Development of cyanobacterial blooms in Italy: towards an integration of scientific research and baseline monitoring

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ABSTRACT

This paper introduces and summarises a selection of contributions that were presented during a workshop on cyanobacterial blooms held at S. Michele all'Adige (Trento) in December 2023. The meeting originated with an increasing interest in a reciprocal exchange of knowledge and experiences between government bodies and research institutions following the widespread cyanobacterial blooms detected in the southern Alpine area and other Italian regions. The papers have been collected in the special issue "Potentially toxic cyanobacteria blooms in the southern Alps and the Italian peninsula".

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Impact of cyanobacterial blooms on water resources and animal and human health

The development of toxigenic cyanobacteria represents one of the main problems for the multiple uses of water, also constituting a risk for the health of people and animals (Meriluoto *et al*., 2017a, 2017b; Chorus & Welker, 2021). In addition to the problems connected with the production of odorous compounds (Akcaalan *et al.*, 2022; Manganelli *et al*., 2023), the presence of cyanobacterial proliferation has important negative consequences for the use of aquatic resources, due to the production of a wide range of toxic molecules (cyanotoxins) in waters intended for drinking and recreational use (Chorus *et al*., 2021).

Cyanotoxins are produced by a wide variety of cyanobacterial species. The most important classes of cyanotoxins include microcystins and nodularins (hepatotoxic), cylindrospermopsins (cytotoxic), anatoxins and saxitoxins (neurotoxic). The abundance of toxins synthesized during a cyanobacterial bloom is not directly linked to biomass but depends on several factors, such as the species involved in the blooms and the proportion of toxic strains within the cyanobacterial population. In addition to species capable of producing one or more classes of toxic compounds, there are other species for which the production of toxins has yet to be proven.

The impact of cyanotoxins on human health can be severe, ranging from skin rash to illness and, rarely, death. Exemplifying cases include deaths caused by microcystin-contaminated water used for hemodialysis in Caruaru (Brazil) (Azevedo *et al*., 2002) and several illness cases (gastrointestinal and skin reaction, asthmatic symptoms, and swelling) documented worldwide connected with the contamination of drinking and bathing waters by cyanobacteria (Metcalf & Codd, 2012; Wood, 2016). Despite the intrinsic difficulties in epidemiological investigations due to the presence of confounding factors, a number of studies have also highlighted a possible association between the incidence of cancer cases in humans and the presence of cyanotoxins in water intended for human consumption (Svirčev *et al*., 2017). Several other cases of lethal intoxication of animals caused by the consumption of water contaminated by toxic cyanobacteria were documented worldwide (Metcalf & Codd, 2012; Fastner *et al*., 2018). Evidence has also been produced on the accumulation of microcystins along the food chain, including fish (Banerjee *et al*., 2021; Falfushynska *et al*., 2023). Effects of blooms can have a serious economic impact on tourism (Hamilton *et al*., 2014) and the exploitation of water for drinking purposes, as in the well-known "water crisis" that impacted the city of Toledo (Ohio), caused by a massive toxic bloom of *Microcystis aeruginosa* (Kützing) Kützing that led to the closure of the aqueducts for weeks due to contamination of lake water by microcystins (Steffen *et al*., 2017).

Documentation of water blooms in Italy

Cyanobacterial growth and blooms are promoted by eutrophication and increasing water temperatures. The increase in algal nutrient loads (phosphorus and nitrogen compounds) discharged into water bodies is the main controlling factor of eutrophication (OECD, 1982; Istvánovics, 2009). Global warming creates favorable conditions for the growth of cyanobacteria both directly and indirectly by increasing water temperatures and stability of the water column (Paerl & Paul, 2012). Eutrophication and climate change act in synergy, reinforcing each other (Moss *et al*., 2011; Fastner *et al*., 2016; Hamilton *et al*., 2016), and causing an expansion of favorable conditions for the development of blooms (Hou *et al*., 2022) and production of cyanotoxins (Mantzouki *et al*., 2018b, 2018a).

The dynamics of cyanobacterial blooms can be highly variable, ranging from localized and episodic events lasting a few hours or days to persistent accumulations of biomass over large areas lasting several days or weeks (Steffen *et al*., 2017). Globally, a significant increase in the occurrence of blooms caused by cyanobacteria has been observed, attributed to the effects of global warming, which for several decades has been causing a systematic increase in water temperatures and, consequently, an increase in thermal stability, which is essential for the initiation and maintenance of blooms over time (Huisman *et al*., 2018; Hou *et al*., 2022).

In the last two decades, the increase in the occurrence of algal blooms has also been documented in the Alpine region south of the Alps, and in several other Italian regions (Manganelli *et al*., 2014). Lake water warming was included among the most important factors promoting cyanobacterial development in the Alpine region (Gallina *et al*., 2013; Salmaso *et al*., 2018, 2024; Fenocchi *et al*., 2025) and, in general, in Italian lakes (Funari *et al*., 2014; Pareeth *et al*., 2017; Ludovisi *et al*., 2021). On the other side, the documentation of the frequency of episodes was improved after the engagement in 2008 of Regional Environmental Protection Agencies (ARPAs) in the monitoring of algal blooms in marine and freshwater environments. Since then, the monitoring of cyanobacteria by ARPAs generated a wealth of information, which, most of the time, has been used exclusively to comply with legislation on the surveillance of water bodies for recreational and drinking purposes on a regional basis. In this regard, these observations represent an invaluable source of knowledge complementing the scientific investigation, which, with the exclusion of the systematic studies carried out under the umbrella of the Long-Term Ecological Research networks (Morabito *et al*., 2018; Capotondi *et al*., 2021), are more focused on specific objectives, with time constraints linked to the life of the projects.

In order to promote a better exchange of information and experience, several local environmental and health authorities and research institutes involved in the monitoring and study of cyanobacteria participated in a meeting organized at S. Michele all'Adige in December 2023, with the aim of creating a common framework for the mutual exchange of information and discussion on the causes and solutions to mitigate the effects of cyanobacterial blooms.

In addition to this introductory paper, this special issue, entitled "Potentially toxic cyanobacteria blooms in the southern Alps and the Italian peninsula", includes a selection of papers published by the participants of the meeting. Although the regional scale in the contributions was mostly limited to the Northern Italian regions, most of the results were also discussed and interpreted taking into account the Italian context.

A few papers were focused on the documentation of the distribution of cyanobacterial blooms at the southern border of the Alps, specifically in the Po River basin and the eastern Alps (Buzzi *et al*., 2025), in the Trentino Province (Pozzi *et al*., 2024) and Lake Garda (Zampieri *et al.*, 2024). Overall, these three contributions demonstrated the existence of a high number of bloom events across the regions investigated by the environmental agencies, with a highly diversified number of cyanobacterial species, most of them potentially toxigenic, and therefore requiring great attention in their development and risk assessment (among others, *M. aeruginosa*, *Aphanizomenon flos-aquae* Ralfs ex Bornet & Flahault, *Planktothrix rubescens* (De Candolle ex Gomont) Anagnostidis & Komárek, *Dolichospermum circinale* (Rabenhorst ex Bornet & Flahault) Wacklin, Hoffmann & Komárek, and *D. lemmermannii* (Richter) P.Wacklin, L.Hoffmann & J.Komárek). In most cases, blooms were associated with the presence of microcystins in the environmental samples, even if no specific analyses were performed on the isolates to clearly identify the producers. These works highlighted the necessity to integrate into the baseline monitoring new technological approaches to monitor real-time episodes characterized by sudden appearance and variable persistence, and to study the taxonomic and functional characteristics of blooming species by molecular and analytical methods (Buzzi *et al*., 2025). These elements are essential considering that the activity by ARPAs allows more timely surveillance and analysis of cyanobacteria in the event of blooms, enabling rapid communication with public authorities and implementation of recovery plans (Pozzi *et al*., 2024; Zampieri *et al*., 2024).

The new occurrence of populations of *Raphidiopsis raciborskii* (Wołoszyńska) Aguilera & al. in small eutrophic lakes in Lombardy and Veneto was the object of the work by Austoni *et al.* (2025). The formation of blooms and discoloration of *R. raciborskii* in small artificial lakes and narrow canals in Emilia Romagna were described by Del Pasqua *et al.* (2024a). An important potential problem connected with the correct identification of the nature of water discolorations in water bodies was addressed by Del Pasqua *et al*. (2024b). These authors reported several interesting case studies including the occurrence of coexisting red and green blooms of *Euglena sanguinea* Ehrenberg and *Oscillatoria* sp. in the same water body, and several purple and orange colorations caused by massive surface development of sulphur bacteria and iron-oxidizing bacteria. With a main focus on the management side, the role of environmental and health agencies in the monitoring of water for human consumption was addressed by Nasello *et al*. (2025). The work identified vulnerabilities in the water drinking supply chain, discovering the presence of cyanobacteria in nearly 20% of samples. At the same time, the authors reported a case study integrating into the Water Safety Plan the characterization, besides cyanobacteria and cyanotoxins, of different congeners of microcystins, viruses (particularly somatic coliphages), and spore-forming bacteria resistant to treatment processes, such as *Clostridium perfringens* and indicators of fecal contamination.

The cited works highlighted the importance of developing monitoring plans incorporating collaboration with research institutions where screening methods for cyanobacteria identification and cyanotoxin determination were already established. Such collaborations were highlighted in the work by Austoni *et al.* (2025), which resumed a few results of an extensive survey on the cyanobacteria and cyanotoxins occurrence in the Alpine region, conducted in the framework of networking Interreg projects.

The implications of the presence of cyanobacteria for human health and ecosystems were addressed in two papers coordinated by the Italian National Health Institute. The work by Testai (2024) provided an update on the relationship between cyanobacteria and cyanotoxin production, the toxicological risks connected with exposure, and the strategies for risk assessment and management. Focusing on the general theme of new emerging contaminants, the work by Manganelli *et al*. (2024) addressed the problems of the presence and spread of Antimicrobial Resistance Genes (ARGs) in cyanobacteria, further highlighting the necessity to enlarge the spectrum of target genes and molecules in cyanobacteria, well beyond the common legacy cyanotoxins.

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