

Taxonomic Note

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A proposal for further integration of the cyanobacteria under the Bacteriological Code

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This taxonomic note reviews the present status of the nomenclature of the cyanobacteria under the Bacteriological Code. No more than 13 names of cyanobacterial species have been proposed so far in the *International Journal of Systematic and Evolutionary Microbiology* (IJSEM)/*International Journal of Systematic Bacteriology* (IJSB), and of these only five are validly published. The cyanobacteria (Cyanophyta, blue-green algae) are also named under the Botanical Code, and the dual nomenclature system causes considerable confusion. This note calls for a more intense involvement of the International Committee on Systematics of Prokaryotes (ICSP), its Judicial Commission and its Subcommittee on the Taxonomy of Photosynthetic Prokaryotes in the nomenclature of the cyanobacteria under the Bacteriological Code. The establishment of minimal standards for the description of new species and genera should be encouraged in a way that will be acceptable to the botanical authorities as well. This should be followed by the publication of an 'Approved List of Names of Cyanobacteria' in IJSEM. The ultimate goal is to achieve a consensus nomenclature that is acceptable both to bacteriologists and to botanists, anticipating the future implementation of a universal 'Biocode' that would regulate the nomenclature of all organisms living on Earth.

Introduction – an historical overview

In 1978, the Subcommittee on the Taxonomy of Phototrophic Bacteria of the International Committee on Systematic Bacteriology (ICSB) unanimously submitted to the ICSB a proposal according to which the nomenclature of cyanobacteria ('blue-green algae') should be governed by the provisions of the International Code for Nomenclature of Bacteria ('Bacteriological Code', ICNB) as of 1 January 1979. That date was proposed as the deadline for the publication of a list of approved names for these prokaryotes (Stanier *et al.*, 1978).

This proposal caused a potential conflict with the botanical nomenclature, as the cyanobacteria (Cyanophyta, blue-green algae) are also named under the International Code of Botanical Nomenclature ('Botanical Code', ICBN). It was discussed by the Judicial Commission at its 1978 meeting in Munich, Germany. The commission expressed the view that scientists who believe blue-green algae to be bacteria

should be at liberty to use the Bacteriological Code for their nomenclature, but considered that further discussion with officers of the Botanical Code was desirable before formal action was taken (Holt, 1979).

The issue of the nomenclature of the cyanobacteria under the Bacteriological Code has since been brought up many times in the meetings of the ICSB/International Committee on Systematics of Prokaryotes (ICSP), its Judicial Commission and its Subcommittee on the Taxonomy of Phototrophic Bacteria. In 1985, the subcommittee had organized a workshop in Paris to discuss the problems of cyanobacterial nomenclature (Trüper, 1986). That workshop aimed to work out a solution to the procedural and technical problems involved in the accession of cyanobacteria under the ICNB, to discuss probable nomenclatural problems that would arise and how they should be dealt with and to devise possible procedures for the validation of new names when both the Bacteriological Code (Lapage *et al.*, 1992) and the Botanical Code (Greuter *et al.*, 2000) must be respected. The following proposal to the ICSB was unanimously adopted during the workshop:

'The subcommittee for the Taxonomy of Phototrophic Bacteria of the ICSB proposes that names of cyanobacteria described and validly published as blue-green algae under the International Code of Botanical Nomenclature are recognized as having been validly published under the

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Abbreviations: ICBN, International Code of Botanical Nomenclature; ICNB, International Code of Nomenclature of Bacteria; ICSB, International Committee on Systematic Bacteriology; ICSP, International Committee on Systematics of Prokaryotes; IJSB, *International Journal of Systematic Bacteriology*; IJSEM, *International Journal of Systematic and Evolutionary Microbiology*.

ICNB.' It was agreed that the Judicial Commission would take this up to make a formal recommendation to the ICSB (Hill, 1987; Trüper, 1986).

The immediate goal of this proposal was to avoid a possible chaotic situation resulting from the introduction of new names for already existing and recognizable taxa. The ultimate goal was to develop a unified system of nomenclature, based on living type material, and the establishment of an approved list of cyanobacterial names in the foreseeable future. The subcommittee recommended that, when cyanobacteria are described under the Bacteriological Code, in addition to depositing a living type culture (Recommendation 30a), a preserved sample of the type culture (preferably as a dry specimen) should be deposited in a permanent institution (herbarium) and that the description be accompanied by photomicrographs or drawings in accordance with Article 39 of the Botanical Code. The new name, together with reference to the type and effectively published description, should be published in the *International Journal of Systematic Bacteriology* (IJSB). Whenever possible, the specimen from which the type culture was obtained should be preserved and information about environmental conditions recorded. An advisory panel on cyanobacterial nomenclature was formed on this occasion. Among the tasks of that committee were: (i) to offer assistance to editorial boards of microbiological journals with respect to submitted manuscripts that newly describe and name cyanobacterial taxa; (ii) to offer assistance and information to anyone who plans new descriptions or taxonomic changes; (iii) to inform botanists (phycologists/planctologists) about what is necessary for the description of cyanobacteria under the ICNB; and (iv) to compile a list of cyanobacterial strains presently in pure culture (Trüper, 1986).

Castenholz & Waterbury (1989) noted that this recommendation had been processed by the Rules Revision Committee, to be formally proposed and voted upon at the International Congress for Microbiology in 1990 in Osaka. However, the minutes of the ICSB meetings in Osaka (Goodfellow, 1991) do not make any explicit statement on the matter beyond stating that 'a good spirit of cooperation is developing between workers from botanical and bacteriological backgrounds, and steady progress is being made on matters such as recognizing well-founded names and types'. The minutes of the meeting of the Judicial Commission added that 'no formal efforts have yet been initiated to bring the nomenclature of cyanobacteria in conformity with both the Bacteriological and the Botanical Codes', but that 'informal discussions have created an atmosphere of cooperation that will facilitate the difficult task of standardizing descriptions and type designations in a form compatible with both codes' (Wayne, 1991; see also Goodfellow, 1995; Hill, 1983; Minutes of the Judicial Commission, 1986).

The status of the cyanobacterial nomenclature has been discussed at several more recent meetings of the ICSB/ICSP

and the Subcommittee on Taxonomy of Photosynthetic Prokaryotes. No explicit statements and recommendations can be found in the minutes of the subcommittee meetings held in Urbino in 1994 (Madigan & Imhoff, 1996), in Vienna in 1997 (Trüper & Imhoff, 1999) or in Barcelona in 2000 (Imhoff & Madigan, 2002) or the Judicial Commission meeting held in Sydney in 1999 (De Vos & Trüper, 2000).

Cyanobacterial taxa validly named under the Bacteriological Code

Species and genera

The number of names of cyanobacterial species that have been validly published under the Bacteriological Code is very small. The *Approved Lists of Bacterial Names* (Skerman *et al.*, 1980) did not include any cyanobacteria. As of May 2003, only 13 species names have been proposed in original articles published in *International Journal of Systematic and Evolutionary Microbiology* (IJSEM)/IJSB or validated in the Validation Lists in the journal as of November 2003 (Table 1). These include three species characterized by the presence of chlorophyll *b* derivatives in addition to chlorophyll *a* and one unicellular and nine filamentous species that contain chlorophyll *a* only. Of these proposed 13 species names, no more than five can be considered to have been validly published according to the rules of the Bacteriological Code (1990 Revision) (Lapage *et al.*, 1992). No more than six genera of cyanobacteria appear in the Validation Lists and the Notification Lists, and one of these ('*Planktothrix*') has no standing in the nomenclature under the Bacteriological Code.

A statement on the description of two new genera, *Cyanobacterium*, with the species *Cyanobacterium stanieri*, and *Cyanobium*, with the species *Cyanobium marinum*, appeared in the minutes of the ICSP Subcommittee on the Taxonomy of Phototrophic Bacteria meeting held in Barcelona in 2000 (Imhoff & Madigan, 2002). However, these names have never been validly published, and they therefore have no standing in bacteriological nomenclature.

Higher taxa

Only two names of families of cyanobacteria have been validly published, both of chlorophyll *b* derivative-containing genera, and the number of orders of cyanobacteria with standing in the nomenclature is presently seven, i.e. considerably more than the number of families (Table 1).

Cavalier-Smith (2002) proposed names for the higher taxa for cyanobacterial classification: the division *Cyanobacteria* (one of the eight proposed divisions of prokaryotes), with two subdivisions, three classes and six orders (Table 1). The terms 'division' and 'subdivision' have no standing under the Bacteriological Code. The rank of 'class' is recognized by the Bacteriological Code, but the Bacteriological Code only regulates matters of priority of taxa up to the level of order (Rule 23a) (Lapage *et al.*, 1992). The earlier

Table 1. Names of cyanobacterial taxa proposed in original articles published in IJSEM/IJSB or that have been validated in the Validation Lists in the journal as of November 2003See also Euzéby (1997) (<http://www.bacterio.cict.fr/classifcyano.html>).

Name	Reference(s)	Comments
Division		
<i>Cyanobacteria</i>	Cavalier-Smith (2002)	The category 'Division' is not covered by the Bacteriological Code
Subdivision		
<i>Gloeobacteria</i>	Cavalier-Smith (2002)	The category 'Subdivision' is not covered by the Bacteriological Code
<i>Phycobacteria</i>	Cavalier-Smith (2002)	The category 'Subdivision' is not covered by the Bacteriological Code
Class		
<i>Oxyphotobacteria</i>	Murray (1984, 1988)	
<i>Chroobacteria</i>	Cavalier-Smith (2002)	
<i>Gloeobacteria</i>	Cavalier-Smith (2002)	
<i>Hormogoneae</i>	Cavalier-Smith (2002)	
Order		
<i>Chroococcales</i>	Cavalier-Smith (2002)	The order proposed by Cavalier-Smith (2002) includes unicellular chlorophyll <i>b</i> -containing prokaryotes (<i>Prochloron</i> , <i>Prochlorococcus</i>), but no proposal was made to replace the validly published order name <i>Prochlorales</i> Florenzano <i>et al.</i> 1986
<i>Gloeobacterales</i>	Cavalier-Smith (2002)	
<i>Nostocales</i>	Cavalier-Smith (2002)	
<i>Oscillatoriales</i>	Cavalier-Smith (2002)	
<i>Pleurocapsales</i>	Cavalier-Smith (2002)	
<i>Prochlorales</i>	Florenzano <i>et al.</i> (1986)	The nomenclatural type should be the genus <i>Prochloron</i> , not the family <i>Prochloraceae</i> (Euzéby & Tindall, 2001). The order name was validly published under the Botanical Code by Lewin (1977)
<i>Stigonematales</i>	Cavalier-Smith (2002)	
Family		
<i>Prochloraceae</i>	Florenzano <i>et al.</i> (1986)	
<i>Prochlorotrichaceae</i>	Burger-Wiersma <i>et al.</i> (1989)	
Genus		
<i>Halospirulina</i>	Nübel <i>et al.</i> (2000)	
<i>Planktotricoides</i>	Suda <i>et al.</i> (2002)	
' <i>Planktothrix</i> '	Suda <i>et al.</i> (2002)	Suda <i>et al.</i> (2002) gave an emended description of the genus. However, the genus name has never been validly published under the Rules of the Bacteriological Code (1990 Revision)
<i>Prochlorococcus</i>	Rippka <i>et al.</i> (2000, 2001)	
<i>Prochloron</i>	Florenzano <i>et al.</i> (1986)	The botanical type is Lewin (1977)
<i>Prochlorothrix</i>	Burger-Wiersma <i>et al.</i> (1989)	
Species		
' <i>Crinalium epipsammum</i> '	de Winder <i>et al.</i> (1990, 1991)	The genus name <i>Crinalium</i> has not been validly published and <i>Crinalium epipsammum</i> is therefore illegitimate (Euzéby & Kudo, 2001)
<i>Halospirulina tapeticola</i>	Nübel <i>et al.</i> (2000)	
' <i>Limnothrix redekei</i> '	Suda <i>et al.</i> (2002)	Suda <i>et al.</i> (2002) gave an emended description of the species ' <i>Limnothrix redekei</i> '. However, the genus name has never been validly published under the Rules of the Bacteriological Code (1990 Revision) and the species was therefore not validly published according to Rule 16, Note 2 (De Vos & Trüper, 2000); <i>Limnothrix redekei</i> (Van Goor) Meffert 1988 was validly published under the ICBN
' <i>Microcystis aeruginosa</i> '	Otsuka <i>et al.</i> (2001)	The name is illegitimate because the genus name <i>Microcystis</i> has never been validly published under the Rules of the Bacteriological Code. The name <i>Microcystis aeruginosa</i> (Kützing) Lemmermann 1907 was validly published under the ICBN

Table 1. cont.

Name	Reference(s)	Comments
<i>Planktotricoides raciborskii</i>	Suda <i>et al.</i> (2002)	Under the ICBN, <i>Planktotricoides raciborskii</i> Suda <i>et al.</i> (2002) is known as <i>Planktothrix raciborskii</i> (Woloszynska) Anagnostidis & Komárek 1988 or as <i>Oscillatoria raciborskii</i> Woloszynska 1912
' <i>Planktothrix agardhii</i> '	Suda <i>et al.</i> (2002)	Suda <i>et al.</i> (2002) gave an emended description of the species ' <i>Planktothrix agardhii</i> '. However, the genus name has never been validly published under the Rules of the Bacteriological Code (1990 Revision), and the species was therefore not validly published according to Rule 16, Note 2 (De Vos & Trüper, 2000); the name <i>Planktothrix agardhii</i> (Gomont) Anagnostidis & Komárek 1988 was validly published under the ICBN
' <i>Planktothrix mougeotii</i> '	Suda <i>et al.</i> (2002)	The name is illegitimate because the genus name <i>Planktothrix</i> has never been validly published under the Rules of the Bacteriological Code (1990 Revision), and the species was therefore not validly published according to Rule 16, Note 2 (De Vos & Trüper, 2000); the basonym, <i>Oscillatoria mougeotii</i> Kützing <i>ex</i> Lemmermann was validly published under the ICBN
' <i>Planktothrix pseudagardhii</i> '	Suda <i>et al.</i> (2002)	The name is illegitimate because the genus name <i>Planktothrix</i> has never been validly published under the Rules of the Bacteriological Code (1990 Revision), and the species was therefore not validly published according to Rule 16, Note 2 (De Vos & Trüper, 2000)
' <i>Planktothrix rubescens</i> '	Suda <i>et al.</i> (2002)	Suda <i>et al.</i> (2002) gave an emended description of the species ' <i>Planktothrix rubescens</i> '. However, the genus name has never been validly published under the Rules of the Bacteriological Code (1990 Revision), and the species was therefore not validly published according to Rule 16, Note 2 (De Vos & Trüper, 2000); the name <i>Planktothrix rubescens</i> (D.C. <i>ex</i> Gomont) Anagnostidis & Komárek 1988 was validly published under the ICBN
<i>Prochlorococcus marinus</i>	Chisholm <i>et al.</i> (1992); Rippka <i>et al.</i> (2000, 2001)	Two subspecies have been described: subsp. <i>marinus</i> and subsp. <i>pastoris</i>
<i>Prochloron didemni</i>	Florenzano <i>et al.</i> (1986)	
<i>Prochlorothrix hollandica</i>	Burger-Wiersma <i>et al.</i> (1989)	
' <i>Tychonema bourrellyi</i> '	Suda <i>et al.</i> (2002)	Suda <i>et al.</i> (2002) gave an emended description of the species ' <i>Tychonema bourrellyi</i> '. However, the genus name has never been validly published under the Rules of the Bacteriological Code (1990 Revision), and the species was therefore not validly published according to Rule 16, Note 2 (De Vos & Trüper, 2000); the name <i>Tychonema bourrellyi</i> (Lund) Anagnostidis & Komárek 1988 was validly published under the ICBN

name of the class *Oxyphotobacteria* (*ex* Gibbons & Murray 1978) Murray 1988 (see also Murray, 1984), to encompass all cyanobacteria, was validly published in 1988 (Murray, 1988). The order *Chroococcales* was proposed as the type order, a name that has only recently obtained standing in the bacterial nomenclature (Cavalier-Smith, 2002).

The status of the ordinal name *Cyanobacteriales*, which was proposed in 1978 (Gibbons & Murray, 1978; see also Rippka & Cohen-Bazire, 1983), was discussed by the Judicial Commission at its meeting in Munich in 1978. The name did not obtain standing in nomenclature as it was not based on the name of a type genus (Holt, 1979).

Treatment of the cyanobacteria in *Bergey's Manual*

The latest edition of *Bergey's Manual* (Boone & Castenholz, 2001) places the oxygenic photosynthetic prokaryotes within the class '*Cyanobacteria*', rather than using the earlier published name *Oxyphotobacteria*. It classifies the cyanobacteria in 'form genera'. This term, coined by Castenholz (1992), has no standing under the Bacteriological Code or under the Botanical Code. The usefulness of this concept was evaluated for the (yet to be validly published) genus name *Nostoc*, based on molecular analyses (Wright *et al.*, 2001). It was recognized that, in view of shared

morphologies of genetically different strains, dissimilar morphologies in strains that share identical genetic markers, incorrect naming of culture collection strains and genetic drift in cultured strains, the successful delineation of cyanobacterial species requires the application of multiple taxonomic criteria. The delineation of ‘form species’ is based on the observations that a single form with very characteristic morphology often dominates cyanobacterial populations and that strains with such morphologies often have global distributions and can readily be identified in diverse geographical localities (Wright *et al.*, 2001). Others, however, have doubted the usefulness of the ‘form species’ concept (see e.g. Whitton & Potts, 2000).

The authors of the sections on the cyanobacteria in *Bergey’s Manual* admit that the proposed classification is a temporary one that will undoubtedly require modification in the future. They state that many generic names used in the past (e.g. *Synechococcus*, *Leptolyngbya*, *Pseudanaebaena*) will eventually have to be split into several new genera (Castenholz, 2001). This is especially true if molecular phylogenetic analyses based on sequence comparison of 16S rRNA and other relevant genes are used as the basis of taxonomy and nomenclature. Members of the orders *Chroococcales*, *Pleurocapsales* and *Oscillatoriales* do not form coherent phylogenetic lineages but instead are dispersed throughout the phylogenetic tree (Wilmotte, 1994; Wilmotte & Herdman, 2001).

Botanical approaches to cyanobacterial nomenclature and attempts to bridge the gap with the bacteriological approach

Historically, the cyanobacteria (Cyanophyta, blue-green algae) have always been considered as part of the plant world, and therefore their nomenclature is governed by the rules of the ICBN (Greuter *et al.*, 2000). The rules of the Botanical Code are quite different from those of the Bacteriological Code, and this makes a reconciliation between the botanical and the bacteriological nomenclature systems quite problematic. However, such a reconciliation is urgently needed. Moreover, the proper way of handling the taxonomy and nomenclature of the cyanobacteria has also long been a topic of dispute among botanists themselves (see e.g. Friedmann & Borowitzka, 1982). However, all approaches are based on morphological properties of field-collected samples, and they therefore differ greatly from the bacteriological approach initiated by Stanier and co-workers (Rippka *et al.*, 1979; Stanier & Cohen-Bazire, 1977; Stanier *et al.*, 1971), which is based on the study of isolated organisms in pure culture. According to the botanical approach, species names can be validly published in any journal. As a result, the existing botanical nomenclatural information is widely scattered. To establish whether a species is novel to science, the literature to be checked extends over more than a hundred years [1886 for filamentous heterocystous species and 1892 for the filamentous non-heterocystous species according to Article 13.1e of the ICBN (Greuter *et al.*, 2000)]. Many species are

known under two or more synonyms. In contrast, IJSEM/IJSB is the only platform for bacteriological nomenclature, and the publication of the *Approved Lists of Bacterial Names* (Skerman *et al.*, 1980) has abolished the need to search the older literature before a new species can be proposed.

During the XIIIth International Botanical Congress, held in Sydney, Australia, in 1981, a symposium was devoted to “taxonomic concepts in ‘blue-green algae’ – towards a compromise with the Bacteriological Code?” The discussions during that symposium, as summarized by Friedmann & Borowitzka (1982), showed many differences in opinion on the value of the bacteriological, pure culture-based approach, for the classification of the cyanobacteria. For example, it was stated that, when cultures are used as types, the name is associated with the culture, not with a description, and cultures are subject to change over time. On the other hand, the bacteriological system of Stanier and his collaborators was claimed to be a logical progression of the botanical ‘Geitlerian’ system (Geitler, 1932), employing bacteriological techniques, while trying to conform wherever possible with the essence of the botanical classification system. In spite of the differences in opinion, a compromise proposal was formulated, which included the following statements (Friedmann & Borowitzka, 1982):

Blue-green algae (cyanobacteria) may be described following either the Botanical or the Bacteriological Code, with nomenclatural types chosen according the Rules of each Code. It is understood that the different type concepts which are intrinsic to each Code are not affected by this proposal.

According to Rule 18a of the Bacteriological Code, the type of a species is, whenever possible, a designated strain made up of living cultures of an organism which are descended from a strain designated the nomenclatural type (or, if unculturable, a description, a preserved specimen or an illustration). [Note: since November 2000, the option to use a description, a preserved specimen or an illustration as the nomenclatural type of a new species no longer exists (De Vos & Trüper, 2000)]. It is recommended that, when describing a cyanobacterium, a large sample of the type culture should be preserved (preferably as a dry specimen), which should then be deposited in a permanent institution (herbarium) and that the description be accompanied by photomicrographs or drawings in accordance with Articles 8.1 and 39 of the ICBN.

Names of Cyanophyta validly published under the Bacteriological Code as cyanobacteria are valid according to the Botanical Code.

Names of cyanobacteria validly published under the Botanical Code as Cyanophyta are valid according to the Bacteriological Code.

It should be stressed that these recommendations of the ad hoc discussion group have never been officially proposed

and accepted by the ICSB/ICSP or by the General Committee on Botanical Nomenclature.

At its meeting in Manchester in 1986, the Judicial Commission agreed unanimously to recommend the following to the ICSB: that 'those names of taxa of *Cyanobacteria* or *Cyanophyta* that are valid under the Botanical Code be considered valid under the Bacteriological Code for the purpose of preparing an acceptable list comparable to the Approved Lists of Bacterial Names' (Jones, 1987). No such formal recommendation has been made, however, so no action was taken by the ICSB on this issue.

Castenholz & Waterbury (1989) conclude that: 'In the foreseeable future, the two systems for the classification of cyanobacteria will exist. This may not cause difficulties if these two systems run in parallel and do not diverge without control. This is best achieved by developing the bacteriological system from the existing botanical assemblage of names, whenever such taxa are recognizable.'

Proposed steps for the future

In order to advance the status of the nomenclature of the cyanobacteria under the Bacteriological Code, I propose the following steps, to be endorsed by the ICSP, its Judicial Commission and its Subcommittee on Taxonomy of Photosynthetic Prokaryotes.

Minimal standards should be established for the description of new species and genera of cyanobacteria under the Bacteriological Code. The preparation of such a document is now in an advanced stage. It should be stressed that the description of new species should be based on the study of pure cultures according to Rule 18a of the Bacteriological Code. In the past, a description, a preserved (non-viable) specimen or an illustration could serve as the type for a species that has not so far been maintained in laboratory culture or for which a living axenic type strain does not exist. However, this option was abolished with the publication of the new version of Rule 18a as approved by the ICSB and its Judicial Commission in Sydney in 1999 (De Vos & Trüper, 2000).

An 'Approved List of Names of Cyanobacteria' should be published in IJSEM. The desirability of the establishment of such a list has been stressed many times in the past, but there has been a consensus in the past among bacteriologists to perpetuate the problem (see e.g. Castenholz & Waterbury, 1989). Appropriate types should be designated at the time of the publication of the 'Approved List'.

The ongoing dialogue (at the level of the ICSP Judicial Commission) with the botanical authorities on the issue of nomenclature of the group should be further strengthened to reach a consensus.

The ultimate goal of taxonomists should be to achieve a universal 'Biocode' that would encompass the nomenclature of all organisms living on Earth. Such a Biocode is presently

in preparation (see <http://www.rom.on.ca/biodiversity/biocode> and <http://www.biosis.org.uk/zrdocs/codes/biocode.htm>).

In anticipation of the implementation of the Biocode, it is highly desirable that the botanical and bacteriological taxonomists use unified rules for the description of new taxa of cyanobacteria/Cyanophyta/blue-green algae and adopt a single taxonomic classification scheme. Unification of the approaches and nomenclatural stability are the first conditions to be met to ensure future progress.

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