



# Distribution and diversity of cyanobacteria in the Azores Archipelago: An annotated checklist

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Academic editor: Paulo Borges

Received: 10 Jun 2022 | Accepted: 19 Jul 2022 | Published: 02 Sep 2022

Citation: Luz R, Cordeiro R, Fonseca A, Raposeiro PM, Gonçalves V (2022) Distribution and diversity of cyanobacteria in the Azores Archipelago: An annotated checklist. Biodiversity Data Journal 10: e87638.

<https://doi.org/10.3897/BDJ.10.e87638>

## Abstract

### Background

Knowledge about cyanobacteria diversity in the Azores is spread over several publications, dating from 1874, with some of them not generally available to the scientific community due to their restricted access. The dispersion and sometimes inaccessibility of this information hinder a deeper analysis and a better understanding of the biodiversity of the Azores Islands and more general ecological processes in oceanic islands. Here we present the first checklist of cyanobacteria for the Azores Archipelago with updated taxonomy of all recorded taxa.

### New information

This work provides a compiled and annotated checklist of all known cyanobacteria from the Azores Archipelago with morphological identification from preserved samples and cultures, based on published literature. All records of taxa known to occur in the Azores were taxonomically updated. The present checklist comprises 225 taxa distributed by six orders (Chroococcales, Nostocales, Oscillatoriales, Pleurocapsales, Spirulinales and

Synechococcales). Our literature review reveals that the Azores Archipelago hosts a high diversity of cyanobacteria, despite several overlooked habitats that may present great potential regarding cyanobacteria diversity. Increasing efforts to study these neglected habitats could contribute to the knowledge of cyanobacteria taxonomy. This checklist provides the basis for future works on the taxonomy and taxa richness of cyanobacteria in the Azores and the Atlantic Islands, as also for understanding and monitoring non-indigenous and invasive species.

## Keywords

Oceanic islands, biodiversity, Cyanophyceae, Macaronesia, Atlantic Ocean

## Introduction

Cyanobacteria are gram-negative photosynthetic prokaryotes that developed around 3500 million years ago (Schirmer et al. 2015). As one of the most primitive organisms on earth (Mareš et al. 2013), they successfully occupy various habitats in terrestrial and aquatic ecosystems, both marine and freshwater (Whitton and Potts 2012). Cyanobacteria diversity amongst these systems is unbalanced, being larger in freshwater and terrestrial ecosystems (Komárek and Johansen 2015). They persist in almost all types of illuminated habitats, with optimum growing temperatures generally higher than microalgae, which enable them to support a wide array of stress conditions, including extreme habitats (Komárek and Johansen 2015).

Freshwater cyanobacteria are commonly present in wetlands, lakes, rivers and streams, both in benthic (Scott and Marcarelli 2012) and planktonic (e.g. Stockner et al. 2000, Oliver et al. 2012) habitats. Benthic cyanobacteria are commonly found solitary or forming mats in the various stream and river substrates, such as rocks, sand, plants and many others (Casamatta and Hašler 2016). In shallow lakes and littoral zones of deep lakes, benthic species of cyanobacteria can also occur if enough light reaches the substrates (Scott and Marcarelli 2012). However, cyanobacteria are mostly known from the plankton of lentic waters, where they can grow in high abundance, usually known as blooms, especially in eutrophic lakes (Paerl et al. 2010, Carmichael and Boyer 2016). Cyanobacteria blooms negatively affect the ecosystems and services they provide (Carmichael and Boyer 2016) as most bloom-forming species produce toxins that can be accumulated at the water surface, causing unpleasant surface scums.

Extreme habitats, such as thermal springs, are successfully occupied by Cyanobacteria, where they are often the main and/or sole autotrophic organisms inhabiting these environments (Komárek and Johansen 2015). In marine systems, cyanobacteria are found in a wide array of habitats, including benthos, plankton, associated with other organisms, amongst others (Golubic et al. 2010, Konstantinou et al. 2018).

In the last ten years, cyanobacteria taxonomy has changed dramatically with the use of new techniques, mainly through 16S rRNA sequencing, contributing to a taxonomic reassessment of the group (e.g. Wacklin et al. 2009, Komárek et al. 2011, Zapomělová et al. 2011, Strunecký et al. 2013, Komárek et al. 2014, Strunecky et al. 2017, Mai et al. 2018).

In the Azores, a remote oceanic archipelago located in the middle of the North Atlantic Ocean, the first work to be published on cyanobacteria taxonomy came from the Challenger expedition that occurred from 1872 to 1876 and had a brief passage in São Miguel Island from 3 July to 9 July 1873 (Brock and Brock 1967). Some members of the Challenger expedition visited the Furnas Village and later Moseley (1874) and Archer (1874), who received samples from Moseley, published the first records. Later, Trelease (1897) and Bohlin (1901) contributed with several cyanobacteria records from several islands. In the 20<sup>th</sup> century, more biologists visited the Islands contributing considerably to the knowledge of the microalgae and cyanobacteria of the Azores. First by Krieger (1931), with a small contribution and after with the valuable works of Cedercreutz (1941), Bourrelly and Manguin (1946) and Johansson (1977), contributing with several detailed descriptions of the cyanobacteria flora in several islands of the Azores. The later works contributed with the highest number of known species for the Azores. Bourrelly and Manguin (1946) also describes a new form *Oscillatoria geitleri* f. *major* Bourrelly in Bourrelly and Manguin (1946), which is the first and only known endemic cyanobacteria to the Azores. After 1980, works were mainly focused on planktonic freshwater species due to the rise of lake eutrophication signs. Important contributions to the known cyanobacteria flora have been provided after the implementation of the Water Framework Directive (WFD) in the Azores, with regular monitoring programmes since 1994 (Santos et al. 2005, Santos et al. 2012, Luz et al. 2020b). The more recent works on cyanobacteria were based on cultured strains isolated from freshwater lakes (Cordeiro 2015), which provide the addition of new species. Several works performed on thermal, terrestrial, brackish and marine habitats, which were overlooked in previous studies, contributed to several new cyanobacteria species records (Luz 2018, Cordeiro et al. 2020b).

Despite the increased research efforts, especially in the last decade, the knowledge of the diversity and distribution of Cyanobacteria in the Azores Archipelago is not consistently organised and a local checklist has never been published. This study aims to present an updated checklist of cyanobacteria present in the Azores, based on a taxonomically updated list of previously reported species from preserved samples and based on cultured strains.

## Materials and methods

### Study Area

The Azores are an oceanic group of islands located in the middle of the North Atlantic Ocean, roughly 1500 km from Europe and 1900 km from America (Fig. 1). The Archipelago is made up of nine islands roughly aligned along 615 km in a WNW-ESE trend, that are divided into three groups according to their geographical position. Although they are in

geographical proximity, the Islands present unique features differentiating themselves from each other (Table 1), with different amounts of annual rainfall (Secretaria Regional do Ambiente e do Mar 2011) and distinct geological settings (e.g. Moore 1990, Azevedo and Portugal Ferreira 2006, Cole et al. 2008).

Table 1.

Island characterisation. [1] Ávila et al. 2016, [2] Secretaria Regional do Ambiente e do Mar 2011, [3] Porteiro 2000, [4] Morton 2014, [5] Cruz and França 2006, [6] Secretaria Regional da Agricultura e Ambiente – Direção Regional do Ambiente 2015, [7] Ramsar 2013, [8] Morton et al. 1997.

Group	Island	Age (Ma) <sup>[1]</sup>	Area (Km <sup>2</sup> ) <sup>[2]</sup>	Freshwater lakes (N) <sup>[3]</sup>	Permanent Streams (N) <sup>[6]</sup>	Coastal lakes (N) <sup>[4, 7, 8]</sup>	Thermal waters (N) <sup>[5]</sup>	Total lake area (km <sup>2</sup> ) <sup>[3, 4, 7, 8]</sup>	Annual precipitation (mm) <sup>[2]</sup>
Eastern	São Miguel	4.00	744,6	33	6	-	14	8.34	1027.1
	Santa Maria	6.30	96,9	-	1	-	-	-	775.2
Central	Terceira	0.40	400,3	18	-	3	-	0.36	1125.6
	Pico	0.27	444,8	28	-	-	-	0.16	956.3
	Faial	0.85	173,1	-	-	-	2	-	974.0
	São Jorge	1.32	243,7	-	-	2	-	0.86	1194.3
	Graciosa	0.70	60,7	-	-	-	1	-	918.4
Western	Flores	2.16	141,0	8	2	-	2	0.72	1716.1
	Corvo	1.50	17,1	1	-	-	-	0.24	1144.6

The western group includes the Islands of Flores and Corvo, which are amongst the smallest islands of the Archipelago. Corvo and Flores are very rich in aquatic habitats despite their small size due to their higher annual precipitation (Secretaria Regional do Ambiente e do Mar 2011). The central group (Graciosa, Faial, Pico, São Jorge and Terceira Islands) comprise the youngest in the Archipelago (Ávila et al. 2016). The islands in the central group include a high diversity of inland aquatic habitats, including freshwater and saline lakes, streams and thermal waters (Morton et al. 1997, Porteiro 2000, Cruz and França 2006, Morton 2014). The eastern group, Santa Maria and São Miguel, includes the Archipelago's oldest (Santa Maria) and the largest (São Miguel) islands. São Miguel is the island with most of the lakes and the larger area of water bodies (Porteiro 2000), whereas Santa Maria is the driest island of the Archipelago, with only 775.2 mm mean annual precipitation and no significant inland water habitats (Secretaria Regional do Ambiente e do Mar 2011).

The Azores are particularly rich in freshwater systems, with 88 lakes (Porteiro 2000), nine permanent streams, five saline lakes and several thermal springs (Table 1). Lakes are located between 230 and 1,050 m altitude and, according to Gonçalves 2008, could be

classified into two main lake types: shallow lakes, with a maximum depth below five metres; and (ii) deep lakes, with maximum depths, greater than five metres. The insular lotic systems are small, narrow, with steep watersheds and are fed by lakes or springs, most of them having torrential or seasonal flowing regimes (Raposeiro et al. 2013).

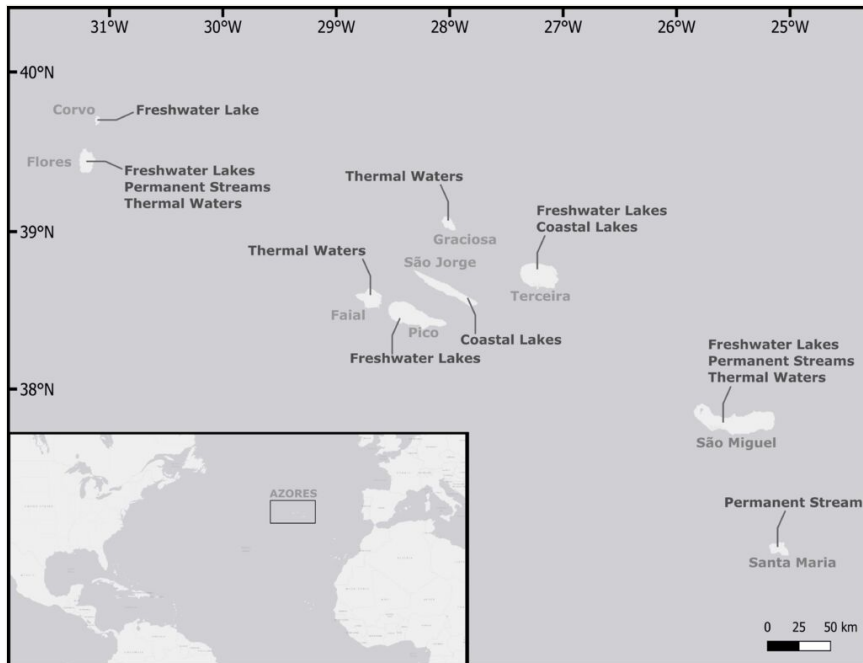


Figure 1. [doi](#)

Azores Archipelago location with an indication of the most represented aquatic habitats on each island.

## Checklist Production

The checklist was based on all known literature mentioning cyanobacteria from the Azores with morphological identification, published until 2020. The nomenclature was revised according to Guiry and Guiry (2022). The complete taxonomic list (taxon data table and occurrence data table) is published in DwC (Suppl. material 1) in GBIF, the Global Biodiversity Information Facility (Luz et al. 2022). Taxa identified only to the family level or above were not included in the discussed taxonomic list.

## Data resources

### Cyanobacteria occurrence in the Azores

**Data set name:** Cyanobacteria Checklist of the Azores Archipelago, Portugal - Occurrence data table

**Data format:** Darwin Core

**Description:** Cyanobacteria occurrence records in the Azores Archipelago, dating from 1874 to 2020, with 2838 records (Luz et al. 2022). Used Darwin Core terms are described in Table 2.

Table 2. Darwin Core terms used in the occurrence data table.	
Column label	Column description
id	Identifier.
type	The nature of the resource.
collectionCode	Acronym identifying the collection from which the record was derived.
basisOfRecord	Specific nature of the data record.
occurrenceID	Occurrence identifier.
catalogNumber	Identifier for the record within the collection.
associatedReferences	Literature associated with the occurrence.
eventDate	Date-time or interval during which the event was recorded.
continent	Name of the continent in which the occurrence location occurs.
waterBody	Name of the water body in which the occurrence location occurs.
islandGroup	Name of the island group in which the occurrence location occurs.
island	Name of the island on which the occurrence location occurs.
country	Name of the country in which the occurrence location occurs.
countryCode	Standard code for the country in which the occurrence location occurs.
municipality	Name of the municipality in which the occurrence location occurs.
locality	Name of the locality in which the occurrence location occurs.
decimalLatitude	Geographic latitude in which the occurrence location occurs.
decimalLongitude	Geographic longitude in which the occurrence location occurs.
geodeticDatum	Geodetic datum upon which the geographic coordinates given are based.
taxonID	Taxon identifier.
scientificName	The full scientific name including author.
acceptedNameUsage	The full scientific name including author currently accepted.
kingdom	Kingdom name in which the taxon is classified.
phylum	Phylum name in which the taxon is classified.

Column label	Column description
class	Class name in which the taxon is classified.
taxonRank	Lowest taxonomic rank of the taxon.

## Cyanobacteria checklist from the occurrence

**Data set name:** Cyanobacteria Checklist of the Azores Archipelago, Portugal - Taxon data table

**Data format:** Darwin Core

**Description:** Cyanobacteria taxa recorded in the Azores Archipelago, based on the occurrence data table, with a total of 229 taxa (Luz et al. 2022). Used Darwin Core terms are described in Table 3.

Table 3.  
Darwin Core terms used in the taxon data table.

Column label	Column description
id	Identifier.
taxonID	Taxon identifier.
scientificName	The full scientific name including author.
kingdom	Kingdom name in which the taxon is classified.
phylum	Phylum name in which the taxon is classified.
class	Class name in which the taxon is classified.
order	Order name in which the taxon is classified
family	Family name in which the taxon is classified.
genus	Genus name in which the taxon is classified.
specificEpithet	Species epithet name in which the taxon is classified.
infraspecificEpithet	Infraspecific epithet name in which the taxon is classified.
taxonRank	Lowest taxonomic rank of the taxon.
scientificNameAuthorship	Authorship information for the scientific name.

## Cyanobacteria checklist from Azores islands

### Genus *Anabaena* Bory ex Bornet & Flahault, 1886

**Distribution:** Corvo (INOVA 1996), Flores (Bourrelly and Manguin 1946), Pico (Luz et al. 2020), São Miguel (Bohlin 1901), Terceira (Luz et al. 2020)

**Notes:** Freshwater (lake), thermal (pool)

### *Anabaena aspera* Frémy, 1930

**Distribution:** Flores (Bourrelly and Manguin 1946)

**Notes:** Freshwater (lake)

### *Anabaena augstumalis* Schmidle, 1900

**Distribution:** Flores (Bourrelly and Manguin 1946)

**Notes:** Freshwater (lake)

### *Anabaena cylindrica* Lemmermann, 1896

**Distribution:** São Miguel (Oliveira 1989)

**Notes:** Freshwater (lake)

### *Anabaena inaequalis* Bornet & Flahault, 1886

**Distribution:** Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

### *Anabaena torulosa* Lagerheim ex Bornet & Flahault, 1886

**Distribution:** Corvo (Trelease 1897)

**Notes:** Freshwater

### Genus *Anabaenopsis* V.V.Miller, 1923

**Distribution:** Corvo (Cordeiro et al. 2020b), Flores (Luz et al. 2020)

**Notes:** Freshwater (lake)



***Anabaenopsis circularis* (G.S.West) Woloszynska & V.Miller in V.Miller, 1923**

**Distribution:** Flores (Gonçalves 2008)

**Notes:** Freshwater (lake)

***Anagnostidinema amphibium* (C.Agardh ex Gomont) Strunecký, Bohunická, J.R.Johansen & J.Komárek, 2017**

**Distribution:** Flores (Bourrelly and Manguin 1946), São Miguel (Cedercreutz 1941), Terceira (Cedercreutz 1941)

**Notes:** Brackish (lake), freshwater (lake)

***Anathece clathrata* (W.West & G.S.West) Komárek, Kastovsky & Jezberová, 2011**

**Distribution:** São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake)

***Anathece minutissima* (West) Komárek, Kastovsky & Jezberová, 2011**

**Distribution:** São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

**Genus *Aphanizomenon* A.Morren ex É.Bornet & C.Flahault, 1886**

**Distribution:** São Miguel (Santos et al. 2001)

**Notes:** Freshwater (lake)

***Aphanizomenon flos-aquae* Ralfs ex Bornet & Flahault, 1886**

**Distribution:** Corvo (INOVA 1996), Flores (INOVA 1996), Graciosa (Azevedo et al. 2005), Pico (INOVA 1996), São Miguel (Krieger 1931)

**Notes:** Freshwater (lake)

***Aphanizomenon gracile* Lemmermann, 1907**

**Distribution:** Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Aphanizomenon manguinii* Bourrelly in Bourrelly & Manguin, 1952**

**Distribution:** Pico (Luz 2018)

**Notes:** Freshwater (lake)

**Genus *Aphanocapsa* Nägeli, 1849**

**Distribution:** São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake)

***Aphanocapsa delicatissima* West & G.S.West, 1912**

**Distribution:** Pico (Santos and Santana 2009b), São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake)

***Aphanocapsa elachista* West & G.S.West, 1894**

**Distribution:** São Jorge (Cedercreutz 1941), São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake), terrestrial

***Aphanocapsa grevillei* (Berkeley) Rabenhorst, 1865**

**Distribution:** São Jorge (Johansson 1977)

**Notes:** Freshwater

***Aphanocapsa incerta* (Lemmermann) G.Cronberg & Komárek, 1994**

**Distribution:** São Miguel (Santos and Santana 2009a)

**Notes:** Freshwater (lake)

**Genus *Aphanothece* Nägeli, 1849**

**Distribution:** Flores (Luz et al. 2020), São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Aphanothece castagnei* (Kützing) Rabenhorst, 1865**

**Distribution:** Flores (Bourrelly and Manguin 1946)

**Notes:** Terrestrial

***Aphanothece microscopica* Nägeli, 1849**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Freshwater (lake), terrestrial

***Aphanothece naegelii* Wartmann in Rabenhorst, 1865**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Freshwater

***Aphanothece nidulans* P.Richter, 1884**

**Distribution:** São Miguel (Bourrelly and Manguin 1946)

**Notes:** Freshwater (lake)

***Aphanothece pallida* (Kützing) Rabenhorst, 1863**

**Distribution:** São Miguel (Bourrelly and Manguin 1946)

**Notes:** Freshwater (lake)

***Aphanothece saxicola* Nägeli, 1849**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Terrestrial

***Aphanothece stagnina* (Sprengel) A.Braun in Rabenhorst, 1863**

**Distribution:** Pico (Johansson 1977)

**Notes:** Freshwater

**Genus *Arthrospira* Sitzenberger ex Gomont, 1892**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake)

**Genus *Calothrix* C.Agardh ex Bornet & Flahault, 1886**

**Distribution:** Flores (Cordeiro et al. 2020b), São Jorge (Luz 2018), Santa Maria (Cordeiro et al. 2020b), São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake, stream)

***Calothrix breviarticulata* West & G.S.West, 1897**

**Distribution:** Flores (Luz 2018)

**Notes:** Freshwater (lake)

***Calothrix castellii* Bornet & Flahault, 1886**

**Distribution:** Pico (Luz 2018), São Miguel (Luz 2018)

**Notes:** Freshwater (lake)

***Calothrix parietina* Thuret ex Bornet & Flahault, 1886**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Terrestrial

***Chlorogloeopsis fritschii* (A.K.Mitra) A.K.Mitra & D.C.Pandey, 1967**

**Distribution:** São Miguel (Luz 2018)

**Notes:** Thermal (stream)

**Genus *Chroococcus* Nägeli, 1849**

**Distribution:** São Miguel (Moseley 1874)

**Notes:** Freshwater (lake), thermal (spring)

***Chroococcus dispersus* (Keissler) Lemmermann, 1904**

**Distribution:** Pico (Santos and Santana 2009b), São Miguel (Santos and Santana 2009a)

**Notes:** Freshwater (lake)

***Chroococcus membraninus* (Meneghini) Nägeli, 1849**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Thermal (stream)

***Chroococcus minor* (Kützing) Nägeli, 1849**

**Distribution:** São Miguel (Archer 1874)

**Notes:** Freshwater (lake)

***Chroococcus minutus* (Kützing) Nägeli, 1849**

**Distribution:** Flores (Luz et al. 2020), Pico (Johansson 1977), São Miguel (Bourrelly and Manguin 1946)

**Notes:** Freshwater (lake)

***Chroococcus tenax* (Kirchner) Hieronymus, 1892**

**Distribution:** São Miguel (Oliveira 1989)

**Notes:** Freshwater (lake)

***Chroococcus turgidus* (Kützing) Nägeli, 1849**

**Distribution:** Corvo (Cedercreutz 1941), Faial (Johansson 1977), Flores (Cedercreutz 1941), Pico (Johansson 1977), São Jorge (Johansson 1977), São Miguel (Bohlin 1901), Terceira (Cedercreutz 1941)

**Notes:** Freshwater (lake), terrestrial

***Chroococcus turicensis* (Nägeli) Hansgirg, 1887**

**Distribution:** Flores (Bourrelly and Manguin 1946)

**Notes:** Freshwater

***Chroococcus westii* J.B.Petersen, 1923**

**Distribution:** São Miguel (Oliveira 1989)

**Notes:** Terrestrial

**Genus *Coelosphaerium* Nägeli, 1849**

**Distribution:** São Miguel (Santos et al. 2001)

**Notes:** Freshwater (lake)

***Coelosphaerium kuetzingianum* Nägeli, 1849**

**Distribution:** São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake)

**Genus *Coleospermum* Kirchner ex Frank, 1886**

**Distribution:** Flores (Luz 2018), Pico (Luz 2018), São Miguel (Luz 2018)

**Notes:** Freshwater (lake), thermal (pool, spring)

***Coleospermum goeppertianum* Kirchner ex Frank, 1886**

**Distribution:** São Miguel (Krieger 1931)

**Notes:** Freshwater (lake)

***Cyanobacterium synechococcoides* Komárek 1999**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake)

**Genus *Cyanobium* R.Rippka & G.Cohen-Bazire, 1983**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake)

***Cyanobium plancticum* (G.Drews, H.Prauser & D.Uhlmann) Komárek, J.Kopecký & Cepák, 1999**

**Distribution:** São Miguel (Xavier et al. 2018)

**Notes:** Freshwater (lake)

**Genus *Cyanosaccus* K.J.Lukas & S.Golubic, 1981**

**Distribution:** Faial (Wisshak et al. 2011)

**Notes:** Marine (intertidal)

**Genus *Cylindrospermum* Kützing ex Bornet & Flahault, 1886**

**Distribution:** Pico (Cedercreutz 1941), São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake, stream)

***Cylindrospermum licheniforme* Kützing ex Bornet & Flahault, 1886**

**Distribution:** São Miguel (Trelease 1897)

**Notes:** Freshwater

***Cylindrospermum majus* Kützing ex Bornet & Flahault, 1886**

**Distribution:** Faial (Johansson 1977), Flores (Bourrelly and Manguin 1946), São Jorge (Johansson 1977), São Miguel (Trelease 1897)

**Notes:** Freshwater (lake)

***Dichothrix baueriana* Bornet & Flahault, 1886**

**Distribution:** Corvo (Trelease 1897)

**Notes:** Freshwater

***Dichothrix orsiniana* var. *africana* Frémy, 1924**

**Distribution:** Flores (Bourrelly and Manguin 1946)

**Notes:** Freshwater (lake)

**Genus *Dolichospermum* (Ralfs ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek, 2009**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake)

***Dolichospermum affine* (Lemmermann) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** Pico (Santos and Santana 2009b), São Miguel (Oliveira 1989)

**Notes:** Freshwater (lake)

***Dolichospermum circinale* (Rabenhorst ex Bornet & Flahault) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** São Miguel (Cordeiro 2015)

**Notes:** Freshwater (lake)

***Dolichospermum delicatulum* (Lemmermann) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** Corvo (Luz et al. 2020), Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Dolichospermum flos-aquae* (Brébisson ex Bornet & Flahault) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** São Miguel (INOVA 1996)

**Notes:** Freshwater (lake)

***Dolichospermum planctonicum* (Brunnthaler) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** Pico (Luz et al. 2020), São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Dolichospermum scheremetieviae* (Elenkin) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** Corvo (Luz et al. 2020), Flores (Luz et al. 2020), Pico (Santos and Santana 2009b), São Miguel (Oliveira 1989)

**Notes:** Freshwater (lake)

***Dolichospermum sigmoideum* (Nygaard) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** Pico (Santos and Santana 2009b), São Miguel (Cordeiro 2015)

**Notes:** Freshwater (lake)

***Dolichospermum solitarium* (Klebahn) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Bourrelly and Manguin 1946), Terceira (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Dolichospermum spiroides* (Klebhan) Wacklin, L.Hoffmann & Komárek, 2009**

**Distribution:** São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Eucapsis alpina* F.E.Clements & H.L.Schantz, 1909**

**Distribution:** Corvo (Luz et al. 2020), Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Luz et al. 2020), Terceira (Luz et al. 2020)



Notes: Freshwater (lake)

***Eucapsis minuta* F.E.Fritsch, 1912**

Distribution: São Miguel (Luz et al. 2020)

Notes: Freshwater (lake)

**Genus *Fischerella* (Bornet & Flahault) Gomont, 1895**

Distribution: São Miguel (Cordeiro et al. 2020b)

Notes: Thermal (pool)

**Genus *Fortiea* De Toni, 1936**

Distribution: Pico (Luz 2018)

Notes: Freshwater (lake)

***Fortiea striatula* (F.C.Hy) De Toni, 1936**

Distribution: Pico (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

***Geitlerinema ionicum* (Skuja) Anagnostidis, 1989**

Distribution: Santa Maria (Bourrelly and Manguin 1946)

Notes: Terrestrial

***Geitlerinema splendidum* (Greville ex Gomont) Anagnostidis, 1989**

Distribution: Pico (Luz et al. 2020), São Miguel (Cedercreutz 1941)

Notes: Freshwater (lake)

**Genus *Gloeocapsa* Kützing, 1843**

Distribution: São Miguel (Luz et al. 2020)

Notes: Freshwater (lake)

***Gloeocapsa atrata* Kützing, 1843**

Distribution: São Miguel (Cedercreutz 1941), Terceira (Johansson 1977)

Notes: Freshwater, terrestrial

***Gloeocapsa caldariorum* Rabenhorst, 1865**

Distribution: Terceira (Johansson 1977)

Notes: Freshwater

***Gloeocapsa compacta* Kützing, 1847**

Distribution: Flores (Bourrelly and Manguin 1946)

Notes: Freshwater (lake)

***Gloeocapsa gelatinosa* Kützing, 1843**

Distribution: São Jorge (Johansson 1977), Terceira (Johansson 1977)

Notes: Freshwater

***Gloeocapsa quaternata* Kützing, 1846**

Distribution: São Miguel (Johansson 1977)

Notes: Freshwater

***Gloeocapsa rupestris* Kützing, 1847**

Distribution: São Jorge (Johansson 1977), Terceira (Johansson 1977)

Notes: Freshwater

***Gloeocapsa thermalis* Kützing, 1843**

Distribution: São Miguel (Johansson 1977)

Notes: Thermal

***Gloeocapsopsis dvorakii* (Nováček) Komárek & Anagnostidis ex Komárek 1993**

Distribution: São Miguel (Cordeiro et al. 2020b)

Notes: Thermal (pool)

***Gloeocapsopsis magma* (Brébisson) Komárek & Anagnostidis ex Komárek, 1993**

Distribution: São Miguel (Bohlin 1901)

Notes: Terrestrial

***Gloeothece cystifera* (Hassall) Rabenhorst, 1865**

Distribution: São Miguel (Bohlin 1901)

Notes: Terrestrial

***Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt, 1880**

Distribution: Flores (Bourrelly and Manguin 1946), São Miguel (Cedercreutz 1941)

Notes: Freshwater (lake)

***Gloeotrichia pisum* Thuret ex Bornet & Flahault, 1886**

Distribution: São Miguel (Bohlin 1901)

Notes: Terrestrial

***Goleter apudmare* Miscoe & J.R.Johansen, 2016**

Distribution: Flores (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

**Genus *Gomphosphaeria* Kützing, 1836**

Distribution: São Miguel (Santos et al. 2001)

Notes: Freshwater (lake)

***Hapalosiphon hibernicus* West & G.S.West, 1896**

Distribution: Corvo (Cedercreutz 1941), Flores (Cedercreutz 1941), São Miguel (Bourrelly and Manguin 1946)

Notes: Freshwater (lake)

***Hapalosiphon intricatus* West & G.S.West, 1894**

Distribution: São Jorge (Cedercreutz 1941), Terceira (Johansson 1977)

Notes: Freshwater (lake, stream)

***Hapalosiphon pumilus* Kirchner ex Bornet & Flahault, 1887**

Distribution: Flores (Bourrelly and Manguin 1946), Santa Maria (Luz 2018)

Notes: Freshwater (stream), terrestrial

**Genus *Hapalosiphon* Nägeli ex É.Bornet & C.Flahault, 1886**

Distribution: São Miguel (Cordeiro et al. 2020b)

Notes: Terrestrial

***Heteroleibleinia kuetzingii* (Schmidle) Compère, 1985**

Distribution: São Jorge (Cedercreutz 1941)

Notes: Freshwater

***Homoeothrix africana* G.S.West, 1912**

Distribution: São Jorge (Johansson 1977)

Notes: Freshwater

***Hydrocoryne spongiosa* Schwabe ex Bornet & Flahault 1887**

Distribution: São Miguel (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

**Genus *Hyella* É.Bornet & C.Flahault, 1888**

Distribution: Faial (Wisshak et al. 2011)

Notes: Marine (intertidal)

***Hyella caespitosa* Bornet & Flahault, 1888**

Distribution: Faial (Wisshak et al. 2011)

Notes: Marine (intertidal)

***Hyella gigas* Lukas & Golubic, 1983**

Distribution: Faial (Wisshak et al. 2011)

Notes: Marine (intertidal)

***Isocystis planctonica* Starmach 1962**

Distribution: Flores (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

**Genus *Kamptonema* O.Strunecký, J.Komárek & J.Smarda, 2014**

**Distribution:** Flores (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

***Kamptonema formosum* (Bory ex Gomont) Strunecký, Komárek & J.Smarda, 2014**

**Distribution:** Santa Maria (Trelease 1897), São Miguel (Bohlin 1901), Terceira (Cedercreutz 1941)

Notes: Freshwater, brackish (lake), thermal (stream)

***Kyrtuthrix dalmatica* Ercegovic, 1929**

**Distribution:** Faial (Wisshak et al. 2011)

Notes: Marine (intertidal)

**Genus *Leptodesmis* Raabová, Kovacik & Strunecký, 2019**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

**Genus *Leptolyngbya* Anagnostidis & Komárek, 1988**

**Distribution:** São Jorge (Luz 2018), São Miguel (Luz 2018)

Notes: Freshwater (lake), marine (lake), thermal (pool, stream)

***Leptolyngbya gelatinosa* (Woronichin) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Luz 2018)

Notes: Thermal (stream)

***Leptolyngbya granulifera* (J.J.Copeland) Anagnostidis 1936**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

Notes: Thermal (pool, spring)

***Leptolyngbya laminosa* (Gomont ex Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Trelease 1897)

**Notes:** Thermal (spring)

***Leptolyngbya nostocorum* (Bornet ex Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Freshwater (lake)

***Leptolyngbya ochracea* (Thuret ex Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Thermal (pool)

***Leptolyngbya rivulariarum* (Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Freshwater (lake)

***Leptolyngbya subuliformis* (Gomont) Anagnostidis 2001**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Thermal (spring)

***Leptolyngbya valderiana* (Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Bourrelly and Manguin 1946)

**Notes:** Terrestrial

**Genus *Limnothrix* M.-E.Meffert, 1988**

**Distribution:** Flores (Cordeiro et al. 2020b), São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake)

***Limnothrix planctonica* (Woloszynska) Meffert, 1988**

**Distribution:** São Miguel (Santos and Santana 2009a)

**Notes:** Freshwater (lake)

**Genus *Lyngbya* C.Agardh ex Gomont, 1892**

**Distribution:** São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake)

***Lyngbya lutea* Gomont ex Gomont, 1892**

**Distribution:** Terceira (Neto et al. 2009)

**Notes:** Marine

***Lyngbya martensiana* Meneghini ex Gomont, 1892**

**Distribution:** São Miguel (Bohlin 1901), Terceira (Johansson 1977)

**Notes:** Freshwater, thermal, terrestrial

**Genus *Mastigocladus* Cohn ex Kirchner, 1898**

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Thermal (spring, stream)

***Mastigocladus laminosus* Cohn ex Kirchner, 1898**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Thermal (spring, pool, stream)

***Mastigocoleus testarum* Lagerheim ex Bornet & Flahault, 1886**

**Distribution:** Faial (Wisshak et al. 2011)

**Notes:** Marine (intertidal)

**Genus *Merismopedia* Meyen, 1839**

**Distribution:** São Miguel (Archer 1874), Pico (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Merismopedia glauca* (Ehrenberg) Kützing, 1845**

**Distribution:** São Miguel (Cedercreutz 1941), Terceira (Cedercreutz 1941)

**Notes:** Freshwater (lake)

***Merismopedia tenuissima* Lemmermann, 1898**

**Distribution:** Graciosa (Azevedo et al. 2005), São Miguel (Oliveira 1989), Terceira (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Microchaete bulbosa* J.Copeland, 1936**

**Distribution:** São Miguel (Luz 2018)

**Notes:** Thermal (spring)

***Microchaete tenera* Thuret ex Bornet & Flahault, 1886**

**Distribution:** Pico (Luz 2018), São Miguel (Bohlin 1901)

**Notes:** Freshwater (lake), terrestrial

***Microcoleus amoenus* (Gomont) Strunecky, Komárek & J.R.Johansen, 2013**

**Distribution:** Flores (Bourrelly and Manguin 1946), São Miguel (Cedercreutz 1941)

**Notes:** Freshwater (lake)

***Microcoleus autumnalis* (Gomont) Strunecky, Komárek & J.R.Johansen, 2013**

**Distribution:** Flores (Cedercreutz 1941), São Miguel (Cedercreutz 1941)

**Notes:** Freshwater (stream), terrestrial

***Microcoleus lyngbyaceus* Kützing ex Forti, 1907**

**Distribution:** Terceira (Neto et al. 2009)

**Notes:** Marine

**Genus *Microcystis* Lemmermann, 1907**

**Distribution:** São Miguel (INOVA 1996)

**Notes:** Freshwater (lake)

***Microcystis aeruginosa* (Kützing) Kützing, 1846**

**Distribution:** Corvo (Luz et al. 2020), Flores (INOVA 1996), São Miguel (Vasconcelos et al. 1994)



Notes: Freshwater (lake)

***Microcystis flos-aquae* (Wittrock) Kirchner, 1898**

Distribution: Flores (Luz et al. 2020), São Miguel (Oliveira 1989)

Notes: Freshwater (lake)

***Microcystis pulverea* (H.C.Wood) Forti, 1907**

Distribution: Pico (Santos and Santana 2009b), São Miguel (Santos and Santana 2004)

Notes: Freshwater (lake)

***Microcystis robusta* (H.W.Clark) Nygaard, 1925**

Distribution: São Miguel (Santos and Santana 2009a), Terceira (Santos and Santana 2009b)

Notes: Freshwater (lake)

***Nodularia harveyana* Thuret ex Bornet & Flahault, 1886**

Distribution: Corvo (Trelease 1897), Terceira (Cedercreutz 1941)

Notes: Brackish (lake), marine

**Genus *Nostoc* Vaucher ex Bornet & Flahault, 1886**

Distribution: Corvo (Cedercreutz 1941), Flores (Cedercreutz 1941), Santa Maria (Bourrelly and Manguin 1946), São Miguel (Moseley 1874)

Notes: Freshwater (lake, stream), terrestrial

***Nostoc carneum* C.Agardh ex Bornet & Flahault, 1886**

Distribution: Faial (Johansson 1977)

Notes: Freshwater

***Nostoc commune* Vaucher ex Bornet & Flahault, 1886**

Distribution: Pico (Johansson 1977)

Notes: Freshwater (lake)

***Nostoc ellipso sporum* Rabenhorst ex Bornet & Flahault, 1886**

**Distribution:** Corvo (Trelease 1897), São Miguel (Bohlin 1901)

**Notes:** Freshwater

***Nostoc paludosum* Kützing ex Bornet & Flahault, 1886**

**Distribution:** Corvo (Cordeiro et al. 2020b), Santa Maria (Bourrelly and Manguin 1946), São Miguel (Bohlin 1901)

**Notes:** Freshwater (lake)

***Nostoc punctiforme* Hariot, 1891**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Freshwater (lake), terrestrial

***Nostoc sphaericum* Vaucher ex Bornet & Flahault, 1886**

**Distribution:** Faial (Johansson 1977), Flores (Bourrelly and Manguin 1946), São Jorge (Johansson 1977), São Miguel (Bourrelly and Manguin 1946)

**Notes:** Freshwater (lake), terrestrial

***Nostoc sphaeroides* Kützing ex Bornet & Flahault, 1886**

**Distribution:** Faial (Johansson 1977), São Jorge (Johansson 1977)

**Notes:** Freshwater

***Nostoc verrucosum* Vaucher ex Bornet & Flahault, 1886**

**Distribution:** São Miguel (Cedercreutz 1941), Terceira (Trelease 1897)

**Notes:** Freshwater (stream)

***Nostochopsis lobatus* H.C.Wood ex Bornet & Flahault, 1886**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Terrestrial

**Genus *Oscillatoria* Vaucher ex Gomont, 1892**

**Distribution:** Flores (Luz et al. 2020), Pico (INOVA 1996), São Miguel (Moseley 1874), Terceira (Neto et al. 2009)

Notes: Freshwater (lake), marine

***Oscillatoria geitleri* f. *major* Bourrelly in Bourrelly & Manguin, 1946**

Distribution: Flores (Bourrelly and Manguin 1946)

Notes: Freshwater (stream)

***Oscillatoria planctonica* Woloszynska, 1912**

Distribution: São Miguel (Oliveira 1989)

Notes: Freshwater (lake)

***Oscillatoria princeps* Vaucher ex Gomont, 1892**

Distribution: Terceira (Neto et al. 2009)

Notes: Marine

***Oscillatoria sancta* Kützing ex Gomont, 1892**

Distribution: São Miguel (Bohlin 1901)

Notes: Terrestrial

***Oscillatoria tenuis* C.Agardh ex Gomont, 1892**

Distribution: Corvo (Cedercreutz 1941), Faial (Cedercreutz 1941), Flores (Cedercreutz 1941), Graciosa (Cedercreutz 1941), Pico (Luz et al. 2020), São Miguel (Bohlin 1901), Terceira (Luz et al. 2020)

Notes: Freshwater (lake, stream), terrestrial

**Genus *Pegethrix* Mai, J.R.Johansen & Bohunická, 2018**

Distribution: São Miguel (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

***Petalonema velutinum* Migula, 1907**

Distribution: Flores (Cedercreutz 1941)

Notes: Freshwater

**Genus *Phormidium* Kützing ex Gomont, 1892**

**Distribution:** Corvo (Luz et al. 2020), Faial (Cedercreutz 1941), Pico (Luz et al. 2020), São Jorge (Luz 2018), São Miguel (Fish and Codd 1994)

**Notes:** Freshwater (lake), marine (lake), thermal

***Phormidium aerugineo-caeruleum* (Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Freshwater (lake)

***Phormidium allorgei* (Frémy) Anagnostidis & Komárek, 1988**

**Distribution:** Terceira (Johansson 1977)

**Notes:** Freshwater

***Phormidium breve* (Kützing ex Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Miguel (Bohlin 1901)

**Notes:** Marine, thermal

***Phormidium durum* N.L.Gardner, 1927**

**Distribution:** São Jorge (Johansson 1977)

**Notes:** Freshwater

***Phormidium irriguum* (Kützing ex Gomont) Anagnostidis & Komárek, 1988**

**Distribution:** São Jorge (Johansson 1977), Terceira (Bohlin 1901)

**Notes:** Freshwater (stream)

***Phormidium pachydermaticum* Frémy, 1930**

**Distribution:** São Jorge (Johansson 1977), Terceira (Johansson 1977)

**Notes:** Freshwater

***Phormidium retzii* Kützing ex Gomont, 1892**

**Distribution:** Faial (Johansson 1977), São Jorge (Johansson 1977), São Miguel (Cedercreutz 1941)

Notes: Freshwater

***Phormidium rotheanum* Itzigsohn in Rabenhorst, 1865**

Distribution: São Jorge (Johansson 1977)

Notes: Freshwater

***Phormidium terebriforme* (C.Agardh ex Gomont) Anagnostidis & Komárek, 1988**

Distribution: São Miguel (Bohlin 1901)

Notes: Thermal

**Genus *Planktolyngbya* Anagnostidis & Komárek, 1988**

Distribution: Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Cordeiro 2015)

Notes: Freshwater (lake)

***Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová & Cronberg, 1992**

Distribution: Pico (Luz et al. 2020), São Miguel (Cedercreutz 1941)

Notes: Freshwater (lake)

***Planktothrix agardhii* (Gomont) Anagnostidis & Komárek, 1988**

Distribution: São Miguel (Santos and Santana 2009a)

Notes: Freshwater (lake)

***Plectonema endolithicum* Ercegovic, 1932**

Distribution: Faial (Wisshak et al. 2011)

Notes: Marine (intertidal)

***Plectonema terebrans* Bornet & Flahault ex Gomont, 1892**

Distribution: Faial (Wisshak et al. 2011)

Notes: Marine (intertidal)

**Genus *Pseudanabaena* Lauterborn, 1915**

**Distribution:** Corvo (Luz et al. 2020), Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Santos et al. 2005)

**Notes:** Freshwater (lake)

***Pseudanabaena catenata* Lauterborn, 1915**

**Distribution:** São Miguel (Oliveira 1989)

**Notes:** Freshwater (lake)

***Pseudanabaena limnetica* (Lemmermann) Komárek, 1974**

**Distribution:** Corvo (Luz et al. 2020), Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Luz et al. 2020)

**Notes:** Freshwater (lake)

***Pseudanabaena minima* (G.S.An) Anagnostidis, 2001**

**Distribution:** Pico (Luz 2018)

**Notes:** Freshwater (lake)

***Pseudanabaena mucicola* (Naumann & Huber-Pestalozzi) Schwabe, 1964**

**Distribution:** São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake)

***Pseudophormidium pauciramosum* (Anissimova) Anagnostidis, 2001**

**Distribution:** Santa Maria (Luz 2018)

**Notes:** Brackish

***Raphidiopsis curvata* F.E.Fritsch & M.F.Rich, 1930**

**Distribution:** Corvo (INOVA 1996), Flores (INOVA 1996), São Miguel (INOVA 1996)

**Notes:** Freshwater (lake)

**Genus *Rivularia* C.Agardh ex Bornet & Flahault, 1886**

**Distribution:** São Miguel (Cordeiro et al. 2020b), Terceira (Neto et al. 2009)

Notes: Freshwater, marine

***Rivularia biasoletiana* Meneghini ex Bornet & Flahault 1886**

Distribution: São Miguel (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

***Rivularia bullata* Berkeley ex Bornet & Flahault, 1886**

Distribution: São Miguel (Trelease 1897)

Notes: Freshwater

***Rivularia nitida* C.Agardh ex Bornet & Flahault, 1886**

Distribution: Flores (Trelease 1897)

Notes: Freshwater

**Genus *Schizothrix* Kützing ex M.Gomont, 1892**

Distribution: Terceira (Johansson 1977)

Notes: Freshwater

***Schizothrix cuspidata* (West & G.S.West) West & G.S.West, 1896**

Distribution: Faial (Bourrelly and Manguin 1946)

Notes: Terrestrial

***Schizothrix fuscescens* Kutzing ex Gomont, 1892**

Distribution: Terceira (Johansson 1977)

Notes: Freshwater

***Schizothrix lacustris* A.Braun ex Gomont, 1892**

Distribution: São Jorge (Johansson 1977)

Notes: Freshwater

***Schizothrix pallida* (Kützing ex Forti) Geitler, 1932**

Distribution: Terceira (Neto et al. 2009)

Notes: Marine

***Schizothrix symplocoides* (N.L.Gardner) Geitler, 1932**

Distribution: Terceira (Johansson 1977)

Notes: Freshwater

***Schizothrix telephoroides* Gomont, 1890**

Distribution: Faial (Johansson 1977)

Notes: Freshwater

***Schizothrix vaginata* Gomont, 1890**

Distribution: São Jorge (Johansson 1977)

Notes: Freshwater

**Genus *Scytonema* C.Agardh ex É.Bornet & C.Flahault, 1886**

Distribution: Flores (Cedercreutz 1941)

Notes: Terrestrial

***Scytonema amplum* West & G.S.West, 1895**

Distribution: São Miguel (Bourrelly and Manguin 1946)

Notes: Terrestrial

***Scytonema dilatatum* Bharadwaja, 1934**

Distribution: Terceira (Johansson 1977)

Notes: Freshwater

***Scytonema guyanense* Bornet & Flahault, 1888**

Distribution: Flores (Bourrelly and Manguin 1946), São Miguel (Bourrelly and Manguin 1946)

Notes: Terrestrial

***Scytonema hofmannii* C.Agardh ex Bornet & Flahault, 1886**

Distribution: São Jorge (Johansson 1977), São Miguel (Cedercreutz 1941)



Notes: Freshwater (lake)

***Scytonema javanicum* Bornet ex Bornet & Flahault, 1886**

Distribution: Flores (Bourrelly and Manguin 1946)

Notes: Freshwater (lake)

***Scytonema mirabile* Bornet, 1889**

Distribution: Pico (Cedercreutz 1941), São Jorge (Cedercreutz 1941), São Miguel (Cedercreutz 1941), Terceira (Cedercreutz 1941)

Notes: Freshwater (lake, stream), terrestrial

***Scytonema stuposum* Bornet ex Bornet & Flahault, 1887**

Distribution: Flores (Bourrelly and Manguin 1946)

Notes: Freshwater (lake)

**Genus *Scytonematopsis* E.I.Kiseleva, 1930**

Distribution: Flores (Cordeiro et al. 2020b), Pico (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

**Genus *Snowella* A.A.Elenkin, 1938**

Distribution: São Miguel (Luz et al. 2020)

Notes: Freshwater (lake)

***Snowella lacustris* (Chodat) Komárek & Hindák, 1988**

Distribution: São Miguel (Santos and Santana 2004)

Notes: Freshwater (lake)

**Genus *Sphaerospermopsis* Zapomelová, Jezberová, Hrouzek, Hisem, Reháková & Komárková, 2010**

Distribution: Pico (Luz 2018)

Notes: Freshwater (lake)

***Sphaerospermopsis aphanizomenoides* (Forti) Zapomelová, Jezberová, Hrouzek, Hisem, Reháková & Komárková, 2010**

**Distribution:** Pico (Santos and Santana 2009b)

**Notes:** Freshwater (lake)

***Spirulina subsalsa* Oersted ex Gomont, 1892**

**Distribution:** São Jorge (Luz 2018)

**Notes:** Marine (lake)

**Genus *Stenomitos* Miscoe & J.R.Johansen, 2016**

**Distribution:** Pico (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake)

***Stigonema hormoides* Bornet & Flahault, 1886**

**Distribution:** Flores (Bourrelly and Manguin 1946), São Jorge (Johansson 1977), São Miguel (Cedercreutz 1941), Terceira (Cedercreutz 1941)

**Notes:** Freshwater (lake), terrestrial

***Stigonema informe* Kützing ex Bornet & Flahault, 1886**

**Distribution:** São Jorge (Johansson 1977), Terceira (Johansson 1977)

**Notes:** Freshwater

***Stigonema mamillosum* C.Agardh ex Bornet & Flahault, 1886**

**Distribution:** São Jorge (Johansson 1977), São Miguel (Bourrelly and Manguin 1946)

**Notes:** Freshwater, terrestrial

***Stigonema minutum* Hassall ex Bornet & Flahault, 1886**

**Distribution:** Flores (Bourrelly and Manguin 1946), São Jorge (Johansson 1977), São Miguel (Bohlin 1901), Terceira (Johansson 1977)

**Notes:** Freshwater (lake)

***Stigonema multipartitum* N.L.Gardner, 1927**

**Distribution:** São Jorge (Johansson 1977)

Notes: Freshwater

***Stigonema ocellatum* Thuret ex Bornet & Flahault, 1886**

**Distribution:** Flores (Cedercreutz 1941), São Miguel (Cedercreutz 1941), Terceira (Johansson 1977)

Notes: Freshwater (lake)

***Stigonema panniforme* Bornet & Flahault, 1886**

**Distribution:** São Miguel (Bourrelly and Manguin 1946)

Notes: Freshwater (stream)

***Stigonema robustum* N.L.Gardner, 1927**

**Distribution:** São Jorge (Johansson 1977)

Notes: Freshwater

***Stigonema tomentosum* Hieronymus, 1895**

**Distribution:** São Jorge (Johansson 1977), São Miguel (Cedercreutz 1941)

Notes: Freshwater, terrestrial

***Symploca dubia* Gomont, 1892**

**Distribution:** São Miguel (Cedercreutz 1941)

Notes: Thermal (pool)

***Symploca thermalis* Gomont, 1892**

**Distribution:** São Miguel (Bohlin 1901)

Notes: Thermal

**Genus *Synechococcus* Nägeli, 1849**

**Distribution:** São Miguel (Luz et al. 2020), Terceira (Luz et al. 2020)

Notes: Freshwater (lake)

***Synechococcus nidulans* (Pringsheim) Komárek, 1970**

**Distribution:** São Miguel (Xavier et al. 2018)

Notes: Freshwater (lake)

**Genus *Synechocystis* C.Sauvageau, 1892**

Distribution: São Miguel (Luz et al. 2020), Pico (Luz et al. 2020)

Notes: Freshwater (lake)

***Tildenella torsiva* Mai, J.R.Johansen & Pietrasiak, 2018**

Distribution: São Miguel (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

**Genus *Tolypothrix* Kützing ex É.Bornet & C.Flahault, 1886**

Distribution: São Miguel (Archer 1874)

Notes: Freshwater

***Tolypothrix distorta* Kützing ex Bornet & Flahault, 1886**

Distribution: São Miguel (Bohlin 1901)

Notes: Freshwater

***Tolypothrix helicophila* Lemmermann, 1910**

Distribution: Pico (Cordeiro et al. 2020b)

Notes: Freshwater (lake)

***Tolypothrix lanata* Wartmann ex Bornet & Flahault, 1886**

Distribution: São Miguel (Cedercreutz 1941)

Notes: Freshwater (lake)

***Tolypothrix tenuis* Kützing ex Bornet & Flahault, 1886**

Distribution: Flores (Bourrelly and Manguin 1946)

Notes: Freshwater

***Trichormus variabilis* (Kützing ex Bornet & Flahault) Komárek & Anagnostidis, 1989**

Distribution: São Miguel (Bohlin 1901)

**Notes:** Thermal (pool)

### Genus *Tychonema* K.Anagnostidis & J.Komárek, 1988

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake)

### Genus *Westiellopsis* Janet, 1941

**Distribution:** São Miguel (Cordeiro et al. 2020b)

**Notes:** Freshwater (lake), thermal (stream)

### *Woronichinia naegeliana* (Unger) Elenkin, 1933

**Distribution:** Corvo Luz et al. 2020), Flores (Luz et al. 2020), Pico (Luz et al. 2020), São Miguel (Santos and Santana 2004)

**Notes:** Freshwater (lake)

## Analysis

The present work comprises 225 taxa, 179 identified species and 11 only to genus level, distributed by six orders (Chroococcales, Nostocales, Oscillatoriales, Pleurocapsales, Spirulinales and Synechococcales), 30 families and 79 genera (Table 4). Most species belong to the Nostocales (43.0%) and Synechococcales (21.2%) orders. Chroococcales and Oscillatoriales orders contributed almost with the same number of species (17.3% and 16.8%, respectively), despite their different genera contributions.

Table 4.

Cyanobacteria taxa richness of the Azores Archipelago.

Order	Taxa	Family	Genus	Species		Habitat (by taxa)			
				Nº	%	Freshwater	Thermal	Brackish	Marine
<b>Chroococcales</b>	36	5	8	31	17.3	34	2	-	-
<b>Nostocales</b>	95	11	34	77	43.0	85	9	1	4
<b>Oscillatoriales</b>	36	4	14	30	16.8	27	7	2	2
<b>Pleurocapsales</b>	4	1	2	2	1.1	-	-	-	4
<b>Spirulinales</b>	1	1	1	1	0.6	-	-	-	1
<b>Synechococcales</b>	53	8	20	38	21.2	47	5	-	2
<b>Total:</b>	225	30	79	179	100	193	23	3	13

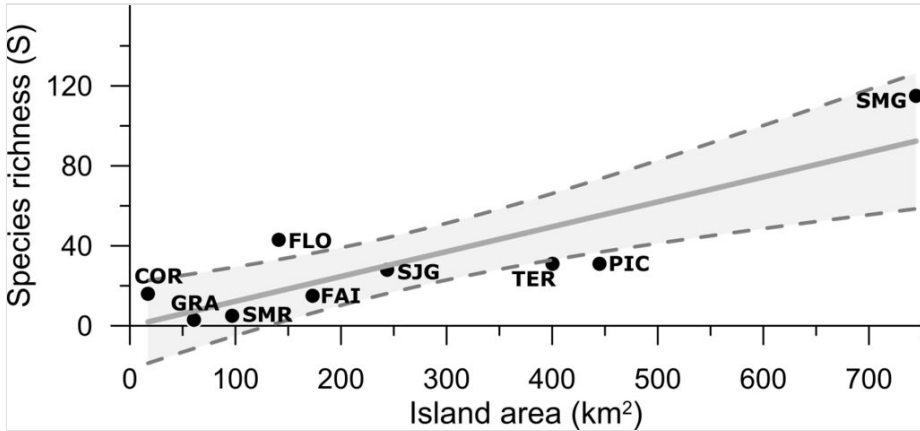


Figure 2. [doi](#)

Species-area relationship. Regression line indicates a significant linear relationship with  $P = 0.003$  and  $R^2 = 0.86$  (Pearson correlation). Dashed lines represent 95% interval confidence. COR: Corvo, FAI: Faial, FLO: Flores, GRA: Graciosa, PIC: Pico, SMR: Santa Maria, SJJ: São Jorge, SMG: São Miguel, TER: Terceira.

A summary of cyanobacteria species richness found in the Azores and on each of the nine islands in the different types of habitats is given in Table 5. The number of recorded species was highest on São Miguel Island (115) and lowest on Graciosa Island (3). Freshwater systems were the most diverse habitats, comprising 193 taxa (85.7%), followed by thermal, with 23 species (10.2%), marine (13 species, 5.8%) and brackish systems (3 species, 1.3%).

Table 5. Cyanobacteria taxa richness in the Azores by island.

	Island	Taxa	Taxonomy				Habitat			
			Order	Family	Genus	Species	Freshwater	Thermal	Brackish	Marine
<b>Eastern</b>	São Miguel	151	4	25	59	115	133	20	1	1
	Santa Maria	7	2	5	6	5	5	-	2	-
<b>Central</b>	Terceira	37	4	14	21	31	28	1	2	4
	Pico	43	4	16	27	31	43	-	-	-
	São Jorge	31	5	14	15	28	28	-	-	3
	Graciosa	3	3	3	3	3	3	-	-	-
	Faial	18	5	8	11	15	10	-	-	8
<b>Western</b>	Flores	56	4	18	33	43	56	-	1	-
	Corvo	21	4	11	16	16	20	-	-	1

A positive Pearson correlation coefficient ( $r = 0.86$ ,  $n = 9$ ,  $P = 0.003$ ) was evident between species richness (S) and island area. This correlation is best described by a linear

relationship (Fig. 2), where Pico and Flores seem to be outliers. Flores presented higher, while Pico has lower than expected species richness concerning its surface area.

## Discussion

The cyanobacteria diversity in the Azores Archipelago is understudied compared to other European regions (Gkelis et al. 2016), despite being one of the best studied archipelagos in the North Atlantic (Cordeiro et al. 2020a). With its first records of cyanobacteria in Furnas, São Miguel Island, under the Challenger expedition, Moseley (1874) identified three genera: *Chroococcus* Nägeli, 1849, *Nostoc* Vaucher ex Bornet & Flahault, 1886 and *Oscillatoria* Vaucher ex Gomont, 1892. After that, as seen in Fig. 3, the contributions of the Cyanobacteria flora were sporadic, but significant, mainly with Bohlin (1901), Cedercreutz (1941), Bourrelly and Manguin (1946) and Johansson (1977). Their contributions were important, but geographically restricted to the larger islands, such as São Miguel and Terceira. From thereon, the number of recorded cyanobacteria species in the Azores has risen throughout the end of the 20<sup>th</sup> century and the 21<sup>st</sup> century and presently stands at 225 taxa with 179 identified species (Fig. 3). This boost in the 21<sup>st</sup> century is mainly due to the implementation of the WFD (e.g. Santos et al. 2005, Santos et al. 2012, Luz et al. 2020) with 39 new described species, which makes 21.8% of the total described species. This programme has helped the continuous study of freshwater cyanobacteria present in the major lakes of the Azores, in Pico, Flores and São Miguel. The works of Luz (2018), Xavier et al. (2018) and Cordeiro et al. (2020b) significantly contributed to the records of cyanobacteria for the Azores, reporting 19 new species, 10.6% of all taxa recorded only through in-vitro cultivation methods. Using a cultivation approach, these studies were able to isolate strains from lakes, terrestrial and thermal habitats, increasing the ability to identify small or rare species normally not detected in regular monitoring works.

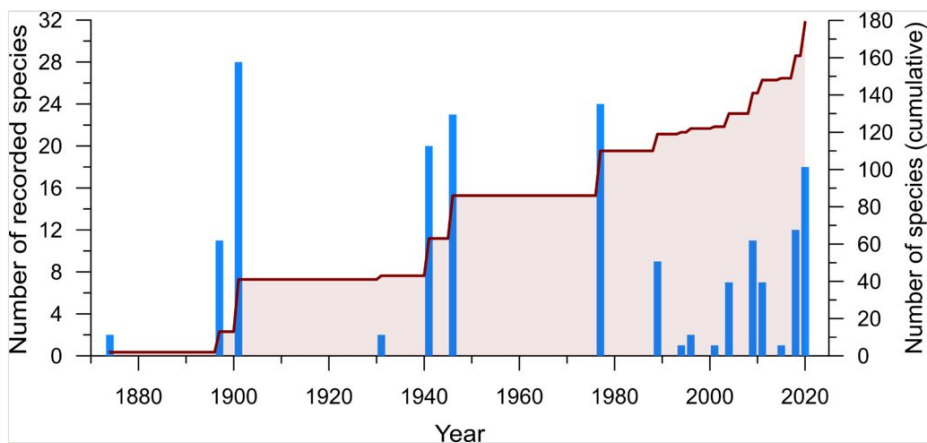


Figure 3. [doi](#)

The number of described species through time from 1874 to 2020. Bars represent the number of species described per year, the line represents the cumulative number of described species.

Freshwater cyanobacteria are the most represented taxa in the Azores records, mainly from lakes. Although this result may reflect the abundance of this type of habitat in the Azores, it may also denote the less effort on diversity studies in other types of habitats. A much lower percentage of cyanobacteria was identified from thermal, marine and brackish habitats (10%, 6% and 1%, respectively), probably due to low sampling efforts. The availability of freshwater habitats in the Azores favours the establishment of incoming cyanobacteria in São Miguel, Flores, Terceira and São Jorge. These Islands have permanent streams, lakes, peat bogs and wetlands, providing highly diverse habitats for incomers, while these are absent in Faial, Graciosa and Santa Maria.

Several islands of the Azores have active volcanoes and present high numbers of fumarolic fields, geysers and hot springs (Cruz and França 2006) creating conditions for the growth of thermophilic cyanobacteria. Nevertheless, the current knowledge about thermal cyanobacteria in the Azores is low with few published works focusing on this habitat (Moseley 1874, Bohlin 1901, Luz 2018, Cordeiro et al. 2020b). The recent works by Luz (2018), with morphological identifications and Cordeiro et al. (2020b), that used both morphological and genetic characters for its identification, contributed to several new cyanobacteria taxa reports for the Azores from thermal habitats in São Miguel.

The cyanobacteria diversity and distribution in lotic systems in the Azores are much less known compared to other sites (Branco et al. 2001, Casamatta and Hašler 2016). Only a few works are available addressing this type of habitat in the Azores, with contributions mainly by Cedercreutz (1941), Bourrelly and Manguin (1946) and Johansson (1977), with no relevant works in the latest years. This is unusual as, in lotic systems, cyanobacteria are easily identified and sometimes even the dominant taxa (Schultz et al. 2013, Casamatta and Hašler 2016).

One of the most accepted explanations for regional biodiversity is the species-area relationship (SAR), according to which the number of species along the spatial scale increases with the area (e.g. Rosenzweig 1995, Drakare et al. 2006). This pattern was thoroughly studied on islands (e.g. Lomolino and Weiser 2001, Whittaker and Fernandez-Palacios 2007, Triantis et al. 2012), where the number of species from different taxonomic groups increases with the increase in island size (Triantis et al. 2012). In our data, a positive relationship between the island area and the number of species was observed (Fig. 3). This increase in cyanobacteria species richness with increasing island area in the Azores is consistent with the work of Borges et al. (2005), for arthropods and bryophytes and Raposeiro et al. (2009) for chironomids with an exception from Flores and Corvo Islands. A possible explanation for these exceptions is the higher percentage that water bodies represent in the total island area (Porteiro 2000) and also the higher precipitation (Secretaria Regional do Ambiente e do Mar 2011, Reichwaldt and Ghadouani 2012, Haakonsson et al. 2017). Compared to Pico Island, the percentage of land covered with water is double in Corvo and almost six times higher in Flores (Porteiro 2000). This suggests that, for cyanobacteria in the Azores, habitat diversity is an important factor in determining the SAR, as shown for other taxonomic groups and islands (Hortal et al. 2009, Chase et al. 2019).



Compared to other North Atlantic islands, the Azores present the highest species richness (Table 6). The overall distribution of species richness in the different cyanobacteria orders on the North Atlantic archipelagos generally follows the same pattern as the total world species, with Nostocales and Oscillatoriales being the richest orders. However, Nostocales represents a much higher contribution to the regional species richness in the Azores and Madeira Archipelagos, which could reflect their longer dispersion capabilities (Ribeiro et al. 2018). Nostocacean cyanobacteria are able to produce akinetes that can resist long periods of unfavourable conditions (Sarma 2012), enabling them to survive during long dispersion routes and colonise remote oceanic archipelagos, such as the Azores and Madeira. The absence of some orders, such as the Chroococciopsidales and Thermostichales, in the Azores and the other Macaronesia Archipelagos, suggests that they probably have a more restricted geographic distribution. Although biological, geographical and climatic factors may contribute to cyanobacteria regional species richness (Moreira et al. 2013, Walter et al. 2017, Ribeiro et al. 2018), the differences amongst islands are most probably related to different sampling efforts (Cordeiro et al. 2020b) and, between Azorean Islands, the distribution of planktic cyanobacteria seems to be mainly related to lake typology rather than environmental parameters (Cordeiro et al. 2020c). For instance, the reduced richness of Oscillatoriales in the Azores could be related to their preference for terrestrial and benthic habitats that are less studied in this Archipelago. With the increase in sampling campaigns covering all types of habitats, the reports of new cyanobacteria in the Azores are expected to increase and the representation of the different orders can become similar to the global pattern.

Table 6.

Cyanobacteria species richness in the Azores compared to world-known species richness (World's order and species number retrieved from Guiry and Guiry (2022); Canary Islands, Madeira and Cuba numbers retrieved from Cordeiro et al. (2020a)).

Order	Azores		Madeira		Canary Islands		Cuba		World	
	N°	%	N°	%	N°	%	N°	%	N°	%
<b>Chroococcales</b>	31	17.32	2	8.33	4	6.35	28	19.05	649	13.20
<b>Chroococciopsidales</b>	0	0	0	0	0	0	2	1.36	37	0.75
<b>Gloeobacterales</b>	0	0	0	0	0	0	0	0	3	0.06
<b>Gloeomargaritales</b>	0	0	0	0	0	0	0	0	1	0.02
<b>Nostocales</b>	77	43.02	11	45.83	20	31.75	44	29.93	1547	31.46
<b>Oscillatoriales</b>	30	16.76	8	33.33	18	28.57	30	20.41	1397	28.41
<b>Pleurocapsales</b>	2	1.12	1	4.17	6	9.52	3	2.04	223	4.53
<b>Spirulinales</b>	1	0.56	0	0	4	6.35	5	3.40	56	1.14
<b>Synechococcales</b>	38	21.23	2	8.33	11	17.46	35	23.81	995	20.23
<b>Thermostichales</b>	0	0	0	0	0	0	0	0	10	0.20
<b>Total:</b>	179		24		63		147		4918	

The hereby presented taxonomic list of cyanobacteria in the Azores represents a valuable resource for biodiversity research and awareness of described cyanobacteria tracked through years that, in the future, will allow the identification of possible invader species and studies of the influence of temperature changes in the World. Besides that, knowing the biodiversity of a specific archipelago enriches its value and allows future works in ecology and, in a more practical way, in biotechnology or pharmaceutical if found to be of increased value.

## Acknowledgements

Rúben Luz was supported by a Ph.D. grant (M3.1.a/F/002/2020) from the Fundo Regional da Ciência e Tecnologia (FRCT). This work was funded by FEDER funds through the Interreg-MAC 2014-2020 Programme under the projects REBECA—Red de excelencia en biotecnología azul (algas) de la región macaronesia (MAC1.1a/060) and REBECA-CCT—Red de Excelencia en Biotecnología Azul de la Región Macaronésica. Consolidación, Certificación y Transferencia (MAC2/1.1b/269) and by Portuguese National Funds, through FCT—Fundação para a Ciência e a Tecnologia, the European Union, QREN, FEDER, COMPETE, by funding the CIBIO/InBIO (project UID/BIA/ 50027/2013 and POCI-01-0145-FEDER-006821). The work was also funded by FEDER (85%) and by Azorean Public funds (15%) through Operational Programme Azores 2020, under the project AZORESBIOPORTAL –PORBIOTA (ACORES-01-0145-FEDER-000072). CIIMAR acknowledges funding by FCT through UIDB/04423/2020 and UIDP/04423/2020.

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## Supplementary material

### Suppl. material 1: Cyanobacteria checklist of the Azores Archipelago, Portugal

**Authors:** Luz R, Cordeiro R, Fonseca A, Gonçalves V

**Data type:** Darwin Core Archive (.zip) of cyanobacteria taxa and occurrence data used for the presented and analysed checklist.

**Brief description:** Published Darwin Core Archive with two data tables in GBIF (doi: [10.15468/bfktqo](https://doi.org/10.15468/bfktqo)) about the reports of cyanobacteria in the Azores Archipelago. The taxon (core) data table contains 229 records of cyanobacteria (from class to species level). One extension data table exists, with a total of 2838 occurrence records of cyanobacteria found in literature. The taxon data table is constructed, based on the occurrence data table.

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