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Review

Bloom-forming cyanobacteria and cyanotoxins in Argentina: A growing health and environmental concern

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ABSTRACT

Toxic cyanobacterial blooms are a water quality issue worldwide whose incidence and severity are predicted to increase due to climate change and eutrophication. Argentina is not an exception to this trend, since those massive proliferations have increased in the last two decades as a consequence of water quality changes due to human activities. This work presents a thorough search and analysis of published literature on the occurrence of cyanobacterial blooms and cyanotoxins in Argentina. We retrieved 241 bloom events (1944–2014) covering 63 impacted water bodies, used either for recreational activities and/or drinking water supply. The highest incidence was concentrated in the central and eastern areas of the country (Chaco-Pampean Plain and Peripampean Sierras), the most densely populated regions, also highly impacted by agro-industrial activities. Intense blooms of *Microcystis, Dolichospermum* and *Cylindrospermopsis* species represent a potential hazard for both human beings and wild–life through oral ingestion and/or direct contact, although quantitative and systematic registers to estimate the extent of occurrence are still missing. Elevated microcystins concentrations, together with the presence of blooms of potential saxitoxin or anatoxin-a producers emphasize the need to increase monitoring of these toxins in drinking water supplies and recreational areas. The data presented are valuable for promoting the generation and implementation of guideline values and risk management frameworks at a national and regional scale.

1. Introduction

Toxic cyanobacterial blooms represent one of the most conspicuous hazards to human health in freshwater systems (Chorus and Bartram, 1999). They are widely recognized as a water quality issue that affects recreational and drinking water due to the production of potent cyanotoxins [such as microcystins (MCs), saxitoxins, anatoxin-a, and cylindrospermopsins]. At elevated concentrations these cyanotoxins pose a risk to the health of humans, wildlife and wildstock, particularly when ingested (Codd et al., 2005; He et al., 2016).

Anthropogenic eutrophication and climate change seem to play a key role in promoting the proliferation and expansion of toxic cyanobacterial blooms (Heisler et al., 2008; O'Neil et al., 2012; Paerl and Huisman, 2008). The incidence of this phenomenon is predicted to increase in frequency and severity globally, affecting areas previously unaffected (Cheung et al., 2013; Reichwaldt and Ghadouani, 2012). South America is not the exception, although there is scant literature on this subject (Dorr et al., 2010).

In the Southern Cone, Brazil and Uruguay follow the guidance and regulations proposed by the World Health Organization (WHO) regarding the monitoring and management of cyanobacteria and cyanotoxins in drinking and recreational waters, based on parameters that reflect cyanobacterial biomass or MCs concentration (Chorus and Bartram, 1999; WHO, 2003). In particular, these countries have adopted the Guideline Value for MC-LR in drinking water (1 $\mu g\ L^{-1}$ for MC-LR), while guidelines for recreational waters await final approval by the Uruguayan legislation (Vidal and Britos, 2012; Ibelings et al., 2014) and is still under development in Brazil (Azevedo Lopes et al., 2016).

Argentina is a vast country (about 2,800,000 km^2, along 3700 km between 22° and 55° South latitude) located within a region of subtropical and mid-latitude climates. It is endowed with a dense

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hydrographic network which includes rivers, streams, stratified lakes and shallow lakes (Quirós and Drago, 1999). Importantly, 85% of the country's surface water is part of the Rio de la Plata basin (3,100,000 km^2) (Pochat et al., 2006) shared with Brazil, Uruguay, and Paraguay. Even though cyanobacterial blooms have been registered in Argentina since 1944 (Mullor, 1945), reports on massive proliferations have alarmingly increased by the end of 1990's, associated with water quality changes due to human activities (i.e., urbanization, agriculture, untreated effluent discharges) (Pizzolon et al., 1999; Quirós and Drago, 1999). This negatively affects drinking and recreational water quality, resulting in animal mortality and concern of public health impairment (Echenique et al., 2014; Giannuzzi et al., 2011; Mancini et al., 2010; Odriozola et al., 1984; Pizzolon et al., 1999; Quirós and Drago, 1999). In contrast to Uruguay and Brazil, national regulations on risk assessment and management of cyanobacterial or cyanotoxin presence have not been adopted as of yet, albeit the increased concern from the public health community (Otaño et al., 2012). Despite the growing interest in this matter and the research activity conducted on harmful cyanobacterial blooms in the last decades, the scope of the issue has not been fully recognized since reports are scattered and no updated review is available.

The aim of this review is to provide data to better understand cyanotoxin occurrence and thus provide a basis for policy decisions on implementing guidelines or alert level frameworks at the national and regional level.

2. Material and methods

A database was constructed with scientific publications retrieved from Scopus, Google Scholar, and SciELO (to cover some reports and papers in Argentinean publications) from 1945 to 2016, using different word combinations as keywords for titles and abstracts (Argentina; Cyanophyceae; cyanobacteria; blooms; scum; cyanobacterial dominance; and cyanotoxins; as English words; and cianobacteria; floración; cianotoxinas; as Spanish words). Studies on freshwater systems that mention the word "bloom" or included quantitative data (such as chlorophyll *a*; cyanobacterial biovolume or cyanobacterial cell counts) albeit not mentioning the term "bloom" *per se* were considered. Cyanobacterial bloom reports that provided no data on dominant species were excluded from the data set. When different papers referred to the same water body and study period; the most informative one was analysed. Information was taken from international and national journals (n = 50); book chapters (n = 3); proceedings (n = 8); conference presentations (n = 9); and technical reports (n = 7). When needed; we clarified or corroborated data by contacting the authors directly (personal communications).

Each quantitative datum was classified in categories following the Alert Levels Framework and the Guidance Levels for drinking and bathing waters, respectively, proposed by WHO (Chorus and Bartram, 1999; WHO, 2003). Quantitative values corresponding to Alert Level 1 (2000 cells mL^{-1}, or 0.2 $\mathrm{mm}^3\,\mathrm{L}^{-1}$ biovolume, or 1 $\mu\mathrm{g}\,\mathrm{L}^{-1}$ chlorophyll *a* in the water body) were considered as a cyanobacterial bloom. Taxa were recorded at species level; however, if species information was not available in a report, we recorded data at the genus level to avoid missing information. Taxonomy was updated according to recent literature whenever possible.

Kruskal-Wallis H tests were used to explore differences between affected ecosystems (lentic, lotic and reservoirs), and Dunn's multiple comparison tests were conducted as *post hoc*, with $p < 0.05$ considered significant. Analyses were performed with SigmaPlot version 11 (Systat Software, Inc).

Maps were elaborated using GIS software ArcMap 10.1. Vector data on administrative limits, water bodies and land cover were downloaded from Instituto Geográfico Nacional (IGN) as shape files (http://ign.gob.ar/sig). Six major geographic lake regions were recognized and digitalized according to Quirós and Drago (1999).

3. Results and discussion

3.1. Main characteristics and geographic distribution of blooms

The literature yielded 241 bloom events and 110 georeferenced data covering 63 water bodies [rivers, estuaries and streams (n = 11), stratified lakes, shallow lakes and ponds (n = 33), reservoirs and dams (n = 19)] affected by blooms at least once. Reports of bloom occurrence before 1999 and between 1990 and 2000 were scarce (3% and 10% of the 241 events, respectively), as compared to reports after 2000 (87%). Even though reports on massive proliferations have risen notoriously since the beginning of this century, since more research groups are getting involved in this topic and, consequently, more studies are published nowadays such increase may not necessarily imply a higher frequency in bloom occurrence. Therefore, we do not discard a possible bias in reported data.

Sampling frequency was not homogeneous (it differed between water bodies and varied from a single sampling to hourly, weekly, fortnightly and monthly sampling, see for example Grosman and Sanzano, 2002; Izaguirre et al., 2015; Sathicq et al., 2014). Such heterogeneity prevented any analysis of the relationship between the number of samples per water body and the frequency of blooms registered. Some publications that contained the word "bloom" (n = 20) included neither quantitative values nor comments on the appearance of phenomena such as scums in the littoral zone and/or changes in water colour. This highlights the lack of a clear definition and the ambiguity in the use of the term "bloom" in the literature. Soares et al. (2013) also report the lack of information in terms of the visual appearance of blooms in Brazil. The inclusion of observational and describing data in cyanobacterial studies would be useful to better appreciate the extent of these phenomena.

The reported cyanobacterial blooms are located along and across the country from North (25° 18′ 0″ N) to South (54° 35′ S) and from East (55° 0′ W) to West (71°16′ W), in a wide range of climatic lentic environments and areas used for intensive agriculture (Figs. 1, S1). The main geographic lake region affected is the Chaco-Pampean Plain (n = 212, 88% of all 241 reports, region 2), followed by the Peripampean Sierras (8%, region 3) and the Patagonian Plateau (4%, region 5). Reports from the Andean Patagonia (region 4) and Misiones Plateau (region 6) are scarce (n = 3 and n = 1, respectively), and no information was retrieved from the Puna (region 1). In general, cyanobacterial dominance was most pronounced during the warmest months, as reported from other temperate climates (Chorus and Bartram, 1999; Jöhnk et al., 2008). Blooms started earlier and persisted longer in the subtropical North. In subtropical and temperate regions (Chaco-Pampean Plain and Peripampean Sierras), peaks of cyanobacterial biomass developed in summer (n = 97, 44%) and mid-summer until mid-autumn (n = 92, 42%). Some blooms extended from spring to summer (n = 6, 2.7%) while reports on cooler seasons and along the whole year (perennial) were scant (less than 2%). Cyanobacterial dominance was restricted to summer in cold-temperate climate lakes (Patagonian Plateau and Andean Patagonia).

The Chaco-Pampean Plain region extends from the centre to the northern and eastern areas of Argentina, and it is characterized by an edaphic heterogeneity and a large climatic variety (from North to South: subtropical and temperate climates) (Fig. 1B, S1) (Quirós and Drago, 1999). This region concentrates more than 50% of the country's population (about 29 million inhabitants) which mainly live in urban areas (INDEC, 2010). The Río de la Plata Basin, the fifth largest basin in the world and the second largest in South America, comprises the Paraná, Paraguay and Uruguay rivers, and the Río de la Plata River (Tundisi et al., 1998), and sustains the region for drinking water supply, generation of hydro-electric power and agriculture. Most cereal and oilseeds are grown in this region, and it is used for breeding most of the country livestock (WWAP, 2007). Additionally some of the largest reservoirs in South America are on the tributaries of Río de la Plata basin.