids	F T*	Macro and micro	9.23
Chlorophyta (see Table 4)	Plantae	1513	7934	6851	Chlorophytes	Green algae	M F T	Macro and micro	12.98
Chromeridophyta (Chromerida)	Chromista	6	8	8	Chromeridophytes	Chromerids	M	Micro	0.01
Cryptophyta (Cryptista)	Chromista	44	245	245	Cryptophytes	Cryptomonads	M F	Micro	0.40
Cyanobacteria	Eubacteria	866	5723	4669	Cyanophytes	Blue-green algae	M F T	Mostly macro	9.36
Dinoflagellata (Table 5)	Chromista	710	3911	2956	Dinophytes	Dinoflagellates	M F	Micro	6.40
Euglenophyta (Euglenozoa)	Protozoa	164	2057	2037	Euglenophytes	Euglenoid flagellates	M F T*	Micro	3.36
Glaucophyta	Plantae	8	25	25	Glaucophytes	Glaucocystids	F T	Micro	0.04
Haptophyta	Chromista	391	1722	517	Haptophytes	Coccoliths, prymnesiophytes	M F	Micro	2.82
Heterokontophyta (see Table 6)	Chromista	1781	23,314	21,052	Heterokontophytes	Heterokonts, diatoms, brown algae	M F T*	Macro and micro	38.13
Picophyta (Picozoa)	Plantae	1	1	1	Picophytes	Picobiliphytes	M	Micro	0.00
Prasinodermatophyta	Plantae	5	10	10	Prasinodermatophytes	Prasinodermids	M	Micro	0.02
Rhodelphidophyta (Rhodelphidia)	Plantae	1	2	2	Rhododelphiophytes	Rhododelphids	M F	Micro	0.00
Rhodophyta (see Table 7)	Plantae	1094	7554	7276	Rhodophytes	Red algae	M (FT)	Macro and micro	12.35
Incertae sedis etc.	Various	887	2995				Various	Macro and micro	4.90
Totals		7707	61,145	50,589					100.00

Note: Habitats: M, Marine; F, Freshwater; T, Terrestrial; asterisks indicate less-favored habitats.

TABLE 3 Numbers of genera and species, living and fossil, of the phylum Charophyta according to classes.

Class	Genera	Species	Species (%)	Fossil species	Extant species	Extant species (%)
Charophyceae	120	1111	19.90	661	450	9.22
Chlorokybophyceae	1	5	0.09	0	5	0.10
Coleochaetophyceae	11	36	0.64	0	36	0.74
Klebsormidiophyceae	8	52	0.02	0	52	1.07
Mesostigmatophyceae	1	1	0.02	0	1	0.02
Zygnematophyceae	172	4378	78.42	43	4335	88.85
Total	313	5583		704	4879	

TABLE 4 Numbers of genera and species, living and fossil, of Chlorophyta according to classes.

Class	Genera	Species	Species (%)	Fossil species	Living species	Extant species (%)
Chlorodendrophyceae	7	60	0.76	15	45	0.66
Chlorophyceae	677	3974	50.09	0	3974	58.01
Chloropicophyceae	2	8	0.10	0	8	0.12
Chuariophyceae	3	3	0.04	3	0	0.00
Mamiellophyceae	9	25	0.32	0	25	0.36
Nephroselmidophyceae	19	29	0.37	0	29	0.42
Pedinophyceae	7	24	0.30	0	24	0.35
Picocystophyceae	1	1	0.01	0	1	0.01
Pyramimonadophyceae	36	166	2.09	59	107	1.56
Trebouxiophyceae	211	926	11.67	1	925	13.50
Ulvophyceae	527	2695	33.97	990	1705	24.89
Classis incertae	14	23	0.29	15	8	0.12
Total	1513	7934		1083	6851	

TABLE 5 Numbers of genera and species, living and fossil, of Dinoflagellata according to classes.

Class	Genera	Species	Species (%)	Fossil species	Living species	Extant species (%)
Acavomonea	1	1	0.03	0	1	0.03
Apicomonadea	3	5	0.13	0	5	0.17
Colponemea	2	7	0.18	0	7	0.24
Colpovorophyceae	1	1	0.03	0	1	0.03
Dinophyceae	661	3781	96.65	953	2828	95.64
Ellobiophyceae	6	21	0.54	0	21	0.71
Noctilucophyceae	12	19	0.49	0	19	0.64
Oxyrrhinophyceae	1	2	0.05	0	2	0.07
Perkinsea	5	12	0.31	0	12	0.41
Syndiniophyceae	17	60	1.53	1	59	2.00
Classis incertae	2	3	0.08	1	2	0.07
Total	711	3912		955	2957	

as much as possible the recommendation of the ICN that "above the rank of family, authors should generally follow the principle of priority" (Rec. 16A). However, I have also had to consider the familiarity of such names to phycologists. Several class names required validation (Guiry, 2023; Molinari-Novoa & Guiry, 2023), and the previously invalid, but widely used, phylum name Heterokontophyta was recently validated by Guiry et al. (2023). "Streptophyta" is a much-favored descriptive name for a grouping, generally unspecified, that includes the non-algal "land-plants" and the algal grouping Charophyta (e.g. Yang et al., 2023).

TABLE 6 Numbers of genera and species, living and fossil, of Heterokontophyta according to classes.

Class	Genera	Species	Species (%)	Fossil species	Extant species	Extant species (%)
Bacillariophyceae	429	14,684	62.98	820	13,864	65.86
Bolidophyceae	3	18	0.08	1	17	0.08
Chrysoparadoxophyceae	1	1	0.00	0	1	0.00
Chrysophyceae	180	1274	5.46	58	1216	5.78
Coscinodiscophyceae	150	1629	6.99	566	1063	5.05
Dictyochophyceae	43	217	0.93	119	98	0.47
Eustigmatophyceae	30	218	0.94	0	218	1.04
Mediophyceae	192	1898	8.14	667	1231	5.85
Olisthodiscophyceae	1	2	0.01	0	2	0.01
Pelagophyceae	22	31	0.13	0	31	0.15
Phaeophyceae	346	2124	9.11	30	2094	9.95
Phaeosacciophyceae	5	8	0.03	0	8	0.04
Phaeothamniophyceae	16	31	0.13	0	31	0.15
Pinguiophyceae	5	5	0.02	0	5	0.02
Raphidophyceae	21	58	0.25	0	58	0.28
Schizocladiophyceae	1	1	0.00	0	1	0.00
Synchromophyceae	6	9	0.04	1	8	0.04
Xanthophyceae	115	616	2.64	0	616	2.93
Classis incertae	215	490	2.10	0	490	2.33
Total	1781	23,314		2262	21,052	

TABLE 7 Numbers of genera and species, living and fossil, of Rhodophyta according to classes.

Class	Genera	Species	Species (%)	Fossil species	Living species	Extant species (%)
Bangiophyceae	17	185	2.45	2	183	2.52
Compsopogonophyceae	14	70	0.93	0	70	0.96
Cyanidiophyceae	7	11	0.15	0	11	0.15
Florideophyceae	990	7155	94.72	276	6879	94.54
Porphyridiophyceae	5	9	0.12	0	9	0.12
Rhodellophyceae	7	8	0.11	0	8	0.11
Stylonematophyceae	19	48	0.64	0	48	0.66
Classis incertae	35	68	0.90	0	68	0.93
Total	1094	7554		278	7276	

The name Streptophyta was first validated by Cavalier-Smith (1993a, p. 340) as an infrakingdom, although it had earlier been introduced invalidly by Jeffrey (1982, p. 411, name only) as a division [phylum] of subkingdom Chlorobionta; it was noted as a division [phylum] by Bremer (1985, p. 381) and stated to encompass "charophytes + embryophytes," which could be regarded as validating the name at the phylum level. Ruggiero et al. (2015, pp. 33–34) retained the Streptophyta as an infrakingdom, which is not incorrect but which is confusing, as the suffix "-phya" is usually interpreted as a phylum. The "Viridiplantae," also a descriptive name, sometimes accorded subkingdom status, is a grouping comprising the Chlorophyta and the Streptophyta (e.g. Yang et al., 2023). "Protist," "Protoctist," and "Stramenopile" (correctly, "Straminopile"; Guiry et al., 2023, p. 2, footnote), as currently employed, are ambiregnal informal names that often do not correspond exactly with any taxa treated here. "Archaeplastida" is another informal name that includes land plants, green algae, red algae, and glaucophytes but does not seem to have been formally described.

It is important to note the names for and treatment of higher taxa (phyla and classes) in the present treatment is from the point of view of phycologists, not protistologists or protozoologists. Little attempt is made to be "ambiregnally correct." AlgaeBase is not intended to be a primary source but is rather an "aide mémoire" to help people with information on names and taxonomy. Although many of the taxon names listed here are well supported phylogenetically, not all are, and there may not be equivalence to well-supported clades in some phylogenetic schemes. Those seeking cladistically correct phylogenetic schemes, particularly at the class and phylum levels, should seek them elsewhere (e.g., Adl et al., 2019; Archibald et al., 2017) where they will find many unfamiliar taxa and informal names, not to mention names that seem not to have been validated under any Code. There seems to be counterculture of introducing taxon or clade names without reference to any nomenclatural code, a recipe for confusion. Such people might recall the biblical Tower of Babel (*Genesis* 11:1–9).

CHAROPHYTA

Of the Charophyta Migula, 1889 (Table 3), the Zygnematophyceae Round ex Guiry, 2013, a typified name (T: *Zygnema* C.Agardh, *nom. et typ. cons.*), is the most species-rich class with over 4378 species, nearly 90% of the phylum total. However, the Charophyceae Rabenhorst, 1863, a typified name (*Chara* Linnaeus), is the most genus-rich class and, unusually for the algae, has an rich fossil record (McCourt et al., 2017). The Chlorokybophyceae Irisarri et al., 2021, a typified name (T: *Chlorokybus* Geitler), Coleochaetophyceae C.Jeffrey ex Guiry (Guiry, 2023; Jeffrey, 1982), a typified name (T: Coleochaete Brébisson, *nom. cons.*), Klebsormidiophyceae C.Jeffrey ex Guiry (Guiry, 2023; Jeffrey, 1982), also a typified name (T: *Klebsormidium* P.C.Silva, Mattox & W.H.Blackwell), and the recently described Mesostigmatophyceae Marin & Melkonian, 1999, a typified name (*Mesostigma* Lauterborn), have relatively small numbers of species to date (Table 3).

CHLOROPHYTA

The phylum Chlorophyta Reichenbach, 1830, is a class-rich phylum, currently with 11 described classes (Table 4). It is likely that several undescribed classes awaiting discovery are included in the Chlorophyceae Wille (in Warming, 1884, a descriptive name, i.e., a name not based on a type as opposed to a typified name), Trebouxiophyceae Friedl, 1995 (a typified name, T: *Trebouxia* Puymaly), and Ulvophyceae Mattox & Stewart, 1984 (a typified name, T: *Ulva* Linnaeus). The most species-rich classes are the Chlorophyceae and Ulvophyceae with nearly the same number of genera (Table 4). The Chlorodendrophyceae Masjuk, 2006 (a typified name, *Chlorodendron* Senn; see Barcyte et al., 2022), Chloropicophyceae Lopes dos Santos & Eikrem, 2017, a typified name (T: *Chloropicon* Lopes dos Santos & Eikrem), Chuariophyceae Gnilovskaya & Ischenko (in Gnilovskaja et al., 1988, as "Chuariaphyceae," apparently extinct; a typified name, T: *Chuaria* C.Walcott), Mamiellophyceae Marin & Melkonian, 2010 (a typified name, T: *Mamiella* Moestrup), Nephroselmidophyceae T. Nakayama et al., 2007 (a typified name, T: *Nephroselmis* F.Stein), Pedinophyceae Moestrup, 1991 (a typified name, T: *Pedinomonas* Korshikov in Isachenko, 1921), Picocystophyceae Eikrem & Lopes dos Santos in Lopes dos Santos et al., 2017 (a typified name, T: *Picocystis* R.A.Lewin), and Pyramimonadophyceae Moestrup & Daugbjerg (in Daugbjerg et al., 2019, a typified name, T: *Pyramimonas* Schmarda) are relatively recent, small segregate classes suggesting perhaps that others will be found.

CHROMERIDOPHYTA

The phylum Chromeridophyta R.B.Moore et al., 2008 (as "Chromerida phyl. nov."; Table 2) is a small phylum that includes some marine photosynthetic species. It includes a single algal class Colpodellophyceae Molinari & Guiry (Molinari & Guiry 2023, a typified name, T: Colpodella Cienkowski) with eight known species and two photosynthetic representatives, *Chromera velia* R.B.Moore et al. and *Vitrella brassiciformis* Oborník et al. (in some publications as "*brassicaeformis*," but see ICN Art. 60.10), symbionts of stony corals, but their putative relatives are apicomplexan parasites or predators with a chloroplast remnant termed the apicoplast, such as *Plasmodium*, the malarial parasite. Other than *Chromera* and *Vitrella*, colpodellids have lost the ability to photosynthesize.

CRYPTOPHYTA

The phylum Cryptophyta Cavalier-Smith, 1986 (Table 2), known as cryptomonads (not equivalent to the Cryptista Cavalier-Smith, 1989; Tanifuji & Onodera, 2017), includes three classes, the largest of which is the Cryptophyceae Fritsch (in West & Fritsch, 1927, a descriptive name), which includes about 245 species. The other two small classes are the Goniomonadophyceae Cavalier-Smith, 1993b (a typified name, T: *Goniomonas* F.Stein, as "Goniomonadea") and the Katablepharidophyceae N.Okamoto & Inouye, 2005 (also referred to the Katablepharidophyta N.Okamoto & Inouye, 2005, a typified name, T: Katablepharis Skuja).

CYANOBACTERIA

The phylum Cyanobacteria Whittaker & Margulis, 1978 (proposed as an alternative for Cyanophyta

Geitler, 1925, as "*Stamm*") and equivalent to Cyanobacteriota Oren et al., 2022, a typified name, is usually thought of as including a single class, the Cyanophyceae Schaffner, 1909, a descriptive name). However, Strunecký et al. (2023) have recently described a segregate class the Vampirovibriophyceae Strunecký & Mares (Strunecký et al., 2023; as "Vampirovibrionia" in Soo et al., 2019, seemingly not an available name under the *International Code of Nomenclature of Prokaryotes*) based on the non-photosynthetic predatory/parasitic genus *Vampirovibrio* Gromov & Mamkayeva 1980. Traditionally, the Cyanobacteria have been treated as exclusively photosynthetic, but *Vampirovibrio* and its relatives are closely related phylogenetically to the Cyanophyceae (Soo et al., 2019; Strunecký et al., 2023). The phylum has been comprehensively reviewed recently by Strunecký et al. (2023) introducing many new groupings. Kaštovský (2023) has also provided a detailed analysis of taxonomy and taxon discovery in the phylum.

DINOFLAGELLATA

While the name "Dinophyta" has been used by some phycologists and some websites (e.g. https://www.dinophyta.org) for dinoflagellates, this does not appear to be a valid name nomenclaturally. It was first introduced by Dillon (1963, p. 77) as a phylum of the subkingdom "Euglenophytaria" of the kingdom Plantae, in which kingdom Dillon included "all living things." Although Dillon's classification was published in the journal *Systematic Zoology*, the suffix "-phyta" and similar were used throughout, and there is no mention of a particular Code. Latin descriptions were not included as required for algae by ICN Art. 44.1 at that time. However, if the name were available under the ICZN, it would be valid under the ICN. However, the default position is that the name is invalid, as botanical suffixes were used and Latin is lacking. The name "Pyrrophyta," a descriptive name if valid, has also been used by phycologists, which was introduced by Pascher (1914) to include the classes Desmokontae, Cryptophyceae, and Dinophyceae but gradually became confined to the dinoflagellates (e.g. Dodge, 1984; Round, 1973) although attributed to Pascher. In recent years, the designation "Pyrrophyta" has rarely been used.

The name "Miozoa" was first introduced as a "branch" of the subkingdom Mitozoa by Cavalier-Smith (1987, p. 21); this "branch" included the phylum Dinozoa. The phylum name "Myzozoa" was later named by Cavalier-Smith (in Cavalier-Smith & Chao, 2004, p. 200) as a phylum with 11 classes, including a class Dinozoa, and was treated as equivalent to his earlier "Miozoa" (see abstract in Cavalier-Smith & Chao, 2004). However, Cavalier-Smith (in Ruggiero et al., 2015, p. 20) reintroduced Miozoa as a phylum name and included the subphylum Myzozoa.[1] These names are all descriptive names and are generally not familiar to phycologists.

The phylum name Dinoflagellata Fensome et al. (1993, p. 39, as "Division") was introduced with a Latin diagnosis referring to *Unterabteilung* (*Ordnung*) Dinoflagellata Bütschli (1884, p. 859). Given the comprehensive treatment of the dinoflagellates, fossil and living, with and without chloroplasts, by Fensome et al. (1993), this seems to be most appropriate, valid name for the dinoflagellates, and one that is recognizable to phycologists (Ø. Moestrup & J. Larsen, pers. comm; Saldarriaga & Taylor, 2017).

As treated in AB, Dinoflagellata is an ambiregnal grouping of nine classes (Table 5) with most of the photosynthetic representatives being included in the Dinophyceae Fritsch (in West & Fritsch, 1927, a descriptive name), with smaller numbers in the Ellobiophyceae A.R.Loeblich (1970, a descriptive name), Noctilucophyceae Fensome et al., 1993 (as "Noctiluciphyceae," a typified name, T: *Noctiluca* Suriray), and Syndiniophyceae A.R.Loeblich, 1976 (a typified name, *Syndinium* Chatton). These four classes are usually perceived as "dinoflagellates" (e.g., Riding et al., 2022) with the remaining classes being less certain in placement. The repeated loss and gain of plastids in the Dinoflagellata (Saldarriaga & Taylor, 2017) have made classification of the phylum difficult.

EUGLENOZOA (EUGLENOPHYTA)

The phylum Euglenozoa Cavalier-Smith, 1998, is an ambiregnal grouping that includes the largely photosynthetic class Euglenophyceae Schoenichen (in Eyferth & Schoenichen, 1925, as "Eugleninae," a typified name: T: *Euglena* Ehrenberg) but also seven further classes of non-photosynthetic, related organisms (Diplonema Cavalier-Smith, Entosiphonea Cavalier-Smith, Kinetoplastea Honigberg, Peranema Cavalier-Smith, Ploeotarea Cavalier-Smith, Postgaardea Cavalier-Smith, and Stavomonadea Cavalier-Smith; see Cavalier-Smith, 2016, p. 255) who wrote "If botanists wish for historical reasons to treat photosynthetic euglenoids under the [ICN], that is not unreasonable provided that this policy is strictly limited to Euglenophyceae as circumscribed here. … The botanical division/phylum name Euglenophyta Pascher, 1931 should not be applied to Euglenozoa … as a whole as it is profoundly misleading for either of these ancestrally phagotrophic, non-photosynthetic, non-algal protozoan taxa." Representatives of these seven classes are

[1]Art. 16.1 (ICN: Turland et al., 2018), poorly known, specifies that "descriptive names [above the level of family] … may be used unchanged at different ranks."

included in AB for reasons of nomenclatural priority but are not listed here as the data are incomplete. Cavalier-Smith's opinion, while worthy, seems inconsistent with the Preamble 8 of the ICN which states that there it treats "photosynthetic protists with their taxonomically related non-photosynthetic groups," especially as Silva (1980) had created botanical names for "non-photosynthetic, non-algal protozoan taxa," such as the Tyrpanosomatophyceae P.C.Silva, a typified name, T: *Trypanosoma* Gruby, 1843, a genus of blood-borne kinetoplastids nesting in the Euglenozoa that parasitize a wide range of vertebrates globally.

The name "Euglenida" has been employed by some authors, such as Leander et al. (2017), but without specifying what taxonomic level is intended. This appears to be an invalid name under the ICN (Turland et al., 2018), as the name does not appear to have been used at the phylum or class level, but it may have been made available under the ICZN and would then be valid under the ICN.

GLAUCOPHYTA

The phylum Glaucophyta Skuja, 1948 (Table 2), a descriptive name, includes about 25 living species, freshwater flagellates referred currently to a single class, the Glaucophyceae Bohlin, 1901 (also a descriptive name; see Price et al., 2017). This phylum may be basal to the Rhodophyta and Chlorophyta (e.g. Bhattacharya et al., 1995).

HAPTOPHYTA

The phylum Haptophyta Hibberd ex Edvardsen & Eikrem (in Edvardsen et al., 2000; Table 2), a descriptive name, includes a relatively large number of marine and freshwater flagellates assigned to three classes the largest of which is the Coccolithophyceae Rothmaler, 1951 (proposed by Rothmaler as a new descriptive name for the "Coccolithophoridae" of Lohmann, 1902). A detailed history of the nomenclature of haptophytes is given by Silva et al. (2007) and Eikrem et al. (2017). The Pavlovophyceae J.C.Green & Medlin (in Edvardsen et al. (2000), a typified name T: *Pavlova* Butcher, 1952[2]) currently includes a small number of delightful marine flagellates. The recently described Rappephyceae M.Kawachi, R.Kamikawa & T.Nakayama (in Kawachi et al., 2021, a descriptive name) includes the marine rappemonads, of which many more representatives are likely to be discovered (Kim et al., 2011). The Haptophyta has 391 genera, 1722 species of which 517 are extant. The fossil record extends back to the Triassic (Eikrem et al., 2017).

HETEROKONTOPHYTA

The Heterokontophyta Moestrup, R.A.Andersen & Guiry (in Guiry et al., 2023), a descriptive name, currently comprises 18 classes, 1781 genera, and 23,314 species of which 21,052 are extant. The phylum name Ochrophyta Cavalier-Smith (e.g., Cavalier-Smith, 1998) has been used in various senses, not always co-extensively, for the Heterokontophyta. Three classes of diatoms are included in the Heterokontophyta, viz., the Bacillariophyceae Haeckel, 1878 (a typified name, T: *Bacillaria* J.F.Gmelin), the Coscinodiscophyceae Round & R.M.Crawford (in Round et al., 1990, a typified name, T: *Coscinodiscus* Ehrenberg, *nom. cons.*), and the Mediophyceae Medlin & Kaczmarska, 2004 (see also Medlin, 2016, a descriptive name). The first of these is the most genus- and species-rich class with over seven times the number of species than the other two classes combined, but not with the same proportion of genera. Unlike most other groupings, the diatoms have an extensive fossil record, of which AB has to date recorded over 2000 species, but a lot of further additions are likely. A number of diatoms originally described from diatom fossil deposits were later discovered to be extant (e.g., Bryłka et al., 2023). Although many diatomists employ the phylum name "Bacillariophyta" for all diatoms, the evidence, morphological and molecular, points to diatoms being heterokont algae as treated (as a single class) by van den Hoek et al. (1995, p. 102), this is not currently supported by molecular evidence (see, for example, Cavalier-Smith, 2017). In any event, "Bacillariophyta" may be an invalid designation. The diatom classes Bacillariophyceae and Mediophyceae are currently included in the subphylum Bacillariophytina Medlin & Kaczmarska, while the Coscinodiscophyceae is included in the subphylum Coscinodiscophytina Medlin & Kaczmarska (Medlin, 2016; Medlin & Kaczmarska, 2004).

The Phaeophyceae Kjellman, 1891, a descriptive name, includes mostly the brown seaweeds (Kawai & Henry, 2017), notably the kelps and wracks, which make up most seaweed biomass worldwide. The Phaeophyceae also has the largest numbers of genera of the heterokonts. The Phaeophyta Wettstein, 1901 (as "*Stamm*"), a descriptive phylum name, has been employed widely for the Phaeophyceae but is not supported by molecular evidence.

The Bolidophyceae Guillou & Chrétiennot-Dinet in Guillou et al., 1999, a typified name (T: *Bolidomonas* Guillou & Chrétiennot-Dinet in Guillou et al., 1999), comprises a small number of marine picoplanktonic organisms inferred to be a sister group to the diatoms (Ichinomiya et al., 2016). The Chrysoparadoxophyceae Wetherbee in Wetherbee et al., 2019, a typified name,

[2]While the genus *Pavlova* Butcher is widely assumed to have been named for the ballerina Anna [Matveyevna] Pavlova (1881–1931), the legendary Russian Prima Ballerina Assoluta, Butcher (1952, pp. 183–4) does not indicate the origin of his genus name. The epithet of the type, *Pavlova gyrans* Butcher, does suggest such an intention.

Kingdom	Genera	Species	Species (%)	Fossil	Living	Extant (%)
Eubacteria	866	5723	9.36	1069	4669	9.08
Chromista	2932	29,200	47.76	4709	24,778	48.75
Plantae	2858	21,170	34.62	2257	19,105	36.88
Protozoa	164	2057	3.36	46	2037	5.3
Incertae	887	2995	4.90	2475		
Total	7707	61,145		10,556	50,589	

TABLE 8 Numbers of living and extinct species of algae according to kingdoms.

is based on a single marine, sand-dwelling species from New South Wales with a double-membrane chloroplast, *Chrysoparadoxa australica* Wetherbee. The Chrysophyceae Pascher, 1914, a descriptive name, includes 1274 species in 180 genera, mostly from freshwaters. The Dictyochophyceae P.C.Silva, 1980 (a typified name T: *Dictyocha* Ehrenberg) is a small class of mostly marine flagellates. The Eustigmatophyceae D.J.Hibberd & Leedale, 1971, a descriptive name, is a small class of coccoid flagellates in marine, freshwater, and terrestrial habitats. The Olisthodiscophyceae Barcyte, Eikrem & M.Eliás, 2021 (a typified name, T: *Olisthodiscus* N.Carter), sister to the Pinguiophyceae (Graf & Yoon, 2021), has only two described species from brackish waters. The Pelagophyceae R.A.Andersen & G.W.Saunders in Andersen et al., 1993 (see also Moestrup, 2021, a typified name T: Pelagomonadales R.A.Andersen & G.W.Saunders) are marine organisms that form a sister grouping to the Dictyochophyceae, currently comprising 22 genera and 31 species. The Phaeosacciophyceae R.A.Andersen, L.Graf & H.S.Yoon in Graf et al., 2020, is another small class (a typified name, T: *Phaeosaccion* Farlow), formerly included in the Phaeophyceae. The Phaeothamniophyceae R.A.Andersen & J.C.Bailey in Bailey et al., 1998 (a typified name, T: *Phaeothamnion* Lagerheim) currently includes 16 genera and 31 species with a range of morphologies mostly found in freshwaters. The Pinguiophyceae Kawachi et al., 2002, a typified name (*Pinguiochrysis* M. Kawachi), includes five genera and five marine species. The Raphidophyceae Chadefaud ex P.C.Silva, 1980, a typified name (T: *Raphidomonas* F.Stein), includes both marine and freshwater unicellular species with 58 species in 21 genera. The Schizocladiophyceae E.C.Henry, K.Okuda & H.Kawai (in Kawai et al., 2003; a typified name, T: *Schizocladia* E.C.Henry, K.Okuda & H.Kawai) is only known from a single filamentous marine species from the subtidal of the Bay of Naples, Italy. The Synchromophyceae S.Horn & C.Wilhelm in Horn et al., 2007 (a typified name, T: Synchromales Schnetter & Ehlers; also known as "Picophagea"), an ambiregnal class, was originally described for an amoeboid marine species but currently includes six genera and nine species with various morphologies. The Xanthophyceae P.Allorge ex F.E.Fritsch (in Fritsch, 1935), a descriptive name, is a mostly freshwater class known for many years as the yellow-green algae (and for a time as "Heterokontae") and presently includes 115 genera and 616 species. Further molecular studies will probably show that the Xanthophyceae contains even further classes to add to the present 18 classes of the Heterokontophyta.

PRASINODERMATOPHYTA

The phylum Prasinodermatophyta B.Marin & Melkonian in Li et al., 2020 (as "Prasinodermophyta"[3]) includes two classes, the Palmophyllophyceae Leliaert et al., 2016 (a typified name, T: *Palmophyllum* Kützing) and the Prasinodermatophyceae B.Marin & Melkonian in Li et al., 2020 (as "Prasinodermophyceae," a typified name T: *Prasinoderma* T.Hasegawa & M.Chihara). The phylum currently includes 10 freshwater and marine species. It is a sister grouping to the Chlorophyta, and the two classes may eventually be shown to be a basal grouping within the Chlorophyta although the rooting of the clade is currently said to be ambiguous (Yang et al., 2023).

RHODELPHIOPHYTA

The phylum Rhodelphidophyta Tikhonenkov et al. in Gawryluk et al., 2019 (as "Rhodelphidia" and validated under the ICZN) includes a single class Rhodelphidophyceae Tikhonenkov et al. (in Gawryluk et al., 2019, as "Rhodelphea," a typified name, T: *Rhodelphis* Gawryluk et al.), a small grouping of non-photosynthetic predators postulated as sister to the Rhodophyta.

RHODOPHYTA

The phylum Rhodophyta Wettstein, 1901, a descriptive name, widely known as the red algae (e.g. Borg et al., 2023; Yoon et al., 2017), comprises six classes currently with 1093 genera and 7268 extant species (Table 7). The largest class is the Florideophyceae Cronquist, 1960, a descriptive name, which includes 95% of extant described species (Table 8). The

[3]The correct orthography for a higher taxon name based on a genus name ending in "-derma" is "-dermat-"as in the Pseudolithodermataceae and Nemodermatales.

Bangiophyceae Wettstein, 1901 (a typified name T: *Bangia* Lyngbye) has seen an explosion of segregate genera of the former *Porphyra* (Yang et al., 2020), although doubt has been cast recently on the taxonomic validity of some of these (e.g. Zuccarello et al., 2022). The Compsopogonophyceae G.W.Saunders & Hommersand, 2004 (a typified name, *Compsopogon* Montagne), Cyanidiophyceae Merola in Merola et al., 1982 (a typified name, *Cyanidium* Geitler), Porphyridiophyceae Shameel, 2001 (a typified name, T: *Porphyridium* Nägeli, *nom. cons.*), Rhodellophyceae Cavalier-Smith, 1998 (a typified name, *Rhodella* L.V.Evans), and the Stylonematophyceae H.S.Yoon et al., 2006 (a typified name, T: *Stylonema* Reinsch), have each seen several additional genera and species added in recent years based upon culturing, electron microscopy, and phylogenetic studies (e.g. Scott et al., 2006).

CONCLUDING REMARKS

So, how many species of algae have been described? Predictably, the answer is not an easy one. Authors frequently give estimates of species numbers but omit to say whether they are referring to extant species only or are including extinct taxa. This is complicated even further for the diatoms by two issues: Some diatoms initially described as fossils were later found to be extant; also, some diatom authors (and other authors) are not always clear that what they are describing are fossil species. The best estimates after 26 years of data entry in AB are given in Table 8. We have recorded (to September 2023) 50,589 species of extant algae that are considered taxonomically valid ("correct" to some), and some 8081 fossil species also thought to be taxonomically correct, giving a total of about 61,145 species. Of these, the Eubacteria comprise 9% extant species, the Chromista 49%, the Plantae 37%, and the Protozoa about 5%. So the "core" algae (Chromista and Plantae) comprise some 86% of all algae.

This brings us to the matter of the numbers of diatom species, which has been a matter of considerable speculation—even vexation on the part of some—with a few authors suggesting more than 200,000 species (e.g. Armbrust, 2009) or even 2 million on some web pages (but without authoritative sources). In a more considered and informed analysis, Mann and Vanormelingen (2013) concluded that the number of extant species of diatoms was estimated to be "at least" 30,000 and "probably ca. 100,000" (see also Mann et al., 2017). Our figure, which is not complete—as is the case with all databases—is for the current total number of taxonomically valid diatom species, extant and extinct, and is 18,186. This number is based on numerous monographs, journals, and national and local lists. The average rate of diatom species description from 2012 to 2022 was 316 per year (Table 9), nearly four times the rate of the nearest phylum, the Rhodophyta (Table 9). At this rate of description, and with the current cohort of diatomists (who seem to have done better in the employment stakes than most other phycologists), it will take at least 36 years to describe the 10,000 or missing diatoms species of Mann and Vanormelingen (2013). Either way, this is a daunting task particularly with the current declining employment opportunities for all taxonomists and the virtual disappearance of taxonomy training worldwide. However, there are in AB some 10,000 names of diatom species for which we have not been able to discover recent references as to their taxonomic status; many of these names seem not to have been employed except in the original publication. Thus, Mann and Vanormelingen's (2013) estimate of 30,000 species appears close to the actual number of described species; however, at least one-third are, to say the least, poorly known or not recently assessed.

TABLE 9 Description of new species fossil and living in the most speciose algal groupings over a 10-year period (2012–2022).

Phylum (class)	2012–2022	Average
Bacillariophyta	3159	316
Charophyta	218	22
Chlorophyta	507	51
Cyanobacteria	472	47
Euglenozoa	79	8
Haptophyta	75	8
Miozoa	259	26
Heterokontophyta	350	35
(Phaeophyceae)	160	16
Rhodophyta	770	77

There are similar uncertainties with the other large groupings of algae such as the Cyanobacteria, for which molecular methods have resulted in an expansion of numbers of genera, but only 47 new species have been described on average each year in the last 10. By contrast, the brown seaweeds (Phaeophyceae) and the red seaweeds have had 16 and 77 species, respectively, on average described each year for the last 10 (Table 9).

Finally, the algae, currently with 63 classes of photosynthetic organisms, is more class rich than (according to Ruggiero et al., 2015) the Fungi (40 classes, including the lichens), the Bryophyta (8 classes), the Marchantiophyta (3 classes), the Pteridophyta (4 classes), and the Tracheophyta (7 classes).

AUTHOR CONTRIBUTIONS

Michael D. Guiry: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal).

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