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

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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 (Schirrmeister 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 re-assessment 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 20th 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).

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).

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.

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 occurrrence data table, with a total of 229 taxa (Luz et al. 2022). Used Darwin Core terms are described in Table 3.

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 (Novácek) 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 ellipsosporum 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 biasolettiana 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)

Tildeniella 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.

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%).

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 20th century and the 21st century and presently stands at 225 taxa with 179 identified species (Fig. 3). This boost in the 21st 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.

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 Chroococcidiopsidales 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.

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.

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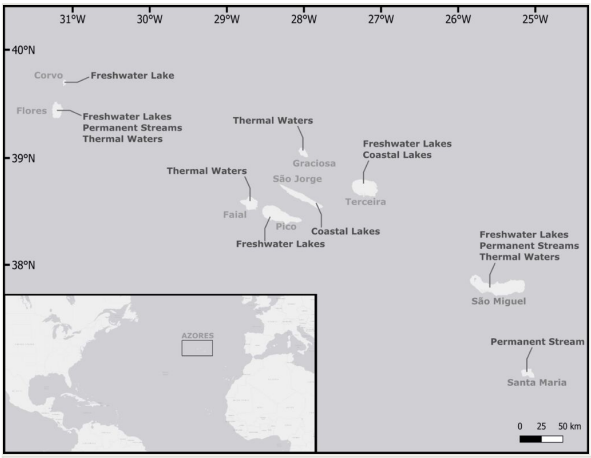

Figure 1.

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

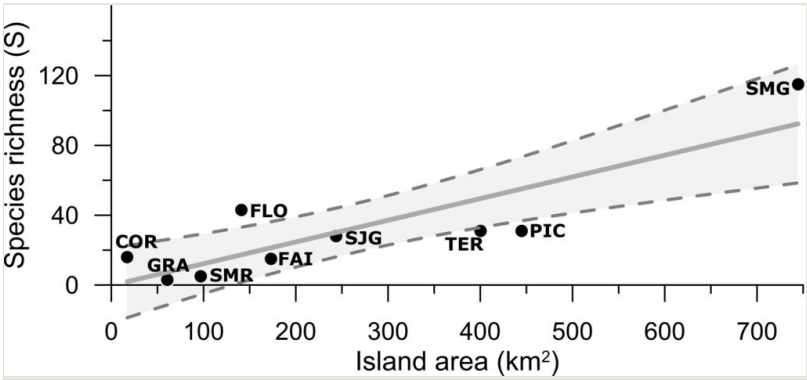

Figure 2.

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, SJG: São Jorge, SMG: São Miguel, TER: Terceira.

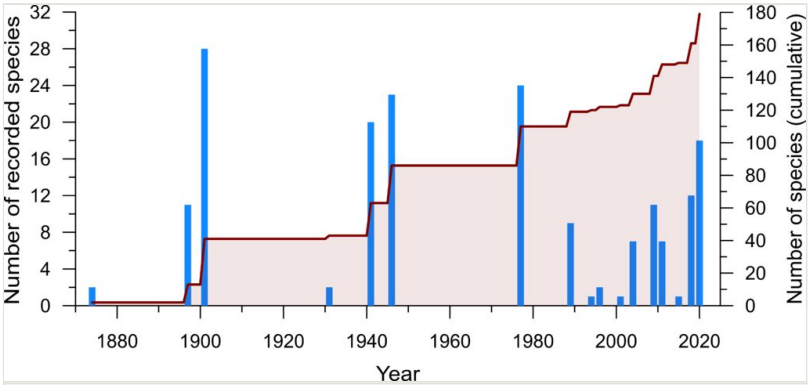

Figure 3.

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.

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)[1]	Area (Km^2)[2]	Freshwater lakes (N)[3]	Permanent Streams (N)[6]	Coastal lakes (N)[4, 7, 8]	Thermal waters (N)[5]	Total lake area (km^2)[3, 4, 7, 8]	Annual precipitation (mm)[2]
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

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

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.

Table 4.

Cyanobacteria taxa richness of the Azores Archipelago.

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

Table 5.

Cyanobacteria taxa richness in the Azores by island.

	Island	Taxa	Taxonomy				Habitat			
			Order	Family	Genus	Species	Freshwater	Thermal	Brackish	Marine
Eastern	São Miguel	151	4	25	59	115	133	20	1	1
	Santa Maria	7	2	5	6	5	5	-	2	-
Central	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
Western	Flores	56	4	18	33	43	56	-	1	-
	Corvo	21	4	11	16	16	20	-	-	1

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	
	Nº	%	Nº	%	Nº	%	Nº	%	Nº	%
Chroococcales	31	17.32	2	8.33	4	6.35	28	19.05	649	13.20
Chroococcidiopsidales	0	0	0	0	0	0	2	1.36	37	0.75
Gloeobacterales	0	0	0	0	0	0	0	0	3	0.06
Gloeomargaritales	0	0	0	0	0	0	0	0	1	0.02
Nostocales	77	43.02	11	45.83	20	31.75	44	29.93	1547	31.46
Oscillatoriales	30	16.76	8	33.33	18	28.57	30	20.41	1397	28.41
Pleurocapsales	2	1.12	1	4.17	6	9.52	3	2.04	223	4.53
Spirulinales	1	0.56	0	0	4	6.35	5	3.40	56	1.14
Synechococcales	38	21.23	2	8.33	11	17.46	35	23.81	995	20.23
Thermostichales	0	0	0	0	0	0	0	0	10	0.20
Total:	179		24		63		147		4918	

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) 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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